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

Final Summary Report

to

Queensland Department of Agriculture and Fisheries

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by

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Agtrans Research

Acknowledgments

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Abbreviations

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

Glossary of Economic Terms

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

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

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

Present Value of Benefits - The discounted value of benefits.

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

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

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

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

Contents

Executive Summary

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

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

- Investment 1: Mud Crabs
- Investment 2: Methyl Bromide
- Investment 3: Central Qld Cotton
- Investment 4: C4 Milk
- Investment 5: Sweet Potatoes (Cluster)
- Investment 6: Plum Breeding (Cluster)

The analyses were carried out to demonstrate accountability and the value of the Queensland Government's contribution to RD&E investment across a range of industries and disciplines. The six investments were all supported by DAF resources, as well as by Research and Development Corporations (RDCs) including those representing fisheries (1), horticulture (3), dairy (1), and grains (1). As each of the six investments were all partly funded by DAF, this report addresses the individual return to:

- The total investment in each project including funding by the funding agencies, as well as any investment provided by researchers and other parties (e.g. CSIRO).
- The specific resource investment provided by DAF.

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

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

The economic analyses were carried out using the current guidelines of the Council of Rural Research and Development Corporations (CRRDC). Impacts were estimated for up to 30 years from the year of last investment in each project. Total costs for each project included the expenditure on the project by DAF and the RDC, as well as any other resources contributed by third parties (e.g. researchers). DAF contributions to the total investment made in each of the six projects/clusters varied from 38% to 80%.

The analyses produced investment criteria by project for the total investment as well as separate investment criteria for DAF and the RDC investment. A degree of conservatism was used when finalising assumptions. Sensitivity analyses were undertaken for several assumptions that had the greatest degree of uncertainty or for those that were seen to be key drivers of the investment criteria.

Some identified impacts were not quantified mainly due to:

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

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

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

Investment Criteria for Total Investment

Project/Cluster Investment	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**BCR**	**IRR (%)**	**MIRR (%)**
Mud Crabs	20.65	0.63	20.02	32.98	132.4	18.0
Fruit Flies	4.15	0.89	3.26	4.64	23.7	10.8
Central Qld Cotton	20.24	1.18	19.06	17.13	69.0	15.4
C4 Milk	29.90	5.78	24.11	5.17	25.9	11.4
Sweetpotato	133.08	15.25	117.83	8.73	nc	23.6
Plum Breeding	255.71	19.71	236.00	12.97	12.4	14.7
Aggregate (Total investment in all Project/Cluster Investments)	463.73	43.44	420.29	10.68	14.7	14.4

nc. not calculable

Investment Criteria for DAF Investment

Investment Project	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**BCR**	**IRR (%)**	**MIRR (%)**
Mud Crabs	13.63	0.41	13.22	32.93	130.1	18.0
Fruit Flies	1.72	0.37	1.35	4.65	23.4	10.8
Central Qld Cotton	7.70	0.45	7.25	17.18	69.5	15.4
C4 Milk	21.06	4.07	16.99	5.17	25.9	11.4
Sweetpotato	58.15	6.67	51.48	8.72	nc	21.0
Plum Breeding	204.67	16.39	188.28	12.49	12.2	14.6
Aggregate (DAF investment in all Project/Cluster Investments)	306.93	28.36	278.57	10.82	13.5	13.5

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1. Introduction

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

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

The investments were made in four individual projects and two clusters of projects. They were:

- Project 1: An Impact Assessment of DAF Investment into the Australian Industry Live Mud Crab Grading Scheme (AILMCGS) through Addressing Grading and Regional Anomalies, 2014-2016: FRDC Project 2014/218
- Project 2: An Impact Assessment of DAF Investment in Low Dose Methyl Bromide against Fruit Flies to Improve Summer-fruit Market Access, 2013-2016: HIA Project SF12016
- Project 3: An Impact Assessment of DAF Investment into CRDC project DAQ1401: Strengthening the Central Highlands Cotton Production System
- Project 4: An Impact Assessment of DAF Investment in C4Milk: Developing and managing a profitable high milk from forage system in the sub-tropics, DA Project C100000928
- Cluster 1: An Impact Assessment of DAF Investment in Sweet Potato Projects between 1998 and 2018 that address Pests, Diseases, Agronomy and New Varieties
- Cluster 2: An Impact Assessment of DAF Investment in Plum Breeding 1981-2007

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 1 to 6 provide the detailed analyses for each of the six investments.

2. Methods

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

Each investment was evaluated through the following steps:

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

The factors that drive the investment criteria for research and development (R&D) include:

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

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

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

A degree of conservatism was used when making specific assumptions. Sensitivity analyses were undertaken for several assumptions that had the greatest degree of uncertainty or for those that were seen to be key drivers of the investment criteria.

Some identified impacts were not quantified mainly due to factors such as:

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

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

3. Summary of Results

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

Further details on each of these investments and the associated results are provided in the individual investment evaluation reports and analyses (Appendices 1 to 6).

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

Project/Cluster Investment	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**BCR**	**IRR (%)**	**MIRR (%)**
Mud Crabs	20.65	0.63	20.02	32.98	132.4	18.0
Fruit Flies	4.15	0.89	3.26	4.64	23.7	10.8
Central Qld Cotton	20.24	1.18	19.06	17.13	69.0	15.4
C4 Milk	29.90	5.78	24.11	5.17	25.9	11.4
Sweetpotato	133.08	15.25	117.83	8.73	nc	23.6
Plum Breeding	255.71	19.71	236.00	12.97	12.4	14.7
Aggregate (Total investment in all Project/Cluster Investments)	463.73	43.44	420.29	10.68	14.7	14.4

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

Investment Project	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**BCR**	**IRR (%)**	**MIRR (%)**
Mud Crabs	13.63	0.41	13.22	32.93	130.1	18.0
Fruit Flies	1.72	0.37	1.35	4.65	23.4	10.8
Central Qld Cotton	7.70	0.45	7.25	17.18	69.5	15.4
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Plum Breeding	204.67	16.39	188.28	12.49	12.2	14.6
Aggregate (DAF investment in all Project/Cluster Investments)	306.93	28.36	278.57	10.82	13.5	13.5

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The aggregate PVCs in Table 2 (DAF) compared to those in Table 1 (Total) demonstrate the importance of DAF funding in most of the six investments. As a proportion of total funding in each investment, DAF funding varied from approximately 38% to 83% with a weighted average of 65% across all six investments.

4. Conclusions

All six of the investments analysed provided positive net present values at the 5% discount rate. The individual benefit-cost ratios varied from 4.6 to 33.0 for the total investment analysis and for the 30-year period from the year of last investment. The highest BCR was for the relatively small total investment in mud crab grading.

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

Across the six investments the aggregate benefit-cost ratio for the total aggregate investment was 10.7 to 1, the aggregate internal rate of return was 14.7%, and the aggregate modified internal rate of return 14.4%.

References

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

Appendices

Appendix 1: An Impact Assessment of DAF Investment into the Australian Industry Live Mud Crab Grading Scheme (AILMCGS) through Addressing Grading and Regional Anomalies, 2014-2016: FRDC Project 2014/218

Acknowledgments

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Abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics
AILMCGS	Australian Industry Live Mud Crab Grading Scheme
CBA	Cost-Benefit Analysis
CRC	Cooperative Research Centre
CRRDC	Council of Research and Development Corporations
DAF	Department of Agriculture and Fisheries, Queensland
FRDC	Fisheries Research and Development Corporation
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NIR	Near Infrared
NMCIRG	National Mud Crab Industry Reference Group
NSW	New South Wales
NT	Northern Territory
PFA	Professional Fishermen’s Association
PVB	Present Value of Benefits
RDC	Research and Development Corporation
R&D	Research and Development
RD&E	Research, Development and Extension
QLD	Queensland
SFM	Sydney Fish Market
WTP	Willingness to Pay

Executive Summary

The Project

This report presents the results of an impact assessment of a Queensland Department of Agriculture and Fisheries (DAF) investment in a project to improve the grading scheme for the Australian live mud crab industry. The project was funded by DAF and the Fisheries Research and Development Corporation (FRDC) over the period 2014-2016.

Methods

The project was analysed qualitatively within a logical framework that included activities/outputs, outcomes, and impacts. Impacts were categorised into a triple bottom line framework. Principal impacts were then valued. Benefits were estimated for a range of time frames up to 30 years from the year of last investment in the project. Past and future cash flows in 2016/17 $ terms were discounted to the year 2016/17 using a discount rate of 5% to estimate the investment criteria.

Impacts

The major impact identified was of a financial nature. However, some social and environmental impacts also were identified but not valued. It is expected the Australian commercial mud crab industry will be the primary beneficiary of the investment.

Investment Criteria

Total funding from all sources for the project was $0.6 million (present value terms). The value of benefits was estimated at $20.6 million (present value terms). This gave an estimated net present value of $20.0 million, and a benefit-cost ratio of 33 to 1.

1. 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 included both qualitative and quantitative descriptions that are in accord with the evaluation guidelines of the Council of Research and Development Corporations (CRRDC, 2014).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, 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, a high degree of uncertainty surrounding the potential impact, or the likely low relative significance of the benefit compared to those that were valued. The impacts valued therefore are deemed to represent the principal benefits delivered by the project.

2. Background and Rationale

Background

The Australian wild catch mud crab industry is a significant fisheries industry. Participants in the industry include recreational crabbers, commercial crabbers and indigenous crabbers. The mud crab fishery extends from northern Australia including Western Australia and the Northern Territory (NT), through Queensland (QLD) and into New South Wales (NSW).

The total annual commercial harvest of mud crabs varies but is in the order of 1,600 tonnes (FRDC, 2016a) having a value of around $40 million (1,600 tonnes x a conservative average value of $25 per kg at harvest). QLD and NSW provide most of the annual commercial catch. A significant part of the total harvest is for recreational and indigenous pursuits.

Exact production figures are difficult to ascertain as the usual source of such data collection, the Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES) does not differentiate mud crabs as a separate species; they are included under the combined grouping of 'crab' which also contains sand and spanner crabs (Poole et al, 2012).

In comparison to the production and value of the mainstream Australian crustacean wild catch (prawns and lobsters), crabs are relatively minor. Nevertheless, the mud crab fishery in the NT is one of the most valuable wild catch fisheries in that jurisdiction. For example, in the year ended June 2014, mud crab production constituted 15 per cent of a total NT wild-catch production by value of $31 million (ABARES, 2014, p22).

Poole at al. (2012) report that over the four years up to 2012, the value of mud crabs sold through the Sydney Fish Market (SFM) increased to number one positioning, with a value close to $10M. The then current 2012 SFM data showed that mud crabs were also the most important product commodity through the SFM by volume. SFM is the major wholesaler of mud crab in Australia and runs the only live auction as the sale mechanism. Poole et al (2012) also state:

'Mud crab is a highly valuable resource for commercial fisheries in the northern half of Australia, currently returning $35M to the harvest sector and an estimate of over

$100M within the retail/restaurant sector'.

Most mud crab fisheries are considered "sustainable" (FRDC, 2016a), except for the Western Gulf (considered a transitional depleting stock) and the Estuary General fishery in NSW (considered undefined).

There are regulations on the mud crab harvest. Regulations general vary between fisheries. For example, female mud crabs cannot be harvested in Queensland fisheries and minimum size constraints exist in all fisheries.

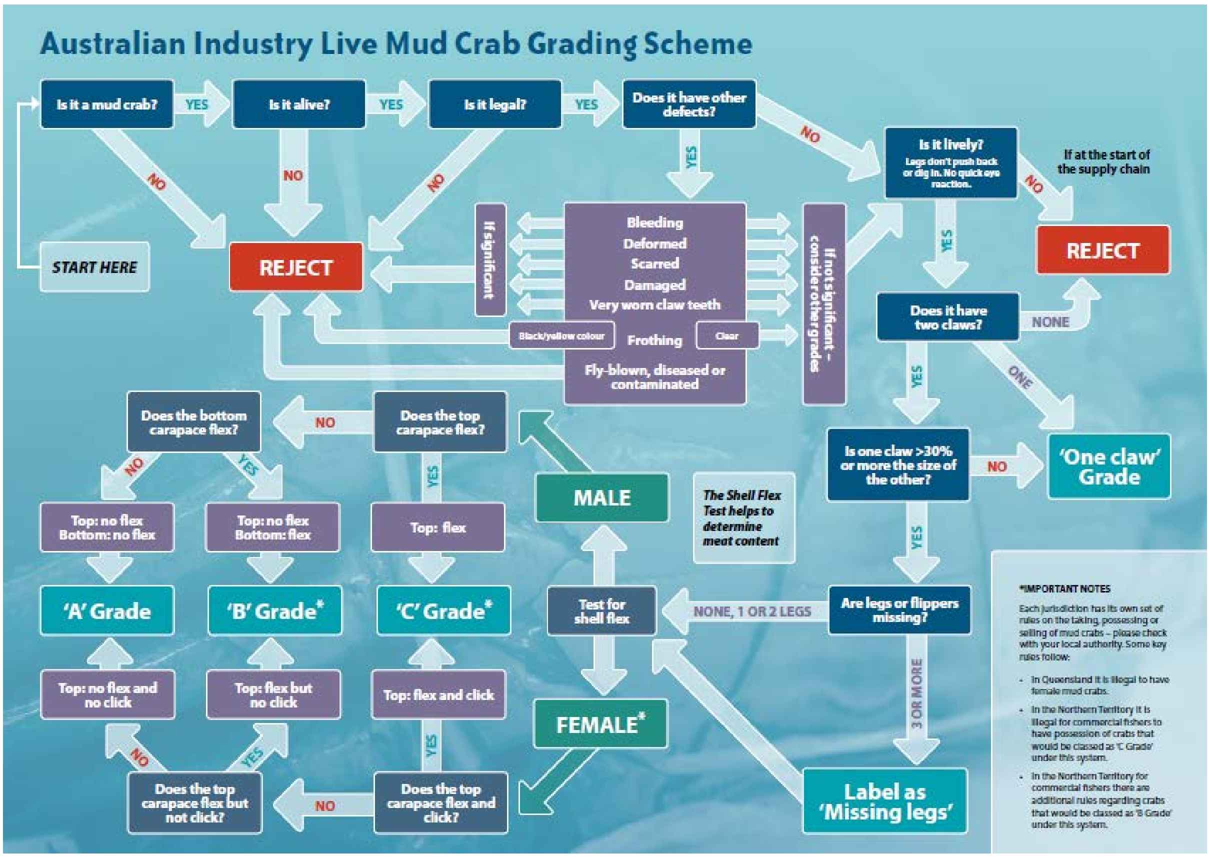
The largest commercial fisheries by tonnage are the Gulf of Carpentaria and the East Coast fishery (both in QLD jurisdictions) making up about 75% of the total Australian commercial catch as estimated subjectively from the catch chart in FRDC (2016a). This would be followed by NSW and then the NT, with Western Australia making only a minor contribution.

Rationale for the Project

A new Australian Industry Live Mud Crab Grading Scheme (AILMCGS Version 1) had been developed and implemented in 2012. This scheme was a result of a previous FRDC project 2011/225, entitled – 'Using industry expertise to develop a National Grading Scheme'. Before this first Australia-wide scheme, different grading schemes operated for crabs caught in different regions.

AILMCGS Version 1 was developed by the National Mud Crab Industry Reference Group NMCIRG). In the new scheme, crab lots were graded A, B, and C based on various criteria. The development of the scheme and its final design is described in Calogeras et al (2012) and summarised in Figure 1.

Figure 1: Schematic Diagram for Version 1 of the Grading Scheme



After the implementation of the national scheme, there was industry concern about some aspects from both crabbers and others along the supply chain to market. These concerns focused on incorrect use of the scheme to manipulate prices. One key concern centred on a misinterpretation of the thumb test. This test was effected by applying pressure to the carapace of the crab to gauge its strength and hence the expected meat yield. It was suspected that the resulting interpretation of the thumb test to gauge meat yield interacted with differences in varying environmental conditions between crab supply regions, e.g. crab with high meat yields also could have weak carapaces depending on rainfall and salinity levels in those regions. The seasonal and regional differences and their grading outcomes needed further confirmation.

It was recognised that hand testing was practical and the tool of choice in the industry for a product that had to be sold live. Given this constraint, an increase in precision of testing procedures that allowed for regional and other differences was required to minimise misinterpretations, damage to the crab and loss of product.

Also, at the same time as AILMCGS was introduced, the SFM changed the auctioning process for mud crabs to one that limited the inspection by buyers before the auction. The bidding process was also changed from highest bid to a form of Dutch auction. These selling changes resulted in auction bids being largely based on knowledge of the quality and accuracy of the previous grading by each supplier.

An additional rationale for the project on improving the grading process emanated from an earlier Seafood CRC project aimed at increasing the sustainable use the of the mud crab resource by recovering revenue from crabs rejected at market. This CRC project was aimed at recovering crabs rejected or downgraded at market and not likely to survive further in the supply chain. Previously the SFM had not accepted C grade crabs but was considering doing so with the assistance of its own trial and was ascertaining the impact of such a move on the price of A and B grade crabs. Recently moulted crab can be slow and show signs of weakness and hence fell into the 'C' grade category. Returning newly moulted crab to the water is viewed as industry best practice but does not always occur particularly with inexperienced or part-time crabbers.

3. Project Details

Summary

Title: Building precision into the Australian Industry Live Mud Crab Grading Scheme (AILMCGS) through addressing grading and regional anomalies
Research Organisation: Department of Agriculture and Fisheries, Queensland
Principal Investigator: John Mayze
Period of Funding: July 2014 to May 2016

Objectives

The objectives of the project were:

1. To attain a defined and precise assessment method of shell hardness using the current Australian Industry Live Mud Crab Grading Scheme (AILMCGS) across whole of industry.
2. To identify objective technologies and/or develop methodologies to support grading assessment within the AILMCGS.

3. To substantiate seasonal and/or regional grading anomalies within the AILMCGS and explore strategies to address them.
4. To increase profitability across industry through equity of grading practices and reduced product downgrades and wastage.

Logical Framework

Table 1 provides a description of the project in a logical framework developed for the project.

Table 1: Logical Framework

Activities and Outputs	• An industry-driven project Steering Committee was selected with representation from key industry supply chain sectors and regions to ensure project objectives were met. • The project involved the Professional Fishermen's Association (PFA) and the Sydney Fish Market (SFM), who both provided support and direction. • An initial survey on the level of knowledge of the scheme by industry established that 83% of respondents involved in the various mud crab supply chains were aware of the Live Mud Crab Grading Scheme and supported the concept of having such a grading scheme; however, there was a high level of dissatisfaction with elements of the scheme such as the thumb pressure testing and its use and impacts along the supply chain. • Results of the survey were distributed to survey responders and other industry groups. • One-on-one interviews were held with key SFM buyer agents and the individuals within the harvest sectors. • Visits to several NSW Fishermen's Cooperatives investigated the differences in flex on the top and underside carapaces and identified the lack of the resulting alignment with A, B and C gradings and the associated meat yields. It was concluded there was a poor alignment. • As the AILMCGS relied on thumb pressure tests on both top and underside carapaces, many crabs were being downgraded whereas their meat yield was high. • This resulted in the AILMCGS being changed with Version 2 no longer using the 'top of carapace flex test' for grading male mud crabs. • Regional anomalies of crabs with high meat yields and shells not fully hardened were observed most frequently in mud crabs harvested from NSW estuarine waters. • Research trials carried out by the project demonstrated that such anomalies were not related to low salinities as previously hypothesised. The investigation showed that environmental salinity difference did not appear to affect mud crab shell hardness. • A survey of participants in the crab supply chain and of consumers was carried out. This showed that the relationship between satisfaction levels and willingness to pay (WTP) for the different crab grades was strong for participants along the supply chain but less strong for consumers. However, generally all respondents' WTP values for C Grade crab were lower than the price attained at auction, so suggesting that the sale of C Grade crab was having an overall negative effect on consumer satisfaction, and lowered the likelihood of a return purchase. • An investigation was made into the parameters of mud crabs that could better predict meat yields. It was found that methods based on shell

	hardness and those methods based on total protein measured by the refractive index, were consistent for female crabs but not for male crabs. • It was also found that heavier crabs with larger, wider and heavier claws have lower meat yield percentages, but that lighter smaller crabs with smaller claws had higher percentages. • These findings were incorporated into Version 2 and then Version 3 of the revised scheme (See Figures 2 and 3 following this table). • The major change made in Version 2 compared to Version 1 (the original scheme) was the removal of the assessment of 'çlick' for female crabs (bottom dark blue boxes in Figure 1) due to agreement by industry sectors that this measurement was highly subjective (Sue Poole, pers. comm., 2017). The schematic also was simplified with details of quality attributes described in separate text instead of in the diagram. • The major change made in Version 3 relative to Version 2 was that it was recognised that more latitude was necessary within grades so that the thresholds were slightly widened. This was agreed at an industry forum attended by representatives from all sectors (Sue Poole, pers. comm., 2017). These changes were indicated in the Version 3 Diagram by agreed wording in dark blue boxes (above for male crabs) and in green boxes (below for female crabs). • Various objective methods for predicting meat yield from live crabs were investigated including measurements of protein levels using refractive indices, X-rays methods, candling (imaging via use of light), near infrared (NIR) methods also involving light, and acoustic velocity (the speed that sound moves through the crab). • Some technical progress was made with these methods but, at the end of the project, an objective test had yet to be developed and applied commercially. • Two technologies showed promise for future development as useful predictive tools. These were acoustic velocity and NIR methods; it was found that the NIR instrument was reported as a good predictor of percentage meat yield and grades.
Outcomes	• On 5 September 2016, partly resulting from the DAF project, SFM advised that the flex test was detrimental to the mud crab and that the downgrading of mud crabs based on shell hardness (flex test) would no longer be permitted at the Sydney auction. • SFM also advised that the grading of crabs was now considered the responsibility of the crabber and SFM wold no longer be involved in grading the crabs. All boxes in future would be listed for auction with the grade quoted by the supplier. • The improvement in 'A' grade and 'C' grade parameters in Version 3 of the scheme was expected to alleviate the incongruities in the variations between meat fullness and shell hardness. • Through changes in criteria to be used in grading, the project provided an increased level of confidence in the grading scheme and encouraged crabbers to grade crabs in accord with the new revised scheme. • As crabbers and other parts of the supply chain were very closely involved in the project and its activities and outputs, Version 3 of the scheme was adopted quickly by a large proportion of the industry. • A positive animal welfare outcome was also delivered by the project. Although the crab only has a short life after passing through the supply chain, the multiple squeezing of crabs along the chain can sometimes break the shell resulting in death or injury of the crabs.

	• A recommendation was made by the project that all efforts should be made to continue to encourage all crabber groups to release newly moulted crab at the point of harvest. This was expected to raise awareness and contribute to some marginal increase in the ‘release’ practice, and potentially to an increase in resource sustainability. • The perceived anomalies of the impact of salinity on shell strength were addressed in both Version 2 and Version 3 of the revised scheme. The findings did not support any relationship between shell strength and salinity. • The project gave positive re-enforcement to the NMCIRG as a valuable industry group to tackle other cross-industry issues in the future.
Impacts	• Reduced product downgrades so that prices received better reflected actual value. • Analyses of the potential revenue resulting from this refinement of the scheme indicate an increase of $2.18/kg for male crabs and $2.80/kg for female crabs across all grades as indicated in the final report for the project (Mayze et al, 2016). • These average gains above refer to gains from moving from Version 2 to Version 3 (not from Version 1 to Version 3) and are therefore conservative estimates of the increased value to the industry. • Potential for an increased demand for mud crab across all qualities due to price better reflecting true value. • Improved market positioning of low grade crabs if market acceptance occurs. • Potential for improved resource sustainability due to reduced harvest of newly moulted crabs. • Contribution to future potential development of objective measurement systems such as use of sound (acoustic velocity), and light (candling, near infrared spectroscopy). • Increased research capacity and scientific knowledge. • Improved skills base of industry participants and strengthened industry confidence in the NMCIRG.

Diagrams of the elements of the improved scheme are represented in Figure 2 (Scheme Version 2) and Figure 3 (Scheme Version 3). The evolution of the improvements can be traced via the changes made from Version 1 (the original scheme depicted in Figure 1) to Version 3 (the final and current grading scheme).

Figure 2: Schematic Diagram for Version 2 of the Grading Scheme

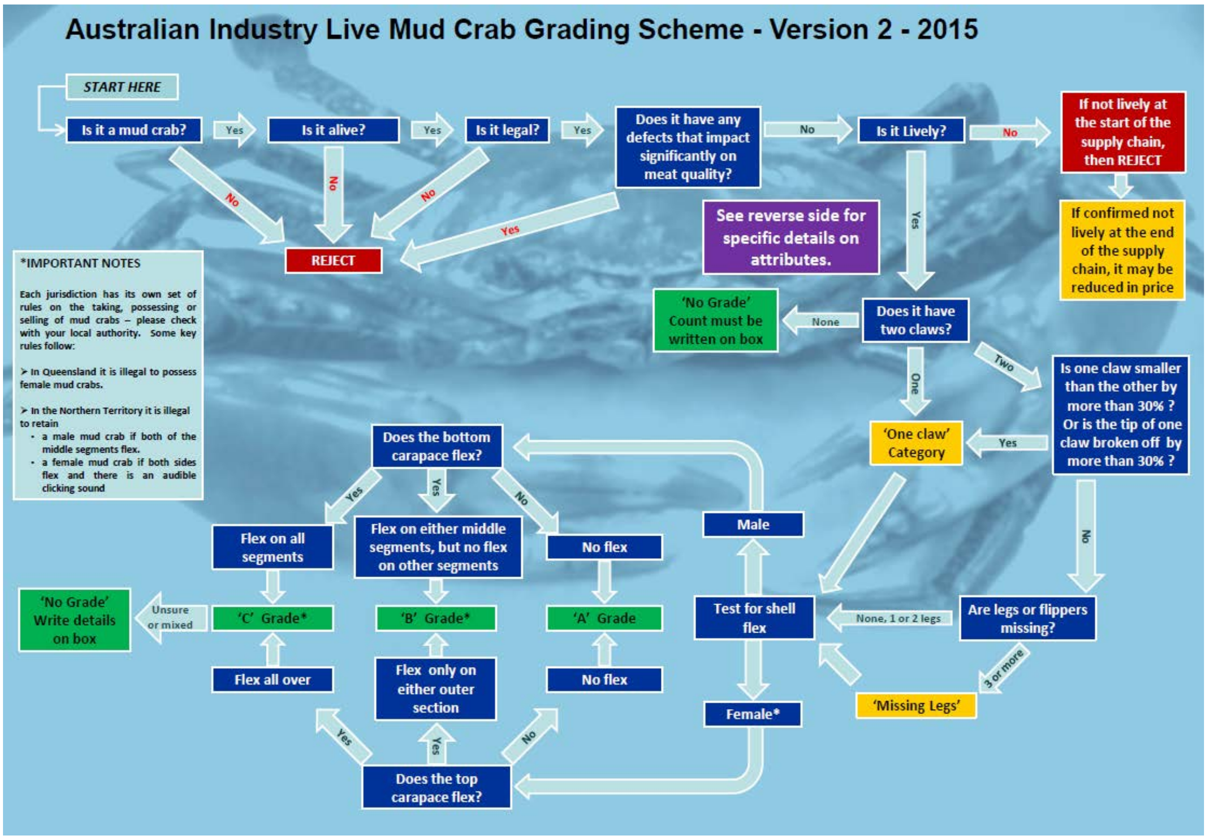
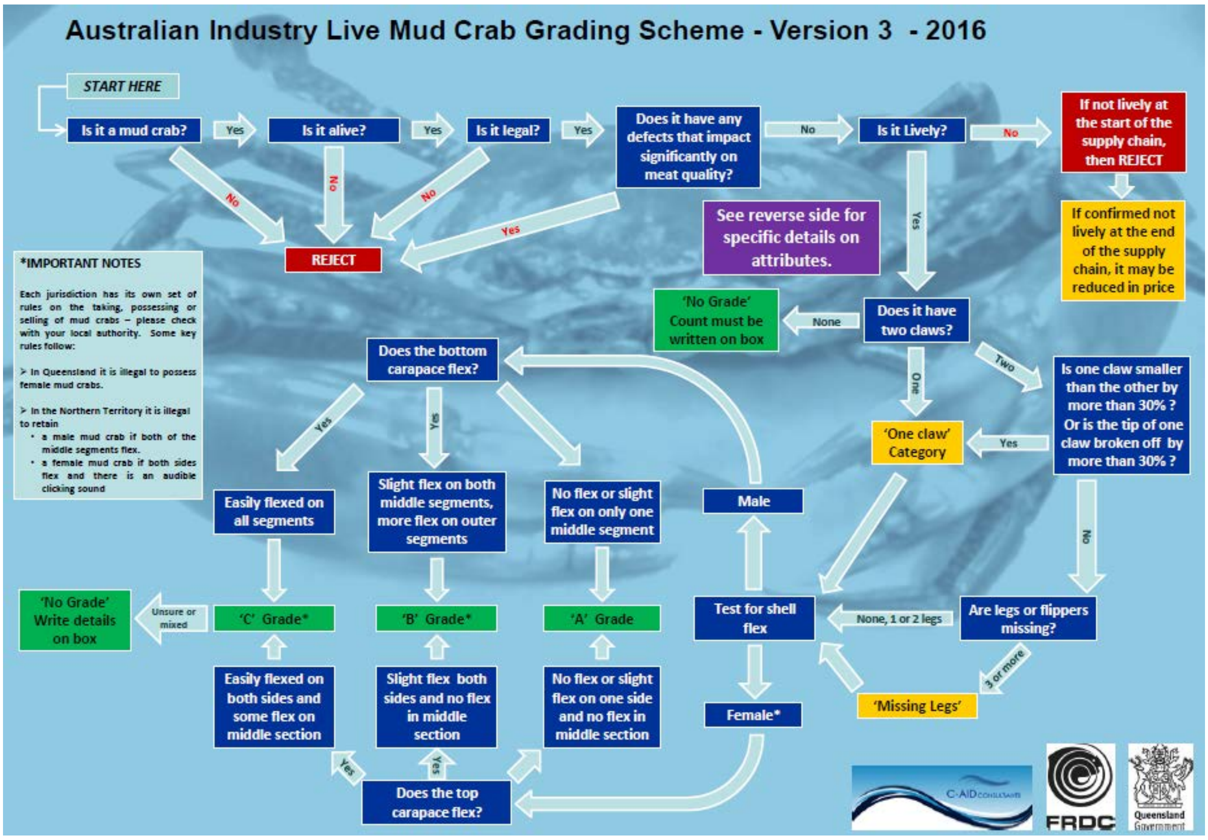


Figure 3: Schematic Diagram for Version 3 of the Grading Scheme



4. Project Investment

Nominal Investment

Table 2 shows the annual investment for the project funded by DAF, FRDC and other investors.

Table 2: Annual Investment in the Project (nominal $)

Year ended 30th June	DAF	FRDC	OTHER	TOTAL
2015	199,249	49,937.80	30,056	279,243
2016	176,079	72,467.20	27,718	276,264
Totals	375,328	122,405	57,774	555,507

Program Management Costs

For the DAF and other investment, the management and administration costs for the project are already built into the nominal $ amounts appearing in Table 2. The salary multipliers that had been used (Wayne Hall, pers. comm., 2017) were:

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

For FRDC investment, the cost of managing the FRDC funding was added to the FRDC contribution via a management cost multiplier (1.115); this was estimated based on the reported share of ‘employee benefits’ and ‘supplier’ expenses in total FRDC expenditure (FRDC, 2016b). This multiplier was applied to the nominal investment by FRDC shown in Table 2.

Real Investment and Extension Costs

For purposes of the investment analysis, the investment costs of all parties were expressed in 2015/16 $ terms using the GDP deflator index. No additional costs of extension were included as the project was extension-focussed and involved a high level of industry participation.

5. Impacts

The revised grading process has been accepted and quickly adopted by all markets and supply chains / industry sectors. This is largely because the industry was highly involved in the project throughout and in the development of the new versions of the grading scheme. There are anecdotal comments in the Final Report from the Project (Mayze et al, 2016) that supports this acceptance. Examples of such plaudits were from major mud crabbers from NSW and Queensland, the Queensland Seafood Association, East Coast Crabfishers’ Industry Network (QLD), a major seafood wholesaler and retailer, and two Fishermens Co-operatives.

The principal potential impacts from the improvements delivered in the mud crab grading improvement include:

- Increased value of the industry via reduced number of product downgrades and rejections so that prices received by crabbers better reflect actual value.
- Potential for an increased demand for mud crabs for all qualities due to price better reflecting true value.

- Greater confidence for crabbers investing in the industry.
- Increased equity among suppliers associated with false or unnecessary downgrades or rejections.

Table 3 provides a summary of the types of impacts categorised into economic, environmental and social impacts.

Table 3: Triple Bottom Line Categories of Impacts from the Improved Grading Scheme

Economic	• Increased income to the industry due to a reduced number of crab downgrades and rejections. • Potential for demand expansion from effect of improved and consistent product quality reaching the consumer. • Increased confidence in the efficiency of the supply chain potentially leading to greater investment in the industry by responsible parties. • Contribution to potential future objective measurement systems that could further increase industry value.
Environmental	• Potential for improved resource sustainability due to increased awareness of reduced harvest of newly moulted crabs.
Social	• Increased equity in the supply chain regarding rewarding compliance and good management. • Animal welfare improvements due to less individual crab damage from strength testing. • Increased industry capacity to develop and negotiate solutions to industry issues in future. • Increased scientific and research capacity relevant to objective measurement of live crustaceans. • Spinoff to increased community well-being through the spill-over effects of increased crabber confidence, incomes, and profitability.

Public versus Private Impacts

Most impacts identified in this evaluation are industry related and therefore the benefits are considered private benefits. Some minor public benefits have been delivered, including social benefits in the form of improved equity, some community spillovers, animal welfare improvements and the building of industry and scientific capacity.

Distribution of Private Impacts

The beneficiaries of the improved commercial grading scheme will be the captured by the commercial sector of the mud crab industry. This will include the SFM suppliers as well as crabbers and suppliers to other markets. There will be only limited impacts for the recreational and indigenous crabber sectors.

It can be assumed that the distribution of the benefits from the revised grading scheme will be distributed between participants along the commercial supply chains, including final consumers. The only losers from the new grading system will be confined to those who were misusing or abusing the previous scheme.

Impacts on other Australian industries

It is assumed that project impacts will be confined to the Australian mud crab industry. Other live crustacean based industries will not benefit (e.g. prawns, lobsters, crayfish).

Impacts Overseas

No benefits to overseas live crab or crustacean industries are expected.

Match with National and State Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 4. The improved grading scheme for mud crabs contributes primarily to Rural RD&E Priorities 1 and 3 and to Science and Research Priority 1.

Table 4: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities (est. 2015)	**Science and Research Priorities (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

Sources: DAWR (2015) and OCS (2016)

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 5. The mud crab project addressed science and research priorities 1 and potentially 5 and 7. In terms of the guides to investment, the project is likely to have a real future impact through improved confidence and equity in the supply chain. The project was supported and funded by others external to Queensland and had a distinctive angle as the Queensland mud crab industry will be a significant recipient of the impacts. Also, the key Australian scientific expertise on mud crab is Queensland based.

Table 5: Queensland Government Research Priorities

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

Source: Office of the Chief Scientist Queensland (2015)

6. Valuation of Impacts

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved. Sensitivity analyses were undertaken on the discount rate as well as for an alternative counterfactual.

Two impacts were valued. The first was the value gain for crab passing through the SFM. And the second was for the value gain due for crab passing through supply chains other than the SFM.

Impacts not Valued

Not all impacts identified in Table 3 could be valued in the assessment. This was for various reasons including time and resources, availability of baseline data, difficulty in quantifying the causal relationships between the research outputs and the specific impact, and the difficulty of placing credible monetary values on some of the environmental and social benefits.

The economic impacts identified but not valued included:

- Potential for demand expansion from effect of improved and consistent product quality reaching the consumer.
- Increased confidence in the efficiency of the supply chain potentially leading to greater investment in the industry by responsible parties.
- The contribution to potential future objective measurement systems that could further increase industry value.

The environmental impact identified but not valued was a marginal increase in improved resource sustainability due to reduced harvest of newly moulted crabs.

The social impacts identified but not valued included:

- Increased community well-being through the spill-over effects of a more profitable crab industry
- Increased equity in the supply chain regarding rewarding compliance and good management.
- Increased industry capacity to develop and negotiate solutions to industry issues in future.
- Increased scientific research capacity about information relevant to live crustacean supply chains.
- Improvements in animal welfare due to less crab damage from strength testing.

Valuation of Benefit 1: Reduced Downgrading Applied to the SFM Throughput

The grade scores for 370 crabs tested in the project were estimated for both Version 2 and Version 3 of the revised grading Scheme. The change in the grades for each crab from Version 3 indicated an average increase in revenue of $2.18 per kg for male crabs and $2.80 per kg for female crabs across all grades. As female crabs cannot be harvested in Queensland, and based on Queensland fisheries contributing 75% of all crab supplied to the SFM, a weighted average of $2.26 per kg for all crabs was estimated from the two figures above.

Based on a total commercial catch of mud crabs of 1,600 tonnes per annum and assuming the improvement applies to all commercial crab passing through the SFM, the annual gain could be of the order of $976,000 per annum ($0.98m). This assumes the SFM accounts for 27% of the total Australian commercial production.

The final report for the project (Mayze et al, 2016, p 111) estimates that the value of crab passing through the SFM would have increased from $11.4 m to $12.4 m, a gain of about $1m per annum due to Version 3 of the scheme. There is consistency between these two estimates of value improvement ($1m versus $0.98m). Specific assumptions for the current estimate of $976,000 are provided in Table 6.

The estimates above are based on the improvement of Version 3 over Version 2. As Version 2 was an improvement over Version 1 (the original scheme), the estimates above are conservative. However, the Version 1 to Version 2 improvements were not included in the Project Final Report and while they could be estimated by the DAF team, time and resource constraints prevented their inclusion for the present economic evaluation.

Valuation of Benefit 2: Improvements in non-SFM Supply Chains

The improvement in the unit price per kg gain along the non-SFM supply chains are assumed the same as for the SFM supply chain. However, while the level of maximum adoption of the grading scheme is assumed to be somewhat lower than that for the SFM pathway, the adoption is assumed to be just as rapid due to the close involvement of the non-SFM crabbers and supply chains in the project. Details of specific assumptions are provided in Table 6.

Base Counterfactual

If this project had not been funded, it is assumed that the existing issues with the Version 1 scheme would have continued. An alternative counterfactual could have been that the issues and dissatisfaction with the scheme would have worsened over time to a point where it would have been essential for a revised scheme to have been developed. Assumptions for such an alternative counterfactual and the resulting investment criteria are provided in Table 6.

Attribution

The research findings and their usage have occurred in close cooperation with industry and the existing crab supply chain. Other direct factors contributing to the impacts valued are considered minimal. However, apportioning of impact needs to accommodate the industry goodwill and respect provided to the Queensland research team that has been developed in past projects. The Queensland team has been involved with many facets and sectors of the industry over a considerable period.

Extension

As the impacts assumed have already occurred, it is assumed the level adoption does not require additional extension resources to that already undertaken. Moreover, it may be difficult to engage the remaining population of crabbers that are currently not using the revised scheme.

Summary of Assumptions

A summary of the key assumptions made for valuation of the impacts is shown in Table 6.

Table 6: Summary of Assumptions

Variable	Assumption	Source
BASE COUNTERFACTUAL: Version 1 continues indefinitely at current dissatisfaction levels.		
Benefit 1: Reduced Downgrading in SFM		
Average Male Crab Sale Price for Version 3 over Version 2	$2.18 per kg	Final Report for FRDC Project 2014/218 (2016)
Average Female Crab Sale Price for Version 3 over Version 2	$2.80 per kg	Final Report for FRDC Project 2014/218 (2016)
Average Sale Price for all Crab Based on a Simple Average	$2.49per kg	($2.18 + 2.80)/2 = $2.49
Proportion of Commercial Mud Crabs from Queensland where Taking Female Mud Crabs is not permitted	75%	Based on FRDC (2016a)
Average Weighted Sale Price Gain due to Version 3	$2.26 per kg	(2.18x0.75 +2.49x0.25) =2.26
National Commercial Catch of Mud Crab	1,600 tonnes per annum	Based on FRDC (2016a)
Commercial Catch of Sydney Fish Market as % total Commercial Catch	27%	Agtrans Research, based on values in Final Report for FRDC Project 2014/218 and confirmed as appropriate by Sue Poole after discussions with a SFM representative
Potential annual benefit to SFM supply chain from Version 3 over Version 2 with total adoption	$0.976 million per annum	1,600 tonnes x 27% x $2.26 per kg
Maximum adoption of Version 3 by SFM suppliers	100%	Agtrans Research after discussion with Sue Poole and Paul Exley
Year in which maximum adoption reached by SFM suppliers	30 June 2017	Agtrans Research after discussion with Sue Poole and Paul Exley
Benefit 2: Reduced Downgrading in Non-SFM Supply Chains		
Non-Sydney Fish Market Supply chain for commercial catch	1,168 tonnes	1600 x (100%-27%)
Potential annual benefit to non-SFM commercial catch from Version 3 over Version 2 with total instant adoption	$2.64 million per annum	1,168 tonnes x $2.26
Maximum adoption of Version 3 by non-SFM suppliers	60%	Agtrans Research after discussion with Sue Poole and Paul Exley
Year in which maximum adoption reached by non-SFM suppliers	30 June 2017	Agtrans Research after discussion with Sue Poole and Paul Exley
Attribution		
Attribution of the above benefit estimated for this project	50%	Agtrans Research, based on communication and goodwill built in previous years by the same Queensland project team
ALTERNATIVE COUNTERFACTUAL: A similar project to FRDC Project 2014/218 that is first funded in the year ended June 2021		
Benefit 1:	Same assumptions as for the Base Counterfactual except delivered 7 years later	
Benefit 2:	Same assumptions as for the Base Counterfactual except delivered 7 years later	

7. Investment Criteria

All past costs were expressed in 2016/17 dollar terms using the Implicit Price Deflator for Gross Domestic Product. The FRDC component of project investment costs was multiplied by a factor of 1.115 to accommodate program management costs. This factor was derived from FRDC (FRDC, 2016b). The DAF investment costs already had multipliers included.

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

Investment Criteria using Base Counterfactual

Tables 7, 8 and 9 show the investment criteria estimated for different periods of benefits for the total investment and the DAF and FRDC investment respectively. The present value of benefits (PVB) attributable to DAF investment only, shown in Table 8, has been estimated by multiplying the total PVB by the DAF proportion of real investment (65.9%).

Table 7: Investment Criteria for Total Investment in the Project

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	5.82	10.37	13.94	16.74	18.93	20.65
Present value of costs ($m)	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Net present value ($m)	-0.63	5.19	9.75	13.32	16.11	18.30	20.02
Benefit-cost ratio	0.00	9.29	16.56	22.27	26.73	30.23	32.98
Internal rate of return (IRR) (%)	neg.	130.8	132.3	132.3	132.3	132.4	132.4
Modified IRR (%)	neg.	64.0	39.0	29.1	23.8	20.3	18.0

Table 8: Investment Criteria for DAF Investment in the Project

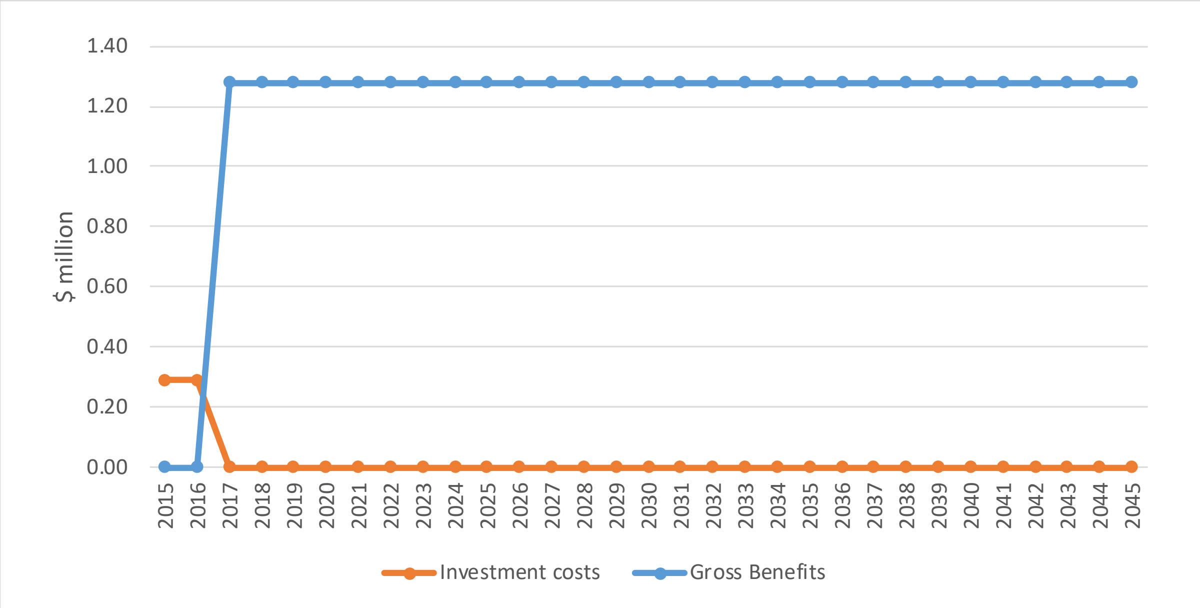
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	3.84	6.85	9.21	11.05	12.50	13.63
Present value of costs ($m)	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Net present value ($m)	-0.41	3.43	6.43	8.79	10.64	12.09	13.22
Benefit-cost ratio	0.00	9.27	16.54	22.23	26.69	30.19	32.93
Internal rate of return (IRR) (%)	neg.	128.6	130.1	130.1	130.1	130.1	130.1
Modified IRR	neg.	63.9	39.0	29.1	23.7	20.3	18.0

Table 9: Investment Criteria for FRDC Investment in the Project

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	1.40	2.49	3.35	4.02	4.55	4.96
Present value of costs ($m)	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Net present value ($m)	-0.15	1.25	2.34	3.20	3.87	4.40	4.81
Benefit-cost ratio	0.00	9.33	16.64	22.37	26.86	30.37	33.13
Internal rate of return (IRR) (%)	neg.	138.7	140.0	140.0	140.0	140.0	140.0
Modified IRR (%)	neg.	64.1	39.0	29.1	23.8	20.4	18.0

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 4.

Figure 4: Annual Cash Flow of Undiscounted Total Benefits and Total Costs



Sources of Benefits for Base Counterfactual

Estimates of the relative contribution of each benefit valued, given the assumptions made, are shown in Table 10.

Table 10: Contribution to Total Benefits from Each Source

Source of Benefits	Contribution to PVB ($m)	Share of benefits (%)
Reduced downgrading in SFM supply chains (Benefit 1)	7.88	38.2
Reduced downgrading in Non-SFM supply chains (Benefit 2)	12.77	61.8
Total	20.65	100.0

Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate for the base counterfactual scenario. 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 11 presents the results. The results showed a high sensitivity to the discount rate.

Table 11: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	**Discount rate**		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	38.38	20.65	13.26
Present value of costs ($m)	0.58	0.63	0.67
Net present value ($m)	37.79	20.02	12.59
Benefit-cost ratio	65.96	32.98	19.74

Investment Criteria using the Alternative Counterfactual

A second analysis was conducted using the alternative counterfactual as specified in Table 6. In this scenario, it was assumed that because of the dissatisfaction of the initial grading scheme the investment would have occurred at some later date. In this alternative scenario, the same assumptions as for the base counterfactual were used, except that the investment and the associated benefits (as well as additional project costs) are assumed to have occurred seven years later. Results are provided in Table 12.

Table 12 shows that the discounted benefits are significantly lower under the alternative counterfactual. This was not unexpected as, under the alternative, there are only seven years of benefit as opposed to 30 years for the base counterfactual. The benefit-cost ratio for the total investment dropped from 33.0 to 1 to 11.7 to 1 under the alternative counterfactual.

Table 12: Investment Criteria for Total Investment in the Project using the Alternative Counterfactual (Total investment, 30 years, 5% discount rate)

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	5.82	7.33	7.33	7.33	7.33	7.33
Present value of costs ($m)	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Net present value ($m)	-0.63	5.19	6.70	6.70	6.70	6.70	6.70
Benefit-cost ratio	0.00	9.29	11.70	11.70	11.70	11.70	11.70

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 13). 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 13: Confidence in Analysis of Project

Coverage of Benefits	Confidence in Assumptions
Medium-High	High

Coverage of benefits was assessed as medium-high as most benefits were economic in nature relating to industry value increases. While some impacts were not valued, their contribution were considered minor compared with those valued. Nevertheless, the investment criteria as provided by the valued benefits are likely to be underestimated to some degree.

Confidence in assumptions was rated as high. The principal assumption of the unit price gain by industry due to avoided downgrading was supported by data provided by the project. The assumptions on adoption were supported by information from both project personnel and by written support by crabbers from throughout the supply chains.

8. Conclusions

The investment in this project has resulted in improvements to the original 2012 grading scheme. These will provide benefits to the Australian Mud Crab Industry, an industry dominated by Queensland crabbers. Further, initial investigations into more objective non-invasive methods of grading of live crab were made in the project and have revealed prospects for further development.

Given the base counterfactual scenario, funding for the project over the two years totalled $0.6 million (present value terms) and produced aggregate total expected benefits of $20.6 million (present value terms). This gave a net present value of $20.0 million, a benefit-cost ratio of 33 to 1, an internal rate of return of 132% and a modified internal rate of return of 18%.

Using the alternative counterfactual that a revised grading scheme would have occurred anyway in future years, the benefit-cost ratio was estimated as 12 to 1. Hence, it can be concluded that the performance of the investment as measured by the benefit-cost ratio was probably at least 12 to 1, and potentially as high as 33 to 1.

The analysis provided a good example of a small investment in a relatively small industry that has provided significant returns to both the Australian and Queensland industry.

References

ABARES (2014) Australian Fisheries and Aquaculture Statistics, Canberra.

Calogeras C, Mayze J, and Poole S (2012) Using Industry Expertise to Build a National Scheme for Grading of Live Mud Crab: Developing the Australian Industry Live Mud Crab Grading Scheme, Final Report, FRDC Project 2011/225

CRRDC (2014) Impact Assessment Guidelines – Version 1, May 2014, CRRDC, Canberra http://www.ruralrdc.com.au/wp-content/uploads/2016/04/CRRDC-Impact-Assessment-Guidelines-V.1-070514.pdf

DAWR (2015) Rural Research and Development Priorities, Department of Agriculture and Water Resources, Canberra, ACT, accessed January 2016 at: http://www.agriculture.gov.au/ag-farm-food/innovation/priorities

FRDC (2016a) Stock Status Report for Mud Crab, accessed 17 February 2017 at: http://www.fish.gov.au/report/41-MUD-CRAB-2016

FRDC (2016b) Fisheries Research and Development Corporation, Annual Report 2015-16, Canberra, accessed February 2017 at http://www.frdc.com.au/about_frdc/Documents/Annual_Report/FRDC_Annual_Report_2016.pdf

Mayze J, Poole S, Exley P and Calogeras C, (2016) Building Precision into the Australian Industry Live Mud Crab Grading Scheme (AILMCGS) through Addressing Grading and Regional Anomalies, Final Report, FRDC Project 2014/218.

OCS (2016) Science and Research Priorities, Office of the Chief Scientist, Department of Industry, Innovation and Science, Canberra, accessed 02 November 16 at: http://science.gov.au/scienceGov/ScienceAndResearchPriorities/Pages/default.aspx

Office of the Chief Scientist, Queensland Government (2015) Revised Queensland Science and Research Priorities, accessed 17 February 2017 at: http://www.chiefscientist.qld.gov.au/images/documents/chiefscientist/pubs/reports-other/qld-science-n-research-priorities-2015-2016.pdf

Poole S, Mayze J and Calogeras C (2012) Equipping the mud crab industry with innovative skills through extension of best practice handling, Final Report, FRDC Project 2010-302, Department of Agriculture, Fisheries and Forestry, Queensland Government.

Appendix 2: An Impact Assessment of DAF Investment in Low Dose Methyl Bromide against Fruit Flies to Improve Summer-fruit Market Access, 2013-2016: HIA Project SF12016

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Abbreviations

CBA	Cost-Benefit Analysis
CRC	Cooperative Research Centre
CRRDC	Council of Research and Development Corporations
DAF	Department of Agriculture and Fisheries, Queensland
DAWR	Department of Agriculture and Water Resources (Australian Government)
GDP	Gross Domestic Product
HIA	Horticulture Innovation Australia
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
OCS	Office of Chief Scientist Queensland
ODS	Ozone Depleting Substance
PVB	Present Value of Benefits
RDC	Research and Development Corporation
R&D	Research and Development
RD&E	Research, Development and Extension

Executive Summary

The Project

This report presents the results of an impact assessment of a Queensland Department of Agriculture and Fisheries (DAF) investment in a project to generate data on the efficacy of low dose methyl bromide against Queensland fruit fly (*Bactrocera tryoni*) to improve summerfruit market access. The project was funded by DAF and Horticulture Innovation Australia (Hort Innovation or HIA) over the period 2013-2016.

Methods

The project was analysed qualitatively within a logical framework that included activities/outputs, outcomes, and impacts. Impacts were categorised into a triple bottom line framework. The principal impact was then valued. Benefits were estimated for a range of time frames up to 30 years from the year of last investment in the project. Past and future cash flows in 2016/17 $ terms were discounted to the year 2016/17 using a discount rate of 5% to estimate the investment criteria.

Impacts

The major impact identified was of a financial nature. However, some social and environmental impacts also were identified but not valued. It is expected the Australian summerfruit industry will be the primary beneficiary of the investment.

Investment Criteria

Total funding from all sources for the project was $0.9 million (present value terms). The value of benefits was estimated at $4.2 million (present value terms). This gave an estimated net present value of $3.3 million, and a benefit-cost ratio of 4.6 to 1.

1. 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 included both qualitative and quantitative descriptions that are in accord with the evaluation guidelines of the Council of Research and Development Corporations (CRRDC, 2014).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, 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, a high degree of uncertainty surrounding the potential impact, or the likely low relative significance of the benefit compared to those that were valued. The impacts valued therefore are deemed to represent the principal benefits delivered by the project.

2. Background and Rationale

Background

The Australian summerfruit industry comprises peaches, nectarines, apricots, plums and pluots (plum apricot hybrid). Annual production is approximately 110,000 tonnes and was valued at $200 million farm gate in 2014-15. Most production takes place in Victoria but all Australian states, including Queensland, have a commercial summerfruit industry (Summerfruit Australia June 2016).

Approximately 80% of Australian summerfruit is consumed fresh in the domestic market, 10% is processed and the balance is exported. In 2015-16 Australia produced around 35,000 tonnes of summerfruit surplus to local market requirements. In 2016-17 a further 7,500 tonnes of summerfruit, mainly nectarines, will be produced on trees already planted with similar increases in the next few years as new plantings come on stream. If Australian summerfruit production continues to grow, the domestic market will not be able to absorb the increase without significant price reductions and associated industry adjustment. Export development, including improved access to markets, is essential for the summerfruit industry (Summerfruit Australia June 2016).

Rationale for the Project

The aim of this project was to gain and improve market access for Australian summerfruit to export markets. Australian summerfruit currently has export protocols in place or being developed for plums, nectarines and pluots, based on cold disinfestation treatments for markets with quarantine barriers against fruit flies. However, the cold disinfestation treatments are not always economically feasible or practical in many markets (e.g. duration of voyage does not coincide with disinfestation time and as a consequence separate onshore storage facilities are required for export fruit). Peaches are not able to withstand long treatments required for cold disinfestation while maintaining fruit quality so no export protocols currently exist for peaches. Protocols using methyl bromide fumigation for airfreight shipments will allow better targeting of market opportunities, allow better quality fruit arrivals for plums and nectarines and allow the development of quarantine protocols for peaches (John Moore, Summerfruit Australia quoted in the project proposal).

3. Project Details

Summary

Title: Low Dose Methyl Bromide against Fruit Flies to Improve Summerfruit Market Access Research Organisation: Department of Agriculture and Fisheries, Queensland Principal Investigator: Pauline Wyatt Period of Funding: February 2013 to May 2016

Objectives

The objective of the project was:

- To generate data to allow the development of export protocols suitable for airfreight.

Logical Framework

Table 1 provides a description of the project in a logical framework developed for the project.

Table 1: Logical Framework

Activities and Outputs	• Nectarines and peaches were fumigated with methyl bromide at a treatment dose of $18g/m^3$ at a pulp temperature of 18^0C for 5.5 hours to kill Queensland fruit fly (Qfly, *Bactrocera tryoni*). • Three large scale trials were conducted against each of the four immature life stages of Qfly. • No Qfly survived, thereby resulting in a >99.99% mortality at the 95% confidence level for each life stage. • There was no adverse effect on fruit quality. • The data package generated from the experiment was sufficient for protocol development for the use of low dose methyl bromide as a quarantine treatment against Qfly in nectarines and peaches. • This project was the first time that a complete data set on low dose methyl bromide use had been assembled (Ekman, 2016). • An export submission was prepared and submitted to the Australian Government Department of Agriculture and Water Resources (DAWR). • In 2015 it was reported "DAWR officers have provided the report to quarantine authorities from China and Thailand. Bilateral negotiations have commenced with both countries, but are not complete yet" (Wyatt et al 2015). • Outputs from the project are relevant to Australian summerfruit protocol markets[1]: China, Vietnam, Thailand, Philippines and Taiwan (NB: Indonesia is a non-protocol market that already accepts methyl bromide fumigation albeit at high dose levels i.e. $64g/m^3$).

[1] Protocol countries have specific phytosanitary and market access requirements which have been negotiated between the importing country and DAWR. Non-protocol countries have fewer import conditions.

Outcomes	• As a result of the project the China market opened for nectarines starting in the 2016-17 summerfruit season. The protocol includes airfreight using 'low dose methyl bromide at 18g/m^3 for 5.5 hours at a pulp temperature of 18°C or above at no more than 34% chamber load' i.e. project recommendations.
	• Australian nectarines were air-freighted to China using the protocol in 2016-17 (John Moore, pers. comm. March 2017).
	• The same low dose methyl bromide based protocol has been requested by Australia for airfreight summerfruit exports to (John Moore, pers. comm. March 2017):
	  • China – access anticipated for peaches in 2017-18.
	  • Vietnam – access anticipated for nectarines and peaches in 2017-18.
	  • Thailand – access anticipated for nectarines and peaches in 2018-19.
	  • Philippines – access anticipated for nectarines and peaches in 2018-19.
	  • Taiwan – access anticipated for nectarines and peaches in 2019-20.
	• In the longer term low dose methyl bromide may also be relevant to the New Zealand and United States markets (Pauline Wyatt, pers. comm. March 2017).
	• While the project outputs are also potentially relevant to the interstate trade in summerfruit – as summerfruit originating in the major Australian production regions are subject to fumigation or other forms of Qfly management prior to entering Western Australia, South Australia and Tasmania – the trade is not based on airfreight and research outputs will not change current interstate trade outcomes.
	• Outputs from the research are also relevant to other horticultural crops whose airfreight export is constrained by Qfly concerns; other crop interests might be able to adapt the research to create an additional phytosanitary treatment option for their particular industries.
	• Use of the new treatment option with half the amount of methyl bromide used and will avoid fumigation burn ('fumo burn') and increase fruit quality. Adoption will result in improved fruit quality in export markets serviced by airfreight (Ekman, 2016).
	• Reducing the volume of methyl bromide used also has implications for the environment – methyl bromide is an ozone depleting substance and until capture is mandatory, a reduction in use volume will also reduce subsequent environmental damage.
	• Methyl bromide adversely affects human health and a reduction in concentration reduces workplace health and safety risk during venting (Pauline Wyatt, pers. comm. March 2017).
	• Reduced methyl bromide use will also result in minor cost savings over 'full dose' methyl bromide use for fumigation operations.
	• Research capacity was built in fumigation, gas chromatography, and fruit fly fumigation techniques.

Impacts	• Summerfruit export sales in Asian airfreight markets resulting in increased grower profit i.e. new sales to China, Vietnam, Thailand, Philippines and Taiwan. • Potential additional phytosanitary treatment options for other horticultural crops because it has been shown to be successful on peaches and nectarines e.g. other summerfruit (apricots, plums and pluots), apples, pears, table grapes, mango, capsicum, pumpkin, strawberry. • Reduction in the volume of ozone depleting substances used in phytosanitary treatments.

	• Improvement in workplace health and safety as a result of lower dose methyl bromide protocols. • Increased research capacity. • Increased regional income in summerfruit growing areas.

4. Project Investment

Nominal Investment

Table 2 shows the annual investment for the project funded by DAF and Hort Innovation.

Table 2: Annual Investment in the Project (nominal $)

Year ended 30th June	DAF	Hort Innovation	TOTAL
2013	80,000	51,208	131,208
2014	208,000	106,507	314,507
2015	36,000	169,686	205,686
2016	36,000	37,499	73,499
Totals	**360,000**	**364,900**	**724,900**

Program Management Costs

DAF investment includes an allowance for program management, administration and corporate infrastructure costs.

For Hort Innovation investment the cost of managing the Hort Innovation funding was added to the Hort Innovation contribution via a management cost multiplier (1.1227); this was estimated based on the reported share of overhead costs including 'employee benefits' in total Hort Innovation expenditure (Hort Innovation, 2016). This multiplier was applied to the nominal investment by Hort Innovation shown in Table 2.

Real Investment and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2016/17 $ terms using the GDP deflator index. 'Extension' costs include a share of costs incurred by DAWR in communicating the data package resulting from project research to quarantine authorities in China, Vietnam, Thailand, Philippines and Taiwan. Communication costs were also incurred informing industry of successful market access outcomes. An allowance of $50,000 in 2015 and again in 2016 has been included to cover these costs.

5. Impacts

As described previously, the data set showing the efficacy of low dose methyl bromide against Qfly was incorporated into an export submission by DAF and made available to DAWR. In 2015 DAWR officers provided the report to quarantine authorities from China and Thailand (Wyatt et al 2015). Subsequently the report has been made available to quarantine authorities in other relevant protocol markets i.e. Vietnam, Philippines and Taiwan (John Moore, pers. comm., March 2017).

The principal actual and potential impacts from evidence of the effectiveness of low dose methyl bromide against Qfly include:

- Summerfruit export sales in Asian airfreight markets resulting in increased grower profit
- Potential additional phytosanitary treatment options for other horticultural crops
- Reduction in volume of ozone depleting substances used in phytosanitary treatments
- Increased research capacity
- Increased regional income in summerfruit growing areas (spillover).

Table 3 provides a summary of the types of impacts categorised into economic, environmental and social impacts.

Table 3: Triple Bottom Line Categories of Impacts from Low Dose Methyl Bromide

Economic	• Summerfruit export sales in Asian airfreight markets resulting in increased grower profit. • Additional phytosanitary treatment options for other horticultural crops e.g. other summerfruit (apricots, plums and pluots), apples, pears, mango, capsicum, pumpkin, strawberry (resulting in increased grower profit).
Environmental	• Reduction in volume of ozone depleting substances (ODS) used in phytosanitary treatments (methyl bromide is a known ODS and half the previous volume will be used in the low dose protocol).
Social	• Improved workplace health and safety – fumigation facilities. • Increased research capacity. • Increased regional incomes resulting from the increased profitability of the Australian summerfruit industry.

Public versus Private Impacts

The majority of benefits identified in this evaluation are summerfruit industry related and therefore are considered private benefits. Public benefits also have been delivered, including environmental benefits and social benefits.

Some environmental and social impacts were reported in Table 3 e.g. decreased methyl bromide use with its known impact on the ozone layer. Some indirect social benefits were delivered also, including increased regional incomes, the result of spillovers from increased summerfruit industry profit.

Distribution of Private Impacts

The benefits to the summerfruit industry from investment in this project will be shared along the supply chain with growers, packers and exporters all sharing impacts produced by the project.

Impacts on other Australian industries

Benefits to other Australian industries include an additional phytosanitary treatment option for other horticultural crops that export and are susceptible to Qfly. These industries include, but are not limited, to other summerfruit (apricots, plums and pluots), apples, pears, citrus, mango, capsicum, cucumber, chillies and eggplant.

Impacts Overseas

The scientific data produced by this project is only relevant to Qfly – an Australian native. Nevertheless, the approach used (low dose methyl bromide) is understood to be a world first (Ekman, 2016). Consequently, the approach applied may be relevant and adapted to other fruit fly species found overseas as well as potentially other overseas pest species. The approach used could be adopted by researchers assisting overseas horticultural industries including US summerfruit producers and Chilean summerfruit and cherry producers.

Match with National and State Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 4. The low dose methyl bromide against Qfly to improve market access project primarily contributes to Rural RD&E Priority 1 and 2 and to Science and Research Priority 1.

Table 4: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities (est. 2015)	**Science and Research Priorities (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

Sources: DAWR (2015) and OCS (2016)

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 5. The methyl bromide project addressed Science and Research Priorities 1 and potentially 6. In terms of the guides to investment, the project will have a real future impact through additional profitable sales of summerfruit, was supported and funded by others external to Queensland, had a distinctive angle with world first use of low dose methyl bromide and further developed Australian scientific expertise in fumigation.

Table 5: Queensland Government Research Priorities

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

Source: Office of the Chief Scientist Queensland (2015)

6. Valuation of Impacts

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved. Sensitivity analyses were undertaken on the discount rate and the probability of access to new markets as well as for an alternative counterfactual.

The single major benefit of the research project has been valued – growth in summerfruit export sales resulting in increased grower profit from sale of better quality fruit into Asian airfreight markets.

Impacts Not Valued

Not all impacts identified in Table 3 could be valued in the assessment. This was for various reasons including time and resources, availability of baseline data, difficulty in quantifying the causal relationships between the research outputs and the specific impact, and the difficulty of placing credible monetary values on some of the environmental and social benefits.

The economic impacts identified but not valued included:
- Potential additional phytosanitary treatment options for other horticultural crops.

The environmental impact identified but not valued was:
- The reduction in volume of ozone depleting substances used in phytosanitary treatments.

The social impacts identified but not valued included:
- Improved workplace health and safety
- Increased research capacity
- Increased regional incomes because of increased profitability of the Australian summerfruit industry.

Valuation of Benefit: Summerfruit Export Sales in Asian Airfreight Markets

The quantified benefit is export sales in Asian airfreight markets. Airfreight is one high priced component of total export sales into these markets with most fruit being delivered by seafreight. Seafreight fruit, with longer transit times necessitated by protocol fumigation requirements, may not have the shelf life and consumer attributes that command the same high price in Asia as niche airfreight sales.

Nectarines and peaches airfreighted to Asia are assumed to achieve an average farm-gate price of $3.55/kg. Phytosanitary treatment costs for export, including low dose methyl bromide, cost $0.05/kg. The next best alternative price for nectarines and peaches is farm-gate $2.00/kg when they are destined for either the seafreight or domestic market. Airfreight supply to Asia nets an additional $1.50/kg.

In 2016-17, the first year of the Australian trade with China, it is estimated that by season's end, fifteen airfreight containers each carrying one hundred and forty 10kg trays of nectarines will be exported to China, a total of 21,000kg of nectarines. Peaches, it is anticipated, will be exported to China by airfreight in 2017-18.

Up to the time of writing in March 2017, 2016-17 had been was a difficult year for Australian summerfruit growers with a slow start to the spring and poor fruit quality. A major investment was made in promoting Australian nectarines in China and wholesale market launches were regarded as successful (Moore, 2016). In subsequent years, the volume of Australian nectarines airfreighted to China is expected to grow off the base established in 2016-17.

In addition to the fledgling trade in nectarines to China, protocols for airfreight of peaches to China and nectarines and peaches to other Asian destinations are anticipated. The year access is first achieved and estimated first year sales are shown in Table 6. Table 6 also shows a 'likelihood of occurrence' factor given that access is not assured.

Counterfactual

If this project had not been funded, it is assumed that no airfreight protocol for export of nectarines and peaches into Asia would have been developed during the analysis period. Industry would have relied on seafreight. An alternative counterfactual is that an irradiation plant is built at the Melbourne wholesale markets. In this scenario, the World Trade Organisation's preference for non-methyl bromide fumigation prevails and Asian countries accept irradiated nectarines and peaches in their markets. Assumptions for both the base and alternative counterfactual are provided in Table 6.

Attribution

There is no other research contributing to anticipated impacts and a high attribution to the DAF project has been assumed.

Extension

An allowance has been made in the analysis for communicating relevant research packages to quarantine authorities in Asia. Australian summerfruit exporters, and growers, are well aware of the opportunity presented and numerous press releases have been made by DAWR. An estimate of the cost of these press releases has been included in 'extension' costs.

Summary of Assumptions

A summary of the key assumptions made for valuation of the impacts is shown in Table 6.

Table 6: Summary of Assumptions

Variable	Assumption	Source
BASE COUNTERFACTUAL: Seafreight cold treatment for summerfruit exported to Asia would have continued as the appropriate disinfestation technology		
Benefit: Summerfruit Export Sales in Asian Airfreight Markets		
Average farm-gate price for nectarines and peaches airfreighted to Asia	$3.55 per kg	Average farm-gate price realised for nectarines sent to China in 2016-17 was between $3.20 and $3.90/kg (John Moore, pers. comm., March 2017)
Cost of phytosanitary treatment including low dose methyl bromide (cost met by exporter)	$0.05 per kg	Adapted from the Summerfruit Australia China Airfreight Calculator February 2017
Average farm-gate price for nectarines and peaches in 'next best' market – seafreight or domestic	$2.00 per kg	Consultant estimate after review of 2016-17 Melbourne wholesale

		market data and adjustment for post farm gate costs
Average increase in economic value due to airfreight access using methyl bromide	$1.50 per kg	$3.55 - $0.05 - $2.00 = $1.50
Airfreight sales of Australian nectarines to China 2016-17	21,000 kg	John Moore, pers. comm., March 2017
New market access - year access achieved and first year sales: - China – peaches - Vietnam – nectarines and peaches - Thailand – nectarines and peaches - Philippines – nectarines, peaches - Taiwan – nectarines and peaches	 2017-18: 21,000kg 2017-18: 2,500kg 2018-19: 3,000kg 2018-19: 2,500kg 2019-20: 2,500kg	 Consultant assumptions following discussions with John Moore, Summerfruit Australia March 2017

Forecast growth in new market sales (kg)

Country	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23	2023-24	2024-25
China - nectarine	21,000	25,000	50,000	60,000	80,000	100,000	100,000	100,000
China – peach		21,000	25,000	50,000	60,000	80,000	100,000	100,000
Vietnam - peach and nectarine		2,500	2,750	5,000	7,500	10,000	10,000	10,000
Thailand - peach and nectarine			3,000	3,250	6,000	7,000	8,000	8,000
Philippine - peach and nectarine			2,500	2,750	5,000	7,500	10,000	10,000
Taiwan -peach and nectarine				2,500	2,750	5,000	7,500	10,000

Probability that access will be achieved in new markets	80%	Consultant assumption based on industry discussions
Year in which maximum nectarine and peach sales achieved in each market	4-5 years after trade established in each market	Consultant assumption assuming high priced airfreight sales remain a niche that is quickly filled. Ongoing sales growth limited by competition from alternative suppliers e.g. cherries from Chile

ALTERNATIVE COUNTERFACTUAL: Methyl bromide is replaced by irradiation as the preferred airfreight protocol in Asian markets in the year ended June 2021

Benefit: Growth in summerfruit exports	Same assumptions as for the Base Counterfactual except benefits cease after 5 years

7. Investment Criteria

All past costs were expressed in 2016/17 dollar terms using the Implicit Price Deflator for Gross Domestic Product. As described earlier, the Hort Innovation component of project investment costs was multiplied by a factor of 1.1227 to accommodate program management costs. The DAF investment costs already had program management costs included.

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

Investment Criteria using Base Counterfactual

Tables 7, 8 and 9 show the investment criteria estimated for different periods of benefits for the total investment and the DAF and Hort Innovation investment respectively. The present value of benefits (PVB) attributable to DAF investment only, shown in Table 8, has been estimated by multiplying the total PVB by the DAF proportion of real investment (41.3%). Hort Innovation's share of benefits has been determined on the same basis (47.1%) and is shown in Table 9. The balance of benefits is attributable to DAWR's activities.

Table 7: Investment Criteria for Total Investment in the Project

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.03	0.74	1.81	2.65	3.31	3.82	4.15
Present value of costs ($m)	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Net present value ($m)	-0.86	-0.15	0.92	1.75	2.41	2.93	3.26
Benefit-cost ratio	0.04	0.83	2.02	2.96	3.70	4.72	4.64
Internal rate of return (IRR) (%)	Negative	Negative	19.0	22.4	23.3	23.6	23.7
Modified IRR (%)	Negative	1.0	12.9	13.1	12.2	11.4	10.8

Table 8: Investment Criteria for DAF Investment in the Project

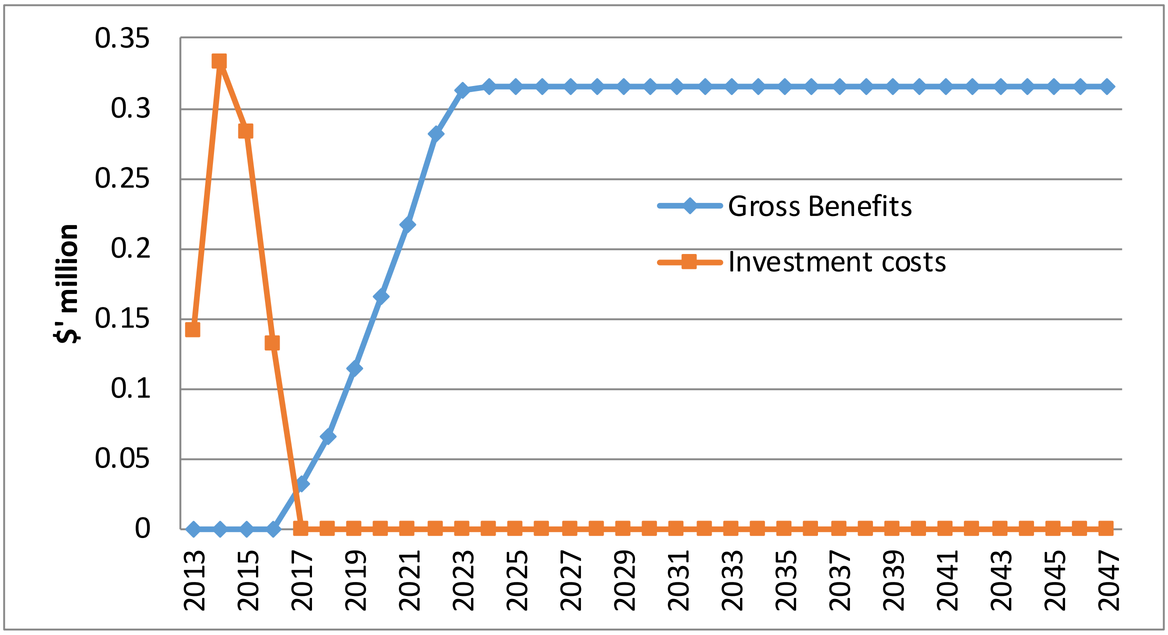
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.01	0.31	0.75	1.10	1.10	1.58	1.72
Present value of costs ($m)	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Net present value ($m)	-0.36	-0.06	0.38	0.73	0.73	1.21	1.35
Benefit-cost ratio	0.04	0.83	2.03	2.97	2.97	4.28	4.65
Internal rate of return (%)	Negative	Negative	19.1	22.5	23.4	23.6	23.4
Modified IRR	Negative	1.0	12.9	13.1	12.3	11.4	10.8

Table 9: Investment Criteria for Hort Innovation Investment in the Project

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.01	0.35	0.85	1.24	1.24	1.80	1.95
Present value of costs ($m)	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Net present value ($m)	-0.41	-0.07	0.43	0.82	0.82	1.38	1.53
Benefit-cost ratio	0.04	0.83	2.02	2.96	2.96	4.72	4.64
Internal rate of return (%)	Negative	Negative	19.0	22.4	23.3	23.6	23.7
Modified IRR	Negative	1.0	12.9	13.1	12.2	11.4	10.8

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 1.

Figure 1: Annual Cash Flow of Undiscounted Total Benefits and Total Costs



Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate for the base counterfactual scenario. 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 10 presents the results. The results showed a moderate sensitivity to the discount rate.

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

Investment Criteria	**Discount rate**		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	8.45	4.15	2.39
Present value of costs ($m)	0.89	0.89	0.90
Net present value ($m)	7.56	3.26	1.49
Benefit-cost ratio	9.51	4.64	2.66

A second sensitivity analysis was completed on the probability of Australian nectarines and peaches gaining access to new Asian airfreight markets (in addition to the Chinese nectarine market) – Table 11. Even at 20% probability of securing access to these new markets, a positive benefit-cost ratio is achieved.

Table 11: Sensitivity to Market Access
(Total investment, 30 years)

Investment Criteria	**Probability that Market Access will be Achieved**		
	20%	**40%**	**80% (base)**
Present value of benefits ($m)	2.58	3.10	4.15
Present value of costs ($m)	0.89	0.89	0.89
Net present value ($m)	1.68	2.21	3.26
Benefit-cost ratio	2.88	3.47	4.64

Investment Criteria using the Alternative Counterfactual

A second analysis was conducted using the alternative counterfactual as specified in Table 6. In this scenario, it was assumed that methyl bromide based airfreight protocols are replaced by the use of irradiation in 2021. Cold disinfestation remains in place. In this alternative scenario, the same assumptions as for the base counterfactual were used, except that benefits cease after 5 years when methyl bromide is replaced. Results are provided in Table 12.

Table 12 shows that the discounted benefits are significantly lower under the alternative counterfactual. This was not unexpected as, under the alternative, there are only five years of benefit as opposed to 30 years for the base counterfactual. The benefit-cost ratio for the total investment dropped from 4.6 to 1 to 0.6 to 1 under the alternative counterfactual.

Table 12: Investment Criteria for Total Investment in the Project using the Alternative Counterfactual (Total investment, 30 years, 5% discount rate)

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.03	0.52	0.42	0.42	0.42	0.42	0.42
Present value of costs ($m)	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Net present value ($m)	-0.86	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37
Benefit-cost ratio	0.04	0.58	0.58	0.58	0.58	0.58	0.58

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 13). 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 13: Confidence in Analysis of Project

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

Coverage of benefits was assessed as high as most benefits were economic in nature and related to increased grower returns. While some impacts were not valued, their contribution was considered minor compared with those valued.

Confidence in assumptions was rated as medium. Principal assumptions around acceptance of methyl bromide based protocols were derived from those close to the negotiation process and have been sensitivity tested.

8. Conclusions

The investment in this project has resulted in the establishment of an airfreight market for Australian nectarines in China. It is also expected to lead to the establishment of an airfreight peach market in China and airfreight nectarine and peach markets in Vietnam, Thailand, the Philippines and Taiwan.

Given the base counterfactual scenario, funding for the project over the two years totalled $0.9 million (present value terms) and produced aggregate total expected benefits of $4.2 million (present value terms). This gave a net present value of $3.3 million, a benefit-cost ratio of 4.6 to 1, an internal rate of return of 24% and a modified internal rate of return of 11%.

Using the alternative counterfactual, that methyl bromide based export protocols are replaced by irradiation in five years, the benefit-cost ratio was estimated as 0.6 to 1. Hence, it can be concluded that the performance of the investment as measured by the benefit-cost ratio was probably at least 0.6 to 1, and potentially as high as 4.6 to 1.

The analysis provided a good example of a relatively small investment that has utilised and built research capacity in Queensland and delivered a net benefit for the nationally significant summerfruit industry.

References

CRRDC (2014) Impact Assessment Guidelines – Version 1, May 2014, CRRDC, Canberra http://www.ruralrdc.com.au/wp-content/uploads/2016/04/CRRDC-Impact-Assessment-Guidelines-V.1-070514.pdf

DAWR (2015) Rural Research and Development Priorities, Department of Agriculture and Water Resources, Canberra, ACT, accessed January 2016 at: http://www.agriculture.gov.au/ag-farm-food/innovation/priorities

Ekman, J (2016) 'Fumo Breakthrough – Dosing Down on Methyl Bromide' in Australian Stonefruit Grower, Issue 3 December 2016

Hort Innovation (2016) Horticulture Innovation Australia Annual Report 2015-16 http://horticulture.com.au/wp-content/uploads/2016/10/Hort-Innovation-Annual-Report-2015-16-Web.pdf

Moore, J (2016) 'Growing Trade with China' in Australian Stonefruit Grower, Issue 3 December 2016

OCS (2016) Science and Research Priorities, Office of the Chief Scientist, Department of Industry, Innovation and Science, Canberra, accessed 02 November 16 at: http://science.gov.au/scienceGov/ScienceAndResearchPriorities/Pages/default.aspx

Office of the Chief Scientist, Queensland Government (2015) Revised Queensland Science and Research Priorities, accessed 17 February 2017 at: http://www.chiefscientist.qld.gov.au/images/documents/chiefscientist/pubs/reports-other/qld-science-n-research-priorities-2015-2016.pdf

Summerfruit Australia (2016) The Summerfruit Manual, June (Draft)

Wyatt, P., Eelkema, M., Wells, I., Joyce, D., Senior, L. and Leach, P. (2015) Low dose methyl bromide against fruit flies to improve market access for Summerfruit. Final Report. Project Number: SF12016

Appendix 3: An Impact Assessment of DAF Investment into CRDC project DAQ1401: Strengthening the Central Highlands Cotton Production System

Acknowledgments

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Abbreviations

ABS	Australian Bureau of Statistics
APVMA	Australian Pesticide and Veterinary Medicines Authority
BCR	Benefit-Cost Ratio
BOM	Bureau of Meteorology
CBA	Cost-Benefit Analysis
CGA	Cotton Growers' Association
CQ	Central Queensland
CRC	Cooperative Research Centre
CRDC	Cotton Research and Development Corporation
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries – Queensland
GDP	Gross Domestic Product
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NPV	Net Present Value
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

The Report

This report presents the results of an impact assessment of a Queensland Department of Agriculture and Fisheries (DAF) investment in a project to strengthen the cotton production system in the Central Highlands. The project was jointly funded by DAF and the Cotton Research and Development Corporation (CRDC) from 1 July 2013 to 30 June 2017.

Methods

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

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

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

Impacts

The major impacts identified were of a financial/economic nature. However, some social and environmental impacts were identified also but not valued. It is expected that the Central Highlands cotton industry will be the primary beneficiary of the investment.

Investment Criteria

Total funding from all sources for the project was approximately $1.18 million (present value terms). The value of total benefits was estimated at $20.24 million (present value terms). This result generated an estimated net present value (NPV) of $19.06 million, and a benefit-cost ratio (BCR) of approximately 17.1 to 1.

1. Method

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

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

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

2. Background and Rationale

Background

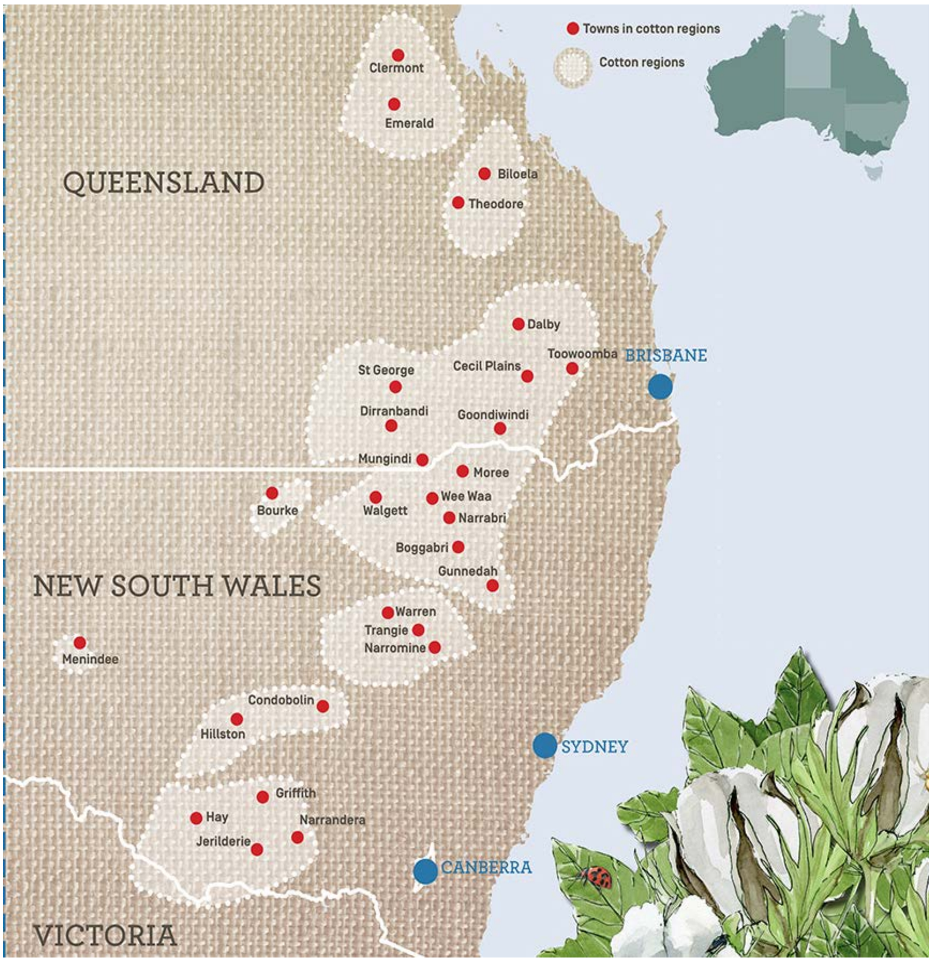
The Australian cotton industry is one of Australia's largest rural export earners and has an estimated annual average gross value of production of $2 billion. Australia produces both cotton lint and cottonseed. Cotton lint (fibre) makes up approximately 42% of picked cotton by weight and contributes about 85% of the total income from a cotton crop. The other 15% comes from cottonseed which is mostly used to make cottonseed oil and stock feed (Cotton Australia, 2016a).

Cotton is a summer crop and approximately 95% of the total area of cotton grown in Australia is grown under irrigation (Cotton Australia, 2016b). Australian irrigated lint yields are the highest of any major cotton producing country in the world and Australian cotton growers have produced, on average, an estimated 2.74 million bales of cotton lint per annum (where a standard Australian bale contains 227 kilograms of cotton lint) from an average cropping area of approximately 300,000 hectares (Cotton Australia, 2017).

There are, approximately 1,200 cotton growers in Australia with about 60% of farms in New South Wales (NSW) and 40% in Queensland (QLD). The major production area in NSW stretches south from the Macintyre River on the QLD border and covers the Gwydir, Namoi and Macquarie valleys. In NSW, cotton is also grown along the Barwon and Darling rivers in the west and the Lachlan and Murrumbidgee rivers in the south.

In QLD, cotton is grown mostly in the south in the Darling Downs, and in the St George, Dirranbandi and Macintyre Valley regions. The remainder is grown in Central Queensland (CQ) near Emerald, Theodore and Biloela. CQ represents approximately 20% of the QLD cotton production area and about 7% of total Australian cotton lint production (in terms of bales) (based on data collated from the annual Cotton Yearbook, 2010 to 2016, published by The Australian Cottongrower, Toowoomba). The major Australian cotton production regions are shown in Figure .

Figure 1: Map of Key Cotton Production Regions in Australia



Source: Cotton Australia, 2017 URL: http://cottonaustralia.com.au/australian-cotton/basics/where-is-it-grown

Rationale for the Investment

Central Queensland has had a long history of cotton production. The hot tropical climate of CQ presents both constraints and opportunities for cotton producers. Over the past decade, a combination of a variable climate, characterised by frequent weather extremes, and specific or exacerbated pest and disease incidence have contributed to a situation of largely static yields and a high frequency of bale quality discounts. On the other hand, the warm climate translates into a relatively long growing season, which in turn facilitates flexibility in sowing times.

Due to a warmer climate in the north, cotton crops in CQ are planted from mid-September and the cotton is picked from late February. This crop cycle means that January is a critical time in cotton plant development. During the January period, cotton crops reach peak flowering and boll fill and variable and sometimes extreme climatic conditions experienced from late January due to monsoonal influences can cause lint yield and quality losses. It was recognised that the climate in CQ could be amendable to earlier planting for cotton crops potentially leading to earlier harvest, thus minimising the risk of a crop being exposed to late summer variable weather conditions during critical growth periods.

Project DAQ1401 “Strengthening the Central Highlands Cotton Production System”, jointly funded by the Department of Agriculture and Fisheries QLD (DAF) and the Cotton Research and Development Corporation (CRDC), was planned to investigate tactics that may enable early flowering of cotton crops in spring, potentially bringing forward the time at which crops mature thus avoiding boll-fill during periods of variable conditions for the Central Highlands in CQ.

3. Project Details

Summary

Project Title: Strengthening the Central Highlands Cotton Production System Research Organisation: Department of Agriculture and Fisheries, Queensland Principal Investigator: Paul Grundy Period of Funding: July 2013 to June 2017

Objectives

The objectives of the project were:

1. To better define yield potential in relation to climate variability and genotype.
2. To develop and test agronomic tactics aimed at increasing the reliability of yield potential and best bet strategies that reduce climate risks.
3. To better understand the interactions that are occurring between climate, causal agents and crop development that may be influencing the incidence and severity of boll rots and then to exploit this knowledge where possible to reduce boll rot yield losses.
4. To investigate the ecology and management of Symphyla, a recurring soil borne pest in the Dawson farming system.

Logical Framework

Table 1 provides a description of the project in a logical framework developed for the project.

Table 1: Logical Framework for Project DAQ1401

Activities and Outputs	*Climate Data Analyses* • An analysis of existing Central Highlands data and modelling scenarios was carried out that substantiated the difficulties reported by growers in the region who have been trying to maximise yield potential in a variable climate. • Analysis and basic modelling for the entire Central Highlands Bureau of Meteorology (BOM) weather data set was conducted to test various climatic risk scenarios for the region and identify gaps and opportunities for cotton research. *Early Crop Establishment Trials* • A fully replicated pilot experiment was implemented and completed during the 2013/14 season. The experiment tested the impact of early establishment with the use of biodegradable films and collected a set of crop responses to different climatic conditions throughout the season. Trial plots were planted at four different sowing dates from the beginning of August (5th and 19th of August, and 2nd and 15th of September). • Extensive plant development measurements (leaf area, light interception, dry matter accumulation and partitioning, total retention, nodes, nodes above white flower, height and maturity) were made throughout the season.

	• A problem was encountered with the first films tested for the August sowings. The film suffered from premature breakdown which negated many of the potential benefits. A new version of film was acquired which lasted 5-6 weeks before beginning to break down. • Where the films remained intact the first season results showed that crop development was hastened by about 7 to 9 days. • The project was varied in early 2014 to allow capital expenditure on a custom-built Film Layer and degradable film (in collaboration with DC Envrioplas) to be used for the following three seasons. The film was then laid mechanically on hills which overcame many of the deployment problems experienced in the first trial. • Trials for the first three seasons of the project (2013/14 to 2015/16) were planted using the Bollgard II® variety. This variety of cotton is commercially restricted to a specific planting window (between September 15 and October 26 for the Central Highlands and the Dawson-Callide Valleys (Monsanto Australia Limited, 2012)) by the Australian Pesticide and Veterinary Medicines Authority (APVMA). • The project findings (up to 2014) were included in submissions to the APVMA seeking a permit to widen the planting window for CQ. • A permit was granted by the APVMA to vary the planting window for Bollgard II® that allowed commercial scale trials to be undertaken for the early sowing dates from the 2014/15 season (Cotton Australia, 2014). • The second trial, the first at a commercial scale, commenced 3 August 2014. This experiment built on the results from the first season field work investigating the potential of late winter sowing with and without degradable films as a tactic for improving the timing of boll fill (so that this growth phase would occur during more reliable spring time weather conditions). • Four sowing dates were again trialled and, despite recording only two days free of cold shocks, the August sown cotton (with and without film) continued to develop and the early sowings were successful and yielded over 10 bales/ha. • There were no significant differences for yield between any of the sowing dates or cotton sown with or without the biodegradable film. • While biomass data indicated that the film sown treatments had quicker early season development, treatment differences dissipated during flowering as the without-film treatments caught up. • Analysis of crop growth and development data showed separate issues for cotton sown both early and at the normal time for the past two seasons. The early sown crops grew in a very compact but efficient manner in terms of yield partitioning. However, biomass and light interception measurements indicated that these sowings did not fully exploit the radiation available during flowering and boll fill during November and early December due to the crop rows not fully closing. • In contrast, the growth and development of the mid-September sowings were more typical of Central Highlands crops, fully intercepting sunlight (row closure) by cut-out[2] and exhibiting a higher growth rate per day due to warmer conditions prior to flowering. • On this basis, the September sowings should have out-performed the August sowings each season and yet, due to variable weather

[2] Cut-out is the point at which the production of new fruiting sites on the cotton plant ceases.

conditions encountered from December onwards, finished with either the same or less yield than the earlier sowings.

- The second commercial-scale experiment testing late winter sowing was established at Orana, Emerald for the 2015/16 season. Air temperatures were cooler than previous seasons with the first three weeks of August being well below 12^{o}C every night. Despite this, soil temperatures remained at or above the critical threshold of 12^{o}C.
- An additional site was sown at a property near Comet, Queensland with a single bulk planting of cotton sown on 1 August 2015. This crop was benchmarked as the primary early sown crop throughout the 2015/16 season against the main experiment where multiple planting dates (with and without biodegradable film) were tested.
- Alternative management practices were implemented during the 2015/16 trials that would encourage greater early season vegetative expansion of cotton on 1m row spacings through changes to water, nitrogen and insect management.
- The 2015/16 early sowings achieved a much larger canopy that fully intercepted sunlight by cut-out in contrast with earlier experiments.
- The increased crop biomass and light interception during spring and early summer conditions resulted in a high number of large bolls culminating in yields just over 14 bales/ha for both early sowings at the end of the season.
- The mid-September sowing yielded significantly less (9.2b/ha) when picked on 23 February after a significant rainfall event. Significant losses occurred due to tight locked bolls and boll rots. Lint quality was also poor due to discolouration and reduced fibre strength.
- Bollgard 3® became available for the 2016/17 season. Bollgard 3® has a more flexible planting window, allowing crops in CQ to be planted between 1 August and 31 October (Monsanto Australia Pty Ltd, 2016).
- The project was extended to allow for additional trials in the 2016/17 season using Bollgard 3®.
- Degradable film was not used in the 2016/17 field experiments.
- Three August sowing dates were planted as well as three December dates. This late planting tactic also serves the purpose of minimising the chance of a wet pick but has associated challenges around crop establishment and flowering if conditions in January/February are wet or hot/humid.
- Yields for the August sown 2016/17 season trials were approximately 12 bales/ha and 9.5 bales/ha for the September sown trials.

Boll Rot Treatment

- A field experiment was conducted during the 2014/15 season at Emerald to test potential infection pathways for tight locking pathogens (boll rot).
- The 2014/15 experiment had a cross-section of treatments implemented on groups of flowers. Treatments ranged from full protection from pathogen spore invasion through to the purposeful introduction of pathogen spores to open flowers. The treatments were applied to flowers over a 4-week period with 1,440 flowers in total being treated. Each flower was followed through to harvest and remaining bolls were hand-picked for further examination.
- The bolls were visually assessed and seeds from tight lock affected bolls were examined for pathogen content and fungal species composition.

	• Results suggested a very high level of *Alternaria* spp. within most tight locked bolls regardless of the inoculation regime utilised in the experiment. • Following from the findings of the 2014/15 experiments, field experiments were conducted in the 2015/16 and 2016/17 seasons. The experiments tested the potential for using the fungicide Presaro 420 SC (210 g/L Prothioconazole & 210 g/L Tebuconazole) and Bion® to reduce the incidence of tight locking in cotton. • The 2015/16 and 2016/17 fungicide experiments showed little promise in terms of reduce the incidence of tight locked bolls. *Symphyla Management* • There had been reports of crop establishment issues in Central Queensland cotton attributed to Symphylid organisms. • Collections of Symphyla were made from the Dawson Valley, Darling Downs and Moree cotton regions to establish a laboratory colony so that basic experimentation could be conducted to determine better sampling techniques, thresholds and management techniques. • Attempts to establish a lab colony were unsuccessful, thus the project focus shifted to in-field experimentation. • Several fields with high numbers of Symphyla were identified on the Darling Downs and experiments were carried out on sampling techniques using targeted baits. • A large number of fields (>20) were sampled for Symphyla and the health and vigour of the crops visually assessed to correlate the presence of Symphyla with signs of early season crop damage. • Several fields were found to host significant populations of Symphyla with no apparent impact on crop establishment or vigour. • Findings suggest that Symphyla are not solely responsible for poor crop establishment and that, instead, a complex of soil pests may be responsible. *Extension & Communication* • Multiple field days were conducted with growers at the research sites during each growing season (2013/14 to 2016/17) as part of a regular program that aimed to inform the local industry of results as they occurred. • Research results were presented to the Emerald Cotton Growers' Association (CGA) in May 2014, presentations regarding the research with Symphyla and soil pests generally were made at the Goondiwindi CGA meeting in July 2014, the Australian Cotton Conference 2014 and Toowoomba FUSCOM November 2014. • Articles from the project team were published in publications including Spotlight and the Cotton Grower magazine. • A cotton production workshop focusing on new sowing window options for Bollgard 3® and how this may relate to the Central Highlands climate was held in June 2016. The workshop was well supported with most Central Highlands growers and advisors attending.
Outcomes	• Project findings and the Principal Investigator (PI) contributed to the development of the Bollgard 3® growing regulations as part of the resistance management plan. • Contributions were made to the advisory committee for chemical and transgenic crop registration issues that provides advice to the APVMA via Cotton Australia.

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In particular, the project findings and advice supplied to the APVMA contributed to the decision to extend the Bollgard 3® planting window to include all of August for future CQ plantings.
The project outputs are expected to give confidence to CQ cotton growers to potentially plant their cotton crops as early as August 1 to take advantage of stable conditions during boll fill and avoid variable climatic conditions around harvest.
Growers may implement alternative management strategies to encourage early season vegetative expansion to optimise plant growth for early sown cotton crops.
Boll Rot remains an issue for growers, particularly in wet seasons. However, the project outputs may be used as a foundation for further research and development (R&D) in relation to other potential fungicides for use against the range of pathogens that cause tight locking of bolls.
The project found that Symphyla alone are unlikely to be solely responsible for poor crop establishment in some fields. These findings may be used as a base for future R&D into soil borne pests that are assumed to affect cotton crop establishment.

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<tr><td>Impacts</td><td>

Potentially increased average yields from early planting through cotton crops being exposed to more favourable conditions during boll fill.
Potentially reduced harvest losses from early planting that result from variable weather conditions in February and March by bringing forward harvest to January or early February.
Potential reduction in quality discounts that result from cotton exposed to wet weather before harvest in some years by bringing forward harvest to January and early February.
Potential opportunity to grow a rotation crop after cotton if harvested in January, should wet weather occur in February (e.g. Mungbean).
Potentially reduced variability of yields from early planting if there is wet weather prior to picking. There is potential to grow the crop on and compensate for reduced yield.
Potentially increased input costs from early planting due to changed agronomic management practices (e.g. higher seeding rates, nutrient management etc.).
Improved grower well-being through reduced stress in terms of crop management resulting from an early sown crop growing slower and increasing decision making time (CRDC, 2017).
Improved community well-being through spill-over benefits from increased grower productivity and/or profitability.

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4. Project Investment

Nominal Investment

Table 2shows the annual investment (cash and in-kind) for the project funded by DAF, CRDC and other investors.

Table 2: Annual Investment in Project DAQ1401[(a)] (nominal $)

Year Ended 30 June	DAF ($)	CRDC ($)	Others ($)	Total
2014	122,083	128,267[(d)]	55,500	305,850
2015	126,818	132,361	55,500	314,679
2016	88,127[(b)]	135,749	55,500	279,376
2017	67,029[(c]	36,262	0	103,261
Total	404,057	432,609	166,500	1,003,166

Source: Project documentation (including original contract and subsequent variations) and input from PI Paul Grundy.

(a) Paul Grundy also managed a second project, DAQ1502, at Emerald. This project included partial funding for a technical officer who spent time on the DAQ1401 project. Investment cost figures for both DAF and CRDC in each year include the budgeted costs for the DAQ1401 contribution by the technical officer (cash and in-kind).

(b) DAF committed to providing an additional $20,000 to DAQ1401 for 2015/16 and CRDC decreased funding by $20,000 in 2015/16 (Schedule 1, Project Variation Executed Agreement, 18th July 2016). The adjustment to the project was then returned by CRDC under a new capital purchase project.

(c) Projected was extended for 12 months with no additional funding. 2016/17 investment was carry-over of uncommitted funds (Item I, DAQ1401 CRDC Financial Statement for the year ending 30 June, 2016).

(d) Includes $11,000 for Major Capital Item “Biodegradable Film Layer” given project code DAQ1401C.

Program Management Costs

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

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

For CRDC investment, the cost of managing the CRDC funding was added to the CRDC contribution via a management cost multiplier (1.1325); this was estimated based on the average reported share of ‘employee benefits’ & ‘supplier’ expenses in total CRDC expenditure for 2014/15 and 2015/16 (CRDC, 2016).

Real Investment and Extension Costs

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

5. Impacts

The principal potential impacts from the positive results exhibited by the project for early planting of cotton crops include:

- Increased average yields as a result of cotton crops in the Central Highlands being exposed to more favourable conditions during boll fill.
- Avoided yield losses in years with severe weather events (e.g. flooding) occurring in February and March by bringing forward harvest to January or early February in the Central Highlands.
- Reduced losses from quality discounts that result from cotton exposed to wet weather before harvest in some years by bringing forward harvest to January and early February in the Central Highlands.

Table Table 3 provides a summary of the types of impacts categorised into economic, environmental and social impacts.

Table 3: Triple Bottom Line Categories of Potential Impacts from DAQ1401

Economic	• Increased average yields through crops exposed to more favourable growing conditions and less variable yields. • Reduced harvest losses from severe weather events (e.g. floods). • Increased profitability for growers from reduced cotton quality discounts and opportunities to grow additional rotation crops. • Some increased input costs due to changed agronomic management practices.
Environmental	• Increases in grower input use (e.g. nutrients, fungicides, water) to manage earlier planting and crops in the ground for longer periods resulting in potentially increased downstream impacts.
Social	• Improved grower well-being through reduced stress in terms of crop management and less variable incomes. • Spill-over benefits in terms of regional community well-being from increased grower productivity and/or profitability.

Public versus Private Impacts

Most impacts identified in this evaluation are industry related and therefore the benefits are considered private benefits. Some minor public benefits have been delivered, including a social benefit in the form of community spill-overs.

Distribution of Private Impacts

The primary beneficiaries of the findings for tactics leading to early flowering of cotton crops in the Central Highlands will be the Central Highland cotton growers.
It can be assumed that the distribution of the benefits from the project findings will be distributed between participants along the commercial supply chains, including final consumers.

Impacts on other Australian industries

It is assumed that project impacts will be confined to the Australian, Central Highlands cotton industry. Other cotton industries are not likely to benefit (e.g. New South Wales).

Impacts Overseas

No impacts to overseas cotton industries are expected.

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 4. The research into tactics to enable early flowering and harvest of cotton crops in the Queensland Central Highlands contributes primarily to Rural RD&E Priorities 3 and 4 and to Science and Research Priority 1.

Table 4: 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 5.

Project DAQ1401 addressed Queensland Science and Research Priorities 1 and 6. In terms of the guides to investment, the project is likely to have a real future impact through improved confidence in cotton planting practices. The project was supported and funded by others external to the Queensland Government and had a distinctive angle as the Queensland cotton industry will be the primary recipient of the impacts.

Table 5: Queensland Government Research Priorities

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

Source: Office of the Chief Scientist Queensland (2015)

6. Valuation of Impacts

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved. Sensitivity analyses were undertaken on the discount rate as well as for the maximum level of adoption and the estimated potential average yield gain.

The R&D undertaken in project DAQ1401 was focussed on cotton sown in the Central Highlands of Queensland. However, the research findings also may be applicable to the Dawson-Callide region in CQ but to a lesser extent. Climate analysis of the Dawson-Callide region shows that monsoon influences are less pronounced than for the Central Highlands and therefore the odds of rain or heat waves during boll filling when planted at the traditional time is lower. Also, early August is too cool for sowing in the Dawson-Callide region, so growers are better off sowing late August. It is expected that a number of growers in the Dawson-Callide region will adopt sowing cotton in late August resulting in increased average yields for the region. However, this will take time to validate (Paul Grundy, pers. comm., 2017). Consequently, any potential benefits for the Dawson-Callide cotton region have been excluded from the current analysis and thus the benefits valued are likely an underestimate of the total value of the potential impacts for the investment in project DAQ1401.

Three impacts for the Central Highlands cotton region were valued. The first was an average yield gain for cotton crops planted early in the Central Highlands (through improved conditions at boll fill, reduced incidence of tick locking and boll rot and compensatory yield in wetter than average seasons). The second was avoided yield losses in years when severe weather events occur in the Central Highlands cotton region prior to harvest (e.g. flooding in February or March). The third impact valued was reduced incidence of quality discounts due to earlier harvesting avoiding wet picking causing discolouration and boll rot.

Impacts not Valued

Not all impacts identified in Table 3 could be valued in the assessment.
The economic impacts identified but not valued included:

- Potential opportunity to grow a rotation crop after cotton if harvested in January, should wet weather occur in February (e.g. mungbean).
- Potentially increased input costs due to changed management practices (nutrient management etc.).

The above economic impacts were not valued due to limited availability of baseline data and difficulty in making credible assumptions in terms of outcomes and potential impacts.

The environmental impact identified but not valued was the potential for changes in grower input use (e.g. nutrients, fungicides, water) to manage earlier planting and crops in the ground for longer periods resulting in increased/decreased downstream impacts. This environmental impact was not valued due to lack of both baseline and marginal impact data.

The social impacts identified but not valued included:

- Improved grower well-being through reduced stress in terms of crop management resulting from an early sown crop growing slower and increasing management time.
- Improved community well-being through spill-over benefits from increased grower productivity and/or profitability.

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

Valuation of Benefit 1: Increased average cotton yields for the Central Highlands

Cotton crops planted in August over the project's four seasons (2013/14 to 2016/17) all established well and were harvested from mid-January to February. The project found that the August sown trials in each season finished with either the same or more yield than the traditional September sowings due to variable weather conditions encountered from December onwards.

To demonstrate this, during the 2013/14 season, a heatwave followed by cloudy weather caused extensive shedding in the September sowings resulting in reduced yield compared with the August sowings. For the 2014/15 trial sowings, the September plantings were on track to significantly out-yield the August sowings. However, variable radiation during late December and early January were sufficient to cause shedding and a reduction in boll size resulting in no significant difference between sowing date yields. The August sowings which were mostly mature by the time the variable radiation occurred were largely unaffected (Grundy, 2015).

Yields for the August sown trial cotton crops during DAQ1401 averaged approximately 11 bales/hectare over the four seasons. Average irrigated cotton yields for the Central Highlands are estimated at 8.0 bales/hectare over the past 10 years (based on data obtained from 'The Australian Cottongrower', 2010, 2011, 2012, 2013, 2014, 2015 & 2016). This indicates an estimated potential average yield improvement of 37.5%.

This improvement includes the effects of earlier flowering and boll fill, and reduced incidence of boll rot through avoidance of potential weather events commonly seen from February, such as extreme heat and humidity, heavy or prolonged periods of rain causing water logging, and reduced radiation from cloud cover. Boll rot alone can cause yields to be reduced by 10% or more in an affected season (CRDC, 2017).

The PI for the project, Paul Grundy, was quoted in a January 2016 article in Rural Weekly magazine as saying:

"You're not always going to get the highest yield, but certainly you're going to lower your risk of crop exposure during wetter-than-average seasons."

A conservative estimated average yield gain of 20% was used for the valuation with a 50% probability of impact. Also, given the positive research findings, it was assumed that 50% of growers in the Central Highlands region would adopt the practice of sowing pre-September and that this adoption will occur over three years.

Specific assumptions for the valuation of benefit 1 are provided in Table 6.

Valuation of Benefit 2: Reduced yield losses in years with severe weather events

Central Queensland is periodically affected by severe weather events such as cyclones and flooding. These events are most common during the summer period from December through to March. For example, floods that occurred during the 2010/11 season destroyed approximately 5,000 hectares of cotton west of Emerald in the Central Highlands growing region (MacDonald & Healy, 2010).

Also, more recently, cotton crops in Central Queensland were impacted by cyclone Debbie which crossed the Queensland coast near Bowen in March, 2017 and caused widespread flooding and wind damage.

Early sown crops may be harvested as early as mid-January. When severe weather events occur later in summer, it is possible that growers could avoid substantial crop losses that may result from these weather events.

It was estimated that a severe weather event (e.g. major flood) occurring late in summer or in early autumn for Central Queensland would take place approximately one year in ten (10% of the time) and that losses for traditional plantings would be 50% in those years (based on reported crop losses in years with severe weather events: ABC Rural, 2011). It was assumed, as for benefit one, that 50% of growers would adopt earlier planting and that this adoption would occur over three years. Adopters of early planting would therefore harvest by mid-February and would avoid any losses that would have resulted from these extreme weather events.

Specific assumptions for the valuation of benefit 1 are provided in Table 6.

Valuation of Benefit 3: Reduced incidence of quality discounts

In 2011/12, quality discounts on cotton for the Central Highlands region were averaging $40 per bale (CRDC, 2015) and data revealed, on average, a strong correlation between poor yields and quality and variable weather conditions in January and February.
If cotton crops are trying to set fruit and fill bolls in January, climate records indicate that they are more likely to have yield and quality potential affected by weather events such as extreme heat and humidity, heavy or prolonged periods of rain causing water logging, and reduced radiation from cloud cover.

By bringing forward the crop harvest there is the potential to avoid variable weather conditions at key stages of plant growth as well as wet picking, which in turn reduces the risk of quality downgrades (e.g. from discolouration as a result of a wet pick) in wetter-than-average years or hotter/more humid years.

It was estimated that 50% of growers in the Central Highlands would adopt the practice of sowing early and this adoption would occur over a period of three years. Wetter-than-average or hotter/more humid years were assumed to occur approximately 40% of the time (two years in five). Adopters would, therefore, avoid quality downgrade losses of $40 per bale in 40% of seasons.

Specific assumptions for the valuation of benefit 3 are provided in Table 6.

Counterfactual

It was assumed that, without the investment in DAQ1401, adjusting the planting window for Bollgard 3® to include all of August would not have been considered (Paul Grundy, pers. comm., 2017). It also was assumed that, if project DAQ1401 had not been funded, RD&E associated with the physiology and agronomic practices related to the Bollgard 3® variety would have been undertaken in CQ but not until a couple of years after its commercial release in 2016/17. It was further assumed that this RD&E would have had similar total investment costs to DAQ1401 and would be carried out over four years. This future RD&E would have been used as part of a four to six-year data collection process required to enable changes to the resistance management plan for Bollgard 3®, including adjusting the planting window. Thus, the required RD&E would not have commenced until 2018/19, the data collection and development process would have taken six years (to 2023/24) and therefore adoption of early sowing practices in the Central Highlands would not have commenced until 2024/25, eight years later than with the investment in DAQ1401.

Attribution

The research findings and their usage have occurred in close cooperation with industry. No other attribution factors have been included in the valuation. All benefits are attributed to the investment in DAQ1401.

Additional Costs

Planting early requires a higher number of seeds to be sown per hectare and mandates the need for seed dressings, that many growers typically use for September sowing but some avoid. Using standard seed for September sowings, growers would use basic treated seed at a cost of approximately $65-87/ha. For August sowing utilising a higher planting rate and fully treated seed the costs would be $132-149/ha. Over the four years of commercial scale trials as part of project DAQ1401, the increased seeding/treatment cost has been the only consistently increased production cost. Each year however, this was partly offset by a saving in irrigation usage which varied between 1-1.6ML/ha. This was due to the August sown crops being compact and setting bolls during a cooler time of year and therefore transpiring less water during the life of the crop compared to September sowing which matures the bolls later when conditions are hotter. The value of the saving in water would be considerable but might vary between growers depending on whether they flood harvest or are channel irrigators (Paul Grundy, pers. comm., 2017).

Insect management was more variable for the August sown crops as it depended on the season. However, the early sown crops tended to utilise one additional insecticide application per season at a cost of $6-12/ha. On the other hand, none of the August sown crops ever required Mepiquat Chloride applications which have been standard in September sowings at a cost of $6-12/ha thus offsetting the additional insecticide application in most years (Paul Grundy, pers. comm., 2017).

It was assumed, based on the information provided, that additional costs of approximately $140/ha would be incurred by growers adopting August sowing for cotton crops in the

Central Highlands. It was further assumed the probability of incurring this additional cost was 50% given the potential for offsetting water savings depending on the season and prevailing crop management practices.

Extension

As extension has been a component of the project throughout the trials, it is assumed that adoption will not require additional extension resources to those already undertaken.

Summary of Assumptions

A summary of the key assumptions made for the valuation of impacts is shown in Table 6.

Table 6: Summary of Assumptions

Variable	Assumption	Source
Benefit 1: Increased average yields		
Average area of irrigated cotton – Central Highlands (10-year average)	14,800 ha	Based on date obtained from The Australian Cottongrower, 2010, 2011, 2012, 2013, 2014, 2015 & 2016
Average yield for irrigated cotton – Central Highlands (10-year average)	8.0 bales/ha	
Average price of cotton lint (5-year average)	$480/bale	Based on data obtained from the Australian Grown Cotton Sustainability Report, 2014
First year of impact	2018	Agtrans Research based on project DAQ1401 being completed 30 June 2017
Maximum adoption	50% of Central Highlands irrigated crop area	Agtrans Research(a)
Time to maximum adoption	3 years	
Average yield improvement	20%	Agtrans Research (based on yield data obtained during the commercial scale trials for DAQ1401)
Risk Factors		
Probability of output	100%	Agtrans Research
Probability of usage	100%	
Probability of impact	50%	Agtrans Research (based on published interviews with trial participants and researchers)
Benefit 2: Reduced crop losses in years with severe weather events		
Average area of irrigated cotton – Central Highlands (10-year average)	14,800 ha	Based on date obtained from The Australian Cottongrower, 2010, 2011, 2012, 2013, 2014, 2015 & 2016
Average yield for irrigated cotton – Central Highlands (10-year average)	8.0 bales/ha	
Average price of cotton lint (5-year average)	$480/bale	Based on data obtained from the Australian Grown Cotton Sustainability Report, 2014

First year of impact	2018	Agtrans Research based on project DAQ1401 being completed 30 June 2017
Maximum adoption	50% of Central Highlands irrigated crop area	Agtrans Research[(a)]
Time to maximum adoption	3 years	
Frequency of severe weather events occurring from mid-February	10% (1 year in 10)	
Production losses for crops sown at traditional times in years with severe weather events	50%	Agtrans Research based on reports of crop losses due to flooding (e.g. ABC Rural, 2011)
Production losses (reduced) for growers who adopt early sowing in years with severe weather events	Nil	Agtrans Research[(a)]
Risk Factors		
Probability of output	100%	Agtrans Research
Probability of usage	100%	
Probability of impact	50%	
Benefit 3: Reduced incidence of quality discounts		
Average area of irrigated cotton – Central Highlands (10-year average)	14,800 ha	Based on date obtained from The Australian Cottongrower, 2010, 2011, 2012, 2013, 2014, 2015 & 2016
Average yield for irrigated cotton – Central Highlands (10-year average)	8.0 bales/ha	
Average price of cotton lint (5-year average)	$480/bale	Based on data obtained from the Australian Grown Cotton Sustainability Report, 2014
First year of impact	2018	Agtrans Research based on project DAQ1401 being completed 30 June 2017
Maximum adoption	50% of Central Highlands irrigated crop area	Agtrans Research[(a)]
Time to maximum adoption	3 years	
Frequency of variable weather conditions (e.g. wetter-than-average or hotter/more humid) years	40% (2 year in 5)	
Average quality discounts on cotton lint for the Central Highlands in wet years for crops planted at traditional times	$40/bale	CRDC, 2015
Quality discount for cotton lint for the Central Highlands in wetter/more humid years for crops planted early	Nil	Agtrans Research[(a)]
Risk Factors		
Probability of outputs	100%	Agtrans Research

Probability of usage	100%	
Probability of impact	50%	
COUNTERFACTUAL: RD&E into agronomic practices for Bollgard 3® (including early sowing) would have happened anyway.		
Cost of RD&E into agronomic practices for Bollgard 3® in Central Queensland	$1.08 million over four years	Based on total investment in DAQ1401 from 2014 to 2017 in real dollar terms
First year of investment/RD&E	2018/19	Agtrans Research (based on first commercial release of Bollgard 3® for the 2016/17 season)
First year of impact	2024/25	Based on six years for data collection and development of an updated resistance management plan for Bollgard 3® from 2018/19
All other variables held constant.	Benefits 1, 2, and 3 delayed eight years.	Agtrans Research
Additional Costs: Adoption of August sowing incurs some addition costs compared to planting during the traditional sowing window for the Central Highlands.		
Average, expected additional crop management costs from increased seeding rates and additional seed treatments.	$140 per hectare	Paul Grundy
Probability of incurring additional cost	50%	Agtrans Research[(a)] based on the potential for offsetting water savings depending on the season and prevailing management practices

(a) Agtrans estimates based on consultation with project PI Paul Grundy

7. Results

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

Investment Criteria

Tables 7, 8 and 9 show the investment criteria estimated for different periods of benefits for the total investment, the DAF and CRDC investment respectively. The present value of benefits (PVB) attributable to DAF investment only, shown in Table 8, has been estimated by multiplying the total PVB by the DAF proportion of real investment (38.0%).

Table 7: Investment Criteria for Total Investment in Project DAQ1401

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	12.40	20.24	20.24	20.24	20.24	20.24
Present value of costs ($m)	1.18	1.18	1.18	1.18	1.18	1.18	1.18
Net present value ($m)	-1.18	11.22	19.06	19.06	19.06	19.06	19.06
Benefit-cost ratio	0.00	10.50	17.13	17.13	17.13	17.13	17.13
Internal rate of return (IRR) (%)	negative	65.7	69.0	69.0	69.0	69.0	69.0
Modified IRR (%)	negative	13.6	15.4	15.4	15.4	15.4	15.4

Table 8: Investment Criteria for DAF Investment in Project DAQ1401

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits[(a)] ($m)	0.00	4.72	7.70	7.70	7.70	7.70	7.70
Present value of costs ($m)	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Net present value ($m)	-0.45	4.27	7.25	7.25	7.25	7.25	7.25
Benefit-cost ratio	0.00	10.53	17.18	17.18	17.18	17.18	17.18
Internal rate of return (%)	negative	66.3	69.5	69.5	69.5	69.5	69.5
Modified IRR	negative	13.6	15.4	15.4	15.4	15.4	15.4

(a) The PVB attributable to DAF investment has been estimated by multiplying the total PVB by the DAF proportion of real investment (38.0%).

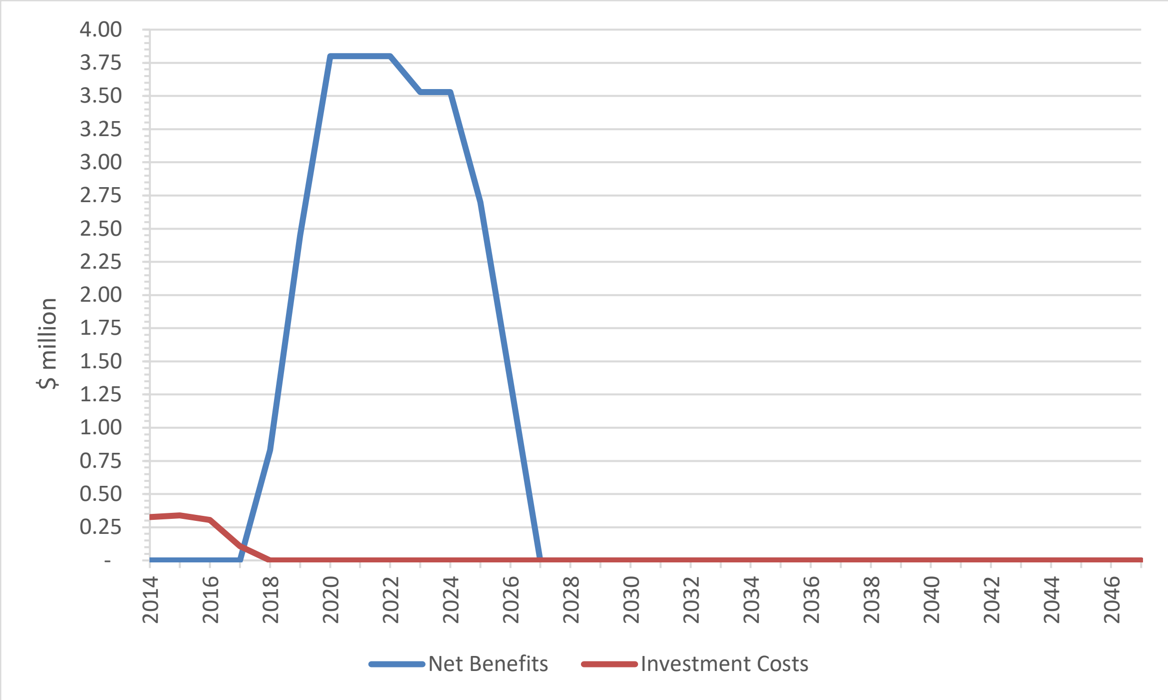
Table 9: Investment Criteria for CRDC Investment in Project DAQ1401

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits[(a)] ($m)	0.00	5.73	9.36	9.36	9.36	9.36	9.36
Present value of costs ($m)	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Net present value ($m)	-0.55	5.19	8.81	8.81	8.81	8.81	8.81
Benefit-cost ratio	0.00	10.50	17.14	17.14	17.14	17.14	17.14
Internal rate of return (%)	negative	66.0	69.2	69.2	69.2	69.2	69.2
Modified IRR (%)	negative	13.6	15.4	15.4	15.4	15.4	15.4

(a) The PVB attributable to CRDC investment has been estimated by multiplying the total PVB by the CRDC proportion of real investment (46.2%).

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 2.

Figure 2: Annual Cash Flow of Undiscounted Total Net Benefits and Total Investment Costs



Sources of Benefits

There are three sources of benefits valued in the analysis. Table 10 shows the relative contributions to the PVB from each source. As the additional costs required to achieve the benefits (i.e. expected additional costs for higher seeding rates and additional seed treatments) could not be apportioned between the three benefits, the contributions to the PVB are based on the proportion of each benefit from the total gross benefits (undiscounted). The benefit increased average yields is the largest contributor to total benefits by a significant margin.

Table 10: Contribution to Total Benefits from Each Source

Source of Benefits	**Contribution to PVB ($m)**	**Share of benefits (%)**
Increase average cotton yields for the Central Highlands (Benefit 1)	14.29	70.6
Reduced crop losses from severe weather events (Benefit 2)	3.57	17.6
Reduced incidence of quality discounts due to variable weather conditions (Benefit 3)	2.38	11.8
Total	**20.24**	**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 11 presents the results. The results showed a low sensitivity to the discount rate. This low sensitivity is because the benefits occur in the first 10 years after the investment and therefore are not subjected to heavy discounting.

Table 11: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	25.79	20.24	16.23
Present value of costs ($m)	1.08	1.18	1.29
Net present value ($m)	24.71	19.06	14.94
Benefit-cost ratio	23.88	17.13	12.58

A sensitivity analysis also was carried out on the maximum level of adoption. Table 12 presents the results. The results showed a high sensitivity to the maximum level of adoption level. However, even at only 10% adoption of early sowing, returns to the investment are positive.

Table 12: Sensitivity to Maximum Level of Adoption
(Total investment, 30 years)

Investment Criteria	Maximum level of adoption		
	10%	**50% (base)**	**70%**
Present value of benefits ($m)	4.78	20.24	27.97
Present value of costs ($m)	1.18	1.18	1.18
Net present value ($m)	3.60	19.06	26.79
Benefit-cost ratio	4.04	17.13	23.67

Finally, a sensitivity analysis was carried out on the estimated average yield gain for benefit 1 as benefit 1 contributed approximately 70% of the total present value of benefits. Table 13 presents the results. The results showed a high sensitivity to the average yield gain assumed. This is primarily because benefit 1 occurs in all years and is therefore contributes the highest proportion of benefits. However, even at an estimated average yield gain of only 2%, returns to the investment are positive.

Table13: Sensitivity to Estimated Average Yield Gain
(Total investment, 30 years)

Investment Criteria	Average Yield Gain		
	2%	**20% (base)**	**40%**
Present value of benefits ($m)	6.06	20.24	36.00
Present value of costs ($m)	1.18	1.18	1.18
Net present value ($m)	4.88	19.06	34.82
Benefit-cost ratio	5.13	17.13	30.47

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 14) 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 14: Confidence in Analysis of Project

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

Coverage of benefits was assessed as medium-high as most benefits were economic in nature relating to reduced losses or yield improvements. While some impacts were not valued, their contributions were considered minor compared with those valued. Nevertheless, the investment criteria as provided by the valued benefits are likely to be underestimated to some degree.

Confidence in assumptions was rated as medium-high. The principal assumption of the average yield gain by the Central Highlands industry due to avoided variable climatic conditions was supported by data provided by the project. The assumptions on adoption were supported by information from project personnel but were less certain given the project's recent completion at the time of conducting the evaluation.

8. Conclusions

The investment in project DAQ1401 has given growers confidence that planting cotton crops early in the Central Highlands is a good tactic that enables early flowering of cotton crops in spring, bringing forward the time at which crops mature thus avoiding boll-fill during periods of variable conditions. This will provide benefits to the Queensland Central Highland cotton industry.

The R&D undertaken in project DAQ1401 was focussed on cotton sown in the Central Highlands in Queensland. However, the research findings also may be applicable to the Dawson-Callide region in CQ but to a lesser extent. The potential benefits for the Dawson-Callide cotton region have been excluded from the current analysis and therefore the benefits valued are likely an underestimate of the total value of the potential impacts for the investment in project DAQ1401.

Given the counterfactual scenario assumed, total funding from all sources for the project was approximately $1.18 million (present value terms). The value of total benefits was estimated at $20.24 million (present value terms). This result generated an estimated net present value (NPV) of $19.06 million, a benefit-cost ratio (BCR) of approximately 17.1 to 1, an internal rate of return of 69.0% and a modified internal rate of return of 15.4%.
Sensitivity analyses carried out on key variables used in the valuation of impacts indicate that, even using extremely conservative assumptions for the maximum level of adoption or the average yield improvement, results remain positive.

The analysis provided a good example of a moderate investment in a geographically specific section of the Australian cotton industry that is likely to provide significant returns to the Queensland cotton industry.

References

ABC Rural. (2011, January 20). *Half of Queensland cotton crop destroyed*. Retrieved from ABC Rural: http://www.abc.net.au/site-archive/rural/news/content/201101/s3117329.htm

Australian Bureau of Statistics. (2016, November 4). *5204.0 - Australian System of National Accounts, 2015-16.* Retrieved from Australian Bureau of Statistics: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5204.02015-16?OpenDocument

Commonwealth of Australia. (2015). *Agricultural Competitiveness White Paper.* Canberra: Commonwealth of Australia. Retrieved from http://agwhitepaper.agriculture.gov.au/SiteCollectionDocuments/ag-competitiveness-white-paper.pdf

Cotton Australia. (2014, September 2). *Planting Window Permit Released for 2014/15 Season*. Retrieved from News/Media - Cotton Matters: http://cottonaustralia.com.au/news/article/planting-window-permit-released-for-2014-15-season

Cotton Australia. (2016a). *Economics of Cotton in Australia*. Retrieved March 2017, from Cotton Australia: http://cottonaustralia.com.au/cotton-library/fact-sheets/cotton-fact-file-the-economics-of-cotton-in-australia

Cotton Australia. (2016b). *Cotton Annual 2016: Australian Cotton Industry Statistics.* Mascot, NSW: Cotton Australia.

Cotton Australia. (2017). *Statistics*. Retrieved March 2017, from Cotton Australia: http://cottonaustralia.com.au/cotton-library/statistics

Cotton Research and Development Corporation. (2015, Autumn). Working with the weather in Central Queensland. *Spotlight*.

Cotton Research and Development Corporation. (2016). *CRDC Annual Report 2015-2016.* Narrabri: Cotton Research and Development Corporation.

Cotton Research and Development Corporation. (2017, Autumn). CRDC's early planting research changing the game. *Spotlight*.

Council of Rural Research and Development Corporations. (2014). *Impact Assessment Guidelines.* Canberra: CRRDC. Retrieved from http://www.ruralrdc.com.au/wp-content/uploads/2016/04/CRRDC-Impact-Assessment-Guidelines-V.1-070514.pdf

Grundy, P. (2015). *August Sowing for more reliable boll filling.* Narrabri: Cotton Research and Development Corporation.

MacDonald, A., & Healy, S. (2010, December 8). *Queensland faces $151m flood disaster clean-up costs*. Retrieved from The Courier Mail: http://www.couriermail.com.au/news/queensland/queensland-faces-151m-flood-disaster-clean-up-costs/news-story/4169b4644c294f0146f944817816fc27

Monsanto Australia Limited. (2012). *Resistance Management Plan for Bollgard II(R) Cotton.* Monsanto Australia Limited.

Monsanto Australia Pty Ltd. (2016). *Bollgard 3 Resistance Management Plan*. Retrieved from Bollgard 3: http://bollgard3.com.au/resistance-management-plan/#post-more-relaxed-planting-windows

Office of the Chief Scientist. (2015). *Strategic Science and Research Priorities.* Canberra: Commonwealth of Australia. Retrieved from http://www.chiefscientist.gov.au/wp-content/uploads/STRATEGIC-SCIENCE-AND-RESEARCH-PRIORITIES_181214web.pdf

Roth, G. (2014). *Australian Grown Cotton Sustainability Report 2014.* Narrabri: Cotton Research and Development Australia.

The Australian Cottongrower. (2010, 2011, 2012, 2013, 2014, 2015 & 2016). *Cotton Yearbook.* Toowoomba: The Australian Cottongrower - Greenmount Press.

Appendix 4: An Impact Assessment of DAF Investment in C4Milk: Developing and managing a profitable high milk from forage system in the sub-tropics

Acknowledgments

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Abbreviations

ABARES	Australian Bureau of Agriculture and Resource Economics and Sciences
BCR	Benefit-Cost Ratio
c/kg	Cents per Kilogram
c/l	Cents per Litre
CBA	Cost-Benefit Analysis
CRC	Cooperative Research Centre
CRRDC	Council of Rural Research and Development Corporations
DA	Dairy Australia
DAF	Department of Agriculture and Fisheries
DAFF	Department of Agriculture, Fisheries, and Forestry
DIA	Dairy in Action
DM	Dry Matter
DOFTL	DairyOne Forage Testing Laboratory
F:C	Forage to Concentrate
HMFT	High Milk from Forage Trial
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
MOFC	Margin Over Feed Costs
NDF	Neutral Detergent Fibre
NSW	New South Wales
iNDF	Indigestible Neutral Detergent Fibre
NPV	Net Present Value
PMR	Partial Mixed Ration
PVB	Present Value of Benefits
PVC	Present Value of Costs
QDAS	Queensland Dairy Accounting Scheme
R&D	Research and Development
RD&E	Research, Development and Extension
RDC	Research and Development Corporation
TFP	Total Factor Productivity
TMR	Total Mixed Ration
UQ	University of Queensland

Executive Summary

The Report

This report presents the results of an impact assessment of a Queensland Department of Agriculture and Fisheries (DAF) investment in a project (C4 Milk) to increase operating margins in milk production enterprises from forage feed sources. This project was funded by DAF and Dairy Australia (DA).

Methods

The project was analysed qualitatively within a logical framework that considered project rationale, objectives, activities/outputs, outcomes, and impacts. The principal impact was then valued. Benefits were calculated for a range of time frames up to 30 years from the year of last investment. Past and future cash flows in 2016/17 $ terms were discounted to the year 2016/17 using a discount rate of 5% to estimate investment criteria.

Impacts

Most of the impacts identified were economic in nature, however social and environmental impacts also were identified. The coverage and certainty of the assumptions associated with the impacts valued are rated as High-Medium. The impacts valued are the increased use of home grown feed and the decreased costs of feed due to improved management of home grown feed.

The project had not been completed at the time of undertaking this evaluation, so not all data from the project were available for consideration. The impacts identified but not valued include the impacts of new types of forage, increased sustainability of the sub-tropical dairy industry, increased knowledge and capacity, and use of alternative feed applicable to southern New South Wales and Victoria. The decision not to value certain impacts was due to restricted data available for on-farm valuation, the required complexity of future scenarios and lack of time and resources for the estimation of adoption and impacts in southern dairy systems.

It is expected the sub-tropical dairy industry will be the primary beneficiary of the investment with other benefits shared along the supply chain including consumers. A second set of benefits will accrue to temperate dairy industries as there has been knowledge transfer between the C4 team and temperate dairying regions.

Investment Criteria

Total funding from all sources for the project was $5.8 million (present value terms). The value of benefits was estimated at $29.9 million (present value terms). This gave an estimated net present value of $24.1 million, and a benefit-cost ratio of 5.2 to 1. The investment criteria estimated support the conclusion that this has been a most worthwhile investment, particularly since assumptions were conservative for the impacts that were valued; furthermore, not all impacts identified were valued so the benefits are likely to be an underestimate.

1. 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 included both qualitative and quantitative descriptions that are in accord with the evaluation guidelines of the Council of Research and Development Corporations (CRRDC, 2014).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, 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 to a shortage of necessary evidence/data and a high degree of uncertainty surrounding the potential impact. The impacts valued therefore are deemed to represent the principal benefits delivered by the project.

2. Background and Rationale

Background

The sub-tropical dairy industry ranges from the Atherton Tablelands in Far North Queensland to Kempsey in the Central Coast of NSW (DA, 2015). The sub-tropical region is further split into the sub-regions of North Queensland, Central Queensland, South-East Coastal, Darling Downs, Far North Coast New South Wales (NSW), and Mid-North Coast NSW. In the sub-tropical region, the ability to grow different types of forage varies depending on the location and climate. There are currently 559 dairy farms in the sub-tropical region (QDAS, 2016; David Barber, pers. comm., 2017) with the farms contributing 4.2% to Australia’s overall dairy production with an annual production value of $404 m (DAF, 2016, page v). In Queensland, the number of dairy farms decreased by 19% over the period from 2012-2013 to 2015-2016. The usage of milk produced in Queensland has also changed over time, moving from both fresh milk and manufactured milk products to currently all local fresh milk (DAFF, 2013a, p.8). Thus, there is a need for a constant milk supply throughout the year.

Farms in the sub-tropical dairy industry have experienced rising productivity. This has been attributed not to pushing the productivity frontier, but to catching up with southern dairy counterparts’ production levels through the application of different, better practices more suited to the sub-tropical region (ABARES, 2014, p.8). Growth has been realised through lower use of inputs, while outputs have also been decreasing (compared to other regions where inputs and outputs have both increased). The sub-tropical industry still lags behind other dairy regions in terms of total factor productivity (TFP) (ABARES, 2014, p.9). The ABARES report (2014, p.10) also recognises that due to a need to produce year-round fresh milk, purchased feed is necessary as home-grown feed is not always readily available during the autumn feed gap.

Over recent years, there has been an increase in volatility of grain prices while fresh milk prices have remained stable. For the sub-tropical dairy industry, this has led to lower margins for farmers. Feed related costs are the largest costs for dairy farms in Queensland, representing about 49% of cash costs in 2015-2016 (DAF, 2016, p.3). Compared to the national average of 31% (ABARES, 2016, p.5) this suggests that there is scope for decreasing feed costs. Fluctuating grain prices along with an increase in feed concentrates have led to a decline in the Margin Over Feed Costs[3] (MOFC).

The forage to concentrate ratio (F:C) is the ratio of forage to concentrate per litre production of milk. In the most recent Queensland Dairy Accounting Scheme (QDAS) report, some regions such as North Queensland were reported as having an F:C ratio of 57.9:42.1, while other regions such as the Darling Downs where more concentrate was used had a F:C ratio of 49.2:50.8 in 2015-2016 (DAF, 2016a, p.23).

Rationale

The project undertaken aimed to increase operating profit margins of sub-tropical dairy farms through developing new forms of sub-tropical forage and feeding regimes to lower overall feed costs.

The sub-tropical environment is suited to many types of pasture; there is potential to lower operating costs by using more home-grown feed in the cow's diet. Also, there are issues with tropical forages over their temperate counterparts. The types of forage available in the sub-tropical regions have been shown to have a higher than recommended Neutral Detergent Fibre (NDF) content leading to a less efficient conversion of the feed into milk (DAFF, 2013a, p.36).

Current industry milk production in Queensland is trending downwards as stated in a recent parliamentary public hearing (Queensland Parliament, 2017). It can be expected that farm gate prices over time could be reduced as processors consider the viability of shipping milk from the southern dairy regions. This could lead to more sub-tropical farmers exiting the industry if costs are not lowered.

Developing high quality forage may significantly reduce cost pressures for farms. Farms with higher home-grown feed per litre produced have been identified as having a lower overall cost per litre of milk. As such, using such feeding systems has been identified as a cost saving measure potentially reducing costs of inputs. The potential for increasing use of sub-tropical forage to lower production costs and increase profitability is the rationale for the project.

The C4 Milk project was undertaken as there was an opportunity for the further development of C4 forages within sub-tropical feeding systems. C4 plant's growing conditions are ideally suited to the sub-tropical climate that applies to the northern dairy industry. Compared to C3 plants, C4 plants are better able to survive the hotter/humid weather, and utilise increased atmospheric CO_2 in comparison to C3 plants (Edwards et al 2010). While the C4 forages are suited to the sub-tropical summer, there are problems growing C4 plants in the cooler autumn months. C4 forages also have a wide variability of dietary quality (NDF and Indigestible Neutral Detergent Fibre (iNDF) content) due to the need for the plant to protect itself from harsher weather compared to C3 types (Harper and McNeill, 2015).

It is recommended that Dry Matter (DM) intake per day should be 3-4% of the cow's body weight for maximum milk production (DAFF, 2013a). To ensure a healthy rumen function, NDF should be 28%-34% of DM intake. If NDF is too high or too low, DM intake, crucial for milk fat content and other nutrients that are required for milk production, can be lowered (DAFF, 2013b). There was therefore a concern over NDF and iNDF quantities in forage diets. Along with starch, crude protein, and other nutritional requirements that are required for milk production, there is a need for concentrates to be used in diets to ensure peak milk production. As the costs of concentrates are high, there is an incentive to change from

[3] Margin over feed costs: The milk price per litre minus feed costs per litre of milk produced.

concentrates to more forage if nutritional requirements are still met. Promoting already existing forage types and developing improved and new forage types to suit sub-tropical conditions can both help the implementation of this type of improved feeding regime. As a previous Department of Agriculture, Fisheries, and Forestry (DAFF) project "Developing flexible tropical dairy feeding systems to meet market and climate driven demands" (Sub Tropical Dairy, 2010, p.30) identified, there are numerous tropical forages available to be used as feed sources without compromising nutritional quality. These have the potential to lower feed costs while maintaining or improving milk yield, and increasing the MOFC.

Different conditions for the use of pasture exist across the different sub-tropical regions. Certain pasture grown in one region or farm, will not have the same nutritional content if grown in another location. With around 25 different types of sub-tropical forages identified as being suitable to be produced, there are numerous strategies that farmers can adopt. As the sub-tropical industry requires constant levels of milk production year-round, development of year-round forage production was a critical requirement of the project. However, there was still an issue of high concentrate use with the autumn feed gap, when high quality pasture is difficult to produce. If forage can be stored and then utilised later, there was a perceived opportunity to reduce concentrate use.

The rationale for the extension component of the project was to increase adoption of sub-tropical forages into dairy herd diets. While face to face consultation was the preferred option by farmers, this has not always been feasible with the sub-tropical industry being spread over a vast geographical area. This geographical spread of the industry had been identified earlier as a constraint to use of workshops (ABARES, 2014, p.24). The delivery methods of new research findings and technology therefore were identified as critical to their implementation. Utilising numerous communication channels was seen to help aid the extension of research and development findings. Through on-farm demonstrations, discussion groups, and internet based learning, multiple extension methods were identified as being required to provide information to as many farmers as possible.

3. Project Details

Summary

Title: C4Milk: Developing and managing a profitable high milk from forage system in the sub-tropics.
Research Organisation: Department of Agriculture and Fisheries, Queensland
Principal Investigator: David Barber
Period: 1 July 2014 to 30 June 2017

Objectives

The objectives of the project were:

1. Increase on-farm trialling and adoption of forage and nutrition management strategies, technologies and systems through development activities
2. Develop forage and nutrition management strategies that increase the quality of tropical forages and diets to increase milk from forage
3. Engage with sub-tropical dairy farmers and service providers through the use of e-Extension technologies in conjunction with existing extension activities to demonstrate and deliver forage and nutrition management strategies

Logical Framework

Table 1 provides a description of the project in a logical framework developed for the project.

Table 1: Logical Framework

Activities and Outputs	• The project conducted research into kikuyu grasses. The project screened 107 plants from two different collections of kikuyu (Redlands Research Station and Camden, NSW) for kikuyu yellows resistance, digestibility, and cold tolerance to identify strains that could be suited to the sub-tropical dairy industry. • Results from the kikuyu grass assessment of types were inconclusive. There were varying degrees of success for the different desired attributes but desirable traits for some ecotypes did not positively correlate with other desirable traits. A new research plan for further research was recommended to be developed due to the inconclusive results. • Research was undertaken to understand the iNDF and DM content of lucerne and forage sorghum. The aims of the lucerne research were to see at what stage of maturity the plant affected iNDF content and if lignin content could predict the iNDF content. Using the grazing height of lucerne in a high forage development trial, the iNDF content was measured by cutting an ungrazed patch of lucerne at the same height that the cows grazed. Results showed as the plant matures, the iNDF content of the stems increased, while the iNDF content of the leaves stayed roughly constant. This was found to be critical for managing the DM digestibility of lucerne, as higher iNDF decreased DM digestibility. • Experiments with sorghum were aimed at determining optimal practices for growing and managing sorghum including stage of growth for grazing and cutting, variety, planting rate, nitrogen application rate and water application rate to lower iNDF content. Samples were tested at UQ Gatton for DM yield, iNDF, NDF, and crude protein content. A full analysis took place at DairyOne Forage Testing Laboratory (DOFTL), Ithaca, USA. • An additional experiment into alternative tropical feeds assessed their energy and protein characteristics. Two types of feed were tested, class one being feed that was already available to grow on farm. Class two included feed types that had the potential to be used but were not commercially available. The first stage of the analysis checked both feed classes for NDF, protein and starch content by sending samples to DOFTL. The second stage ascertained impacts on DM of both feed classes using In Vitro True Digestibility measured at the University of Queensland (UQ), Gatton. • Another experiment tested white sorghum and corn silage both of which were high in starch to see if there was a cost reduction over purchased grain, while maintaining nutritional quality. The findings showed that white sorghum may be used to replace grain as it has a lower cost per kg of starch for both silage and headlage at 29 and 30 cents per kg(c/kg) compared to 50 c/kg for purchased grain. • Twelve different corn varieties were tested with 4 different planting densities. The results showed that planting at 80,000 seeds per hectare was best practice to obtain the highest DM yield per hectare,

as the starch content did not vary significantly between planting rates.

- From April 2015, brigadier and suga fodder beet were grown to see if they could be used for grazing and silage production respectively in the sub-tropical region. Both fodder beet varieties were shown to have high sugar levels and lower the cost per kg of dry matter and energy.
- An experiment at Pimpimbudgee and Goomeri with irrigated and dryland forage types was undertaken to assess yields, DM content, and other nutritional value from forages for silage use. For both dryland and irrigated crops, there was found to be a trade-off between producing high quality feed and high yielding feed. The conclusion reached was that it was for the individual farmer to decide which would be the best crops to grow depending on their feed needs in terms of quality and quantity.
- A High Milk from Forage Trial (HMFT) investigated different diets to see if the diets could sustain similar milk yields to current diets in industry and have a higher MOFC compared with the average MOFC in the industry**.** Research and development at the UQ Gatton campus aimed to develop a year-round feeding strategy with high forage diets. Partial Mixed Ration (PMR) and Total Mixed Ration (TMR) diet systems were identified to be applicable across the sub-tropical dairy regions. This accounted for both irrigated and dryland dairy farms with different forages selected to match the conditions of those regions.
- Management of pasture was identified as crucial to ensure adequate utilisation of pasture and to ensure cows did not eat lower quality stems. It was found that cows consistently ate the same proportion of leaf on offer for kikuyu, lablab, and lucerne, irrespective of the size of the grazing area. The conclusion was that to increase DM consumed from pasture, grazing area should be increased. After the research into the nutritional quality of kikuyu, lucerne and lablab, further research was recommended into optimal yield and forage use.
- Results from the high milk from forage trials showed MOFC had a range between 36.6 cents per litre (c/l) and 40.7 c/l (assuming milk income at 60 c/l) with the F:C ratio for all 6 diets having a range of 79:21 to 92:08. Diet costs were lower than industry norms. MOFC was higher than the current industry average of 30.2 c/l (31.1 c/l when adjusted for same milk receipts) (QDAS, 2016).
- A continuation of the HMFT is taking place to demonstrate to farmers the further commercial implications.
- At the request of farmers, the lucerne research was extended within the current project. From the findings of the HMFT and the previous lucerne research, cows were tested at various levels of lucerne pasture intake to see the trade-off between increased consumption of pasture allocated and milk yields per DM intake. A response curve from increased pasture consumed, DM intake, and milk yields is being developed to represent this trade off.
- Throughout the C4 Milk project numerous extension activities were held at both UQ Gatton and in the sub-tropical regions. The extension activities related to the application of findings of the research and development to improved dairy farm management. The extension activities included Busting the Myths of Grazing demonstrations, Dairy in Action (DIA) discussion groups, Walking the

	Seasons field days, HMFT open days, and Milking at the Margins workshops. There are still more activities to be completed as part of the project. In all these extension activities, a large majority of farmers rated the extension positively. Most farmers involved within each extension activity said they would implement some of the findings communicated on their farm. • The DIA extension involved discussion groups covering numerous topics in each region throughout the program. The groups covered topics such as feed production and the methods to lower feed costs. The result of the DIA groups was that some farmers made productive changes to their farms through the discussions. • Four open days during the HMFT were conducted while the trial was taking place. • Milking at the Margins Workshops were held between July and August 2016, covering the results from the HMFT trial and how the findings could be implemented. • News articles published in the Northern Dairy Farmer throughout the trial outlined the findings of the research, development, and extension (RD&E) activities. • E-extension activity was utilised with YouTube videos and blogs throughout the project. Views of the videos were reported as ranging between 205 to 786 (YouTube, 2017). The project advisory team noted that gaining feedback from the videos was difficult to measure, but generally positive feedback from farmers was received.
Outcomes	• For a new research project, a research plan was developed to conduct further research into kikuyu grass, but this plan has not been implemented to date. • Sub-tropical dairy farmers are now undertaking new harvesting and grazing regimes for lucerne and forage sorghum due to increased knowledge of NDF, iNDF, and DM content. • Farmers have reported improved productivity and lower feed costs as a result of the DIA discussions and other extension activities. Sources of improvement included improving irrigation for pastures, leasing more land for feed, and changing planting regimes. • An outcome from the Pimpimbudgee and Goomeri field days is that some farmers have changed their home-grown forage regime by identifying yield requirements against nutritional needs. • A wider range of forages is being used in the sub-tropical dairy region with increased knowledge of their nutritional content. • Farmers who have implemented more home-grown feed strategies as a result of the C4 project have decreased feed related costs. • Some farms have lowered their use of starch and protein concentrates by using white sorghum and corn, so potentially reducing cost of protein and starch feed. • Extension actives undertaken allowed farms to have more confidence and capacity in implementing findings from the project. • Through e-Extension and media presence, farmers stated that they had gained increased confidence in carrying out further research and development activities. As a result, farmers explored new ways to implement home-grown forage within their own farming systems. • Stronger farmer to farmer and farmer-researcher networks were developed with DAF, UQ Gatton, and farmers being closely involved with extension activities.

	• C4 milk team communicated results from the project to the southern New South Wales and Victorian dairy industry.
Impacts	• Expected higher MOFC for farms across all the sub-tropical regions as more home-grown feed is being used to replace concentrate and grain, due to the HMFT feeding system and other activities. This has led to increased farm profitability and a decreased dependency on grain and purchased feed. • Better management practices of home-grown feed implemented, resulting in increased profitability of farms through improved quality of home grown feed. • More industry certainty due to increased profitability for farmers who implement high forage diets. The increased certainty may lead to some farmers continuing to operate profitably in the industry if farm gate prices for fresh milk decrease. Less farmers may exit the industry due to scenarios of high feed costs and/or lower milk prices. • Farmers have the capacity to keep up to date with the latest forage technology and research due to the networks established through the DIA and other extension activities. • Expected higher profitability of farms throughout the sub-tropical region due to a reduction in feed costs through the implementation of new feed types being identified. • Continued or increased spillovers to regional dairy communities from maintained or increased farm incomes. • Less milk may be transported to Queensland from southern States resulting in potentially decreased greenhouse gas emissions; however, the net carbon impact would depend on the overall comparative energy intensity in all facets of milk production between temperate and sub-tropical systems. • Increased pressure on water resources in dairy regions due to increased water use on farms due to use of irrigation. But less water being used to grow concentrate and grain by suppliers. • Higher level of animal welfare as a result of a reduction in grain use that in turn may lead to reduced incidents of laminitis in cows. • Increased research capacity and scientific knowledge relevant to the sub-tropical dairy industry (forage types and their nutritional characteristics). • Demonstrated potential for improved home-grown feed productivity and increase home-grown feed use in Southern NSW and Victoria.

4. Project Investment

The Investment

Table 2 shows the annual investment for the project funded by DAF, DA, Sub-Tropical Dairy, and Queensland Dairy Organisation.

Table *2*: Investment by DAF and others for Years ending June 2015 to June 2017 (nominal $)

Year ended 30th June	DAF	DA	Sub-Tropical Dairy and Queensland Dairy Organisation	TOTAL
2015	1,350,300	504,000	10,000	1,864,300
2016	1,213,139	448,000	10,000	1,671,139
2017	1,247,069	448,000	10,000	1,705,069
Totals	3,810,508	1,400,000	30,000	5,240,508

Program Management and Extension Costs

The DAF investment in Table 2 already includes an allowance for program management, administration and corporate infrastructure costs. As DA research and development overheads could not be easily isolated from their annual report, a multiplier of 1.12 was applied based on an approximate average multiplier for other RDCs.
No additional costs of extension were included as the project already included a strong extension component.

5. Impacts

The research findings from the C4 milk project have been positively received by sub-tropical dairy farmers. All issues addressed by the project were included in the extension effort. This ensured farmers had a full understanding of the project and how findings were relevant to their farms. While the research and development has provided useful results, farms cannot implement all the findings and achieve the same results found in the project. Despite this, there has been feedback from farmers stating that they are likely to implement at least one of the findings on their farm.

The principal potential impacts from the improvements identified in the C4 project are included in Table 3. The table provides a summary of the types of impacts categorised into economic, environmental and social impacts.

Table 3: Triple Bottom Line Categories of Principal Impacts from the C4 Project

Economic	• Increased MOFC from the use of increased home-grown feed replacing the use of concentrates. This led to higher productivity and profitability on adopting farms from the research and development activities undertaken by the C4 project. • Reduced feed costs on some farms as improved forage management practices have been implemented. • Reduced feed costs for farms that implemented new types of sub-tropical feed such as soybeans or fodder beet. • Increased farm financial sustainability and ability for dairy farms to deal with potential future impacts (e.g. higher purchased grain prices, lower farm gate milk prices). • Potential for increased use and higher productivity of home-grown feed in Southern NSW and Victoria.
Environmental	• Lower total cost of transport of milk from southern states so lowering greenhouse gas emissions from transport; however, the net impact would depend on the overall comparative energy intensity in all facets of milk production between temperate and sub-tropical systems. • Use of more water resources on farm due to increase in production of home-grown irrigated feed. But less water being used to grow concentrates and grain by suppliers.
Social	• Increased regional community well-being through the spillover effects of increased or maintained farm incomes. Less social disruption due to reduced number of farmers leaving the industry. • Increased scientific research capacity and human capital of research personnel through involvement in the project. • Increased farmer capacity to change in the future through improved networks established in the C4 project. • Increased animal welfare through lower incidence of laminitis from reductions in high grain intakes.

Public versus Private Impacts

Most of the impacts identified are private benefits captured by sub-tropical dairy farmers. There are some public benefits with stronger farming and regional communities, and increased research and scientific knowledge, as well as enhanced human capacity for the future of those involved in the project.

Distribution of Private Benefits

The direct beneficiaries of the project will be sub-tropical dairy farmers. There may be an impact on processors in the future, if the sub-tropical industry remains sustainable with less transport costs incurred by processors in shipping milk from other regions. There is also impacts on dairy producers in Southern NSW and Victoria, with increased knowledge of home grown feed production to these regions.

It can be assumed that the benefits will be captured by farmers who implement the findings of the C4 project. The principal direct losers from increased home-grown feed would be the companies that supply purchased feed.

Impacts on other Industries

There is not expected to be a significant impact on industries other than dairying. There may be some spillovers to the beef industry in Queensland and Northern New South Wales if further sub-tropical forages are developed.

Impacts Overseas

There is not expected to be any significant impacts overseas. There may be some increased scientific knowledge and research of tropical feeds that may be utilised internationally in other sub-tropical or tropical dairy regions.

Match with National Priorities

The Australian Government's Science and Research Priorities and Rural RD&E Priorities are reproduced in Table 4. The C4 Milk investment contributes primarily to Rural RD&E Priorities 1 and 4, and to Science and Research Priority 1.

Table 4: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities (est. 2015)	**Science and Research Priorities (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

Sources: DAWR (2015) and OCS (2016)

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 5. The C4 Milk project addressed Science and Research Priority 1. In terms of the guides to investment, the project is likely to have a real future impact through improved feed management strategies and reduction in feed costs. In addition to DAF funding, the project was supported and funded by others external to Queensland, but with the majority of the benefits flowing to Queensland dairy farmers.

Table 5: 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 a high degree of uncertainty was involved. Sensitivity analyses were undertaken for those variables where there was greatest uncertainty or for those that were identified as key drivers of the investment criteria.

Two of the impacts identified in Table 3 were valued. The two benefits were:

- Benefit 1: Increased MOFC due to replacement of some concentrates with home-grown fodder.
- Benefit 2: Decreased feed costs due to research into improved forage management.

Impacts not Valued

Not all impacts identified in Table 3 could be valued in the assessment.

The economic impacts identified but not valued included:

- Potential reduction in feed costs due to new types and varieties of forage being researched (such as soybeans or fodder beet).
- The increased certainty and sustainability of the sub-tropical dairy industry to deal with industry disruption due to the C4 program.
- Increased productivity and use of the home-grown feed developed in the C4 program in Southern NSW and Victoria.

The three economic impacts identified above were not valued because of restricted data available for on-farm valuation, the complexity of future scenarios and lack of time and resources for identifying the level of adoption and value of impacts on southern dairy systems.

The environmental impacts in Table 3 were not valued as there were significant data limitations in making the various linkages between the project findings and the impacts. None of the four social impacts were valued due to the difficulty of placing credible monetary values on the benefits as well as time and resource constraints.

Valuation of Benefit 1: Increased MOFC due to replacement of some concentrates with home-grown fodder.

It is assumed that a proportion of sub-tropical farmers would have undertaken greater use of home-grown forage due to the project findings and the associated extension effort. An assumption of 2% of sub-tropical farmers are assumed to have implemented more home-grown feed if this project had not been funded. From the remaining farms, it is assumed 15% across all regions will adopt the findings of the C4 investment. These farms are assumed to have had some previous experience with home-grown feed production but would not have necessarily replaced concentrates with more home-grown feed, without the influence of the C4 project. From the draft final report, it has been shown that adoption has already commenced and is assumed that this adoption will have reached a maximum of 15% in the year ending June 2024 and thereafter.

The adopting farms are assumed to benefit from a reduction in their marginal cost per litre of milk. This was estimated via their MOFC compared to the existing industry average, and assumes that their quantity and quality of milk output remains the same after their change in feeding strategy.

A breakdown of the MOFC between the sub-tropical dairy regions cannot be reasonably estimated as there is no breakdown available of where the adopting farms are located. While there are regional disparities in farming conditions, a TMR/PMR breakdown adequately captures the potential gains. From DAF (2016a), the HMFT showed a range of increases in MOFC from 5.5 c/l to 9.6 c/l. This varied across the different feeding systems, so an assumption was made to use the medium MOFC gains for the TMR and PMR systems of 6c/l and 9.2c/l respectively.

Specific assumptions for valuing this benefit are provided in Table 6.

Valuation of Benefit 2: Decreased feed costs due to research into improved forage management

The increased knowledge of iNDF and DM digestibility of plants has led to changes in feed strategies for some farms. For farms that have changed strategies it was found there was an increase in DM intake and digestibility. As the main research was on lucerne utilisation, these changes apply mainly to the Southern Downs and Central Queensland regions for grazing, but also apply throughout the sub-tropical region as lucerne is used also for silage and hay. Other research and extension activities showed that grazing times for other forages can have an influence on digestibility as well. The forage sorghum research findings provided ideal crop manipulation in terms of timing of grazing and harvesting management options for forages. The reaction to the extension activities provided evidence that farmers are likely to implement such options. These activities were not used in the HMFT.

Specific assumptions on adoption and value of the improved forage management practices are provided in Table 6.

Base Counterfactual

For the first benefit, an increase of 2% in the number of farms assumed to increase sub-tropical home-grown feed use is assumed without the C4 project; hence, the adoption assumptions for valuing the first benefit exclude these farms.

For the second benefit, it is assumed that no farmers would have adopted the forage management improvements (iNDF and nutritional improvements) without the C4 Milk project. This assumption is based on the amount of research into this component of the project that would be difficult to replicate on farm without the necessary research personnel and equipment.

Attribution

A previous C4 project had outlined the nutritional value of some the feeds used in the HMFT. The experience of the team with the dairy industry, either through the previous project or being part of the industry themselves also has influenced the adoption of the C4 project results. The DIA discussions groups were previously running before the project took place. The DIA groups affected the implementation of the research and development components significantly. Taking these factors into account, an attribution factor for the current C4 Milk project of 70% has been set for both Benefit 1 and Benefit 2.

Future extension

The C4 milk project undertook considerable extension activities engaging a wide range of farmers across the sub-tropical dairy industry. It has been identified in discussions with the project team that further extension can help increase the uptake of findings, as farmers stated that they would like further one on one consultation for them to implement on farm.

From the extension activities, it is recognised that further extension may be needed to increase the adoption of findings above that already assumed in this assessment. This would most likely involve one on one farm consultations. The current adoption level assumed and included in the assumptions takes into account the networks farmers have established from the investment already made.

Summary of Assumptions

A summary of assumptions used in the valuation of impacts is provided in Table 6.

Table *6*: Summary of Assumptions

Variable	Assumption	Source
BASE COUNTERFACTUAL: A small increase (2%) in the number of farms assumed to use sub-tropical home-grown feeds without the C4 project would have occurred in future. For adopting new forage management methods, it is assumed that no farms would implement these methods without the C4 project. The assumptions below accommodate these counterfactuals.		
Benefit 1: Increased MOFC due to replacement of some concentrates with home-grown fodder.		
Improved MOFC from HMFT for farms in TMR	6c per litre	Progress Report 4
Improved MOFC for farms in PMR	9.2 c per litre	Progress Report 4
Total number of sub-tropical dairy farms	559	QDAS (2016) for Queensland farms and feedback from David Barber (pers. comm., 2017) for Northern NSW farms.

Total number of sub-tropical dairy farms who would not have implemented home-grown feed otherwise	548	549*(1-0.02)
Proportion of farms in TMR system	32.2%	Based on QDAS (2016)
Proportion of farms in PMR system	67.8%	Based on QDAS (2016)
Average milk production in sub-tropical industry	835,237 litres per farm per annum	Based on ABARES (2016)
Estimated adoption of HMFT components	45%	Based on proportion of technologies adopted as per survey results in Progress Report 5, rounded to whole percentage by Agtrans Research
Probability of impact of increasing MOFC for those adopting	75%	Agtrans Research
Maximum adoption by eligible sub-tropical farms	15%	Agtrans Research based on feedback from extension and discussions with David Barber (pers. comm., 2017)
First year of adoption impacts	30 June 2017	Agtrans Research
Year of maximum adoption impacts	30 June 2024	Agtrans Research
Cumulative adoption levels from years 1 to 8 as % maximum of 15%	40%, 50%, 70%, 80%,85%,90%,95%, 100%	Agtrans Research
Expected total annual benefit after full adoption	$1.89 million per annum	0.06*45%*835,237*0.322*548*15%*75% + 0.092*45%*835,237*0.678*548*15%*75%
Benefit 2: Decreased feed costs due to research into improved forage management		
Reduction in feed costs due to better forage management practices	2c/l	Assumption based on draft final report.
Maximum number of farms implementing practices	20%	Agtrans Research based on discussions with Craig Findsen (pers. comm., 2017)
Average milk production in sub-tropical industry	835,237 litres per farm per annum	Based on ABARES (2016)
Likelihood of maximum of 20% farmers adopting	75%	Agtrans Research
Likelihood of impact of 2c/l	75%	Agtrans Research
First year of adoption impacts	30 June 2017	Agtrans Research and from draft final report
Year of maximum adoption	30 June 2024	Agtrans Research
Cumulative adoption levels from years 1 to 8 as % maximum of 20%	40%, 50%, 70%, 80%, 85%, 90%, 95%, 100%	Agtrans Research
Expected total annual benefit at full adoption	$1.05 million per annum	835,237*$0.02*20%*559*0.75*0.75
Attribution to Benefit 1 and 2		
Attribution to Project	70%	Agtrans Research, based on some attribution to earlier R&D investment

7. Results

All past costs were expressed in 2016/17 dollar terms using the Implicit Price Deflator for Gross Domestic Product.

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

Investment Criteria

Tables 7, 8 and 9 show the investment criteria estimated for different periods of benefits for the total investment and the DAF and DA investment respectively.

Table *7*: Investment Criteria for Total Investment

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.82	7.38	14.24	19.68	23.94	27.28	29.90
Present value of costs ($m)	5.78	5.78	5.78	5.78	5.78	5.78	5.78
Net present value ($m)	-4.97	1.60	8.46	13.90	18.16	21.50	24.11
Benefit-cost ratio	0.14	1.28	2.46	3.40	4.14	4.72	5.17
Internal rate of return (IRR) (%)	neg.	11.92	22.96	25.10	25.66	25.82	25.87
Modified IRR (%)	neg.	11.02	15.98	14.77	13.40	12.27	11.37

Table 8: Investment Criteria for DAF Investment

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.58	5.20	10.04	13.87	16.87	19.22	21.06
Present value of costs ($m)	4.07	4.07	4.07	4.07	4.07	4.07	4.07
Net present value ($m)	-3.50	1.12	5.96	9.79	12.79	15.15	16.99
Benefit-cost ratio	0.14	1.28	2.46	3.40	4.14	4.72	5.17
Internal rate of return (%)	neg.	11.93	22.98	25.12	25.68	25.84	25.89
Modified IRR (%)	neg.	11.02	15.98	14.77	13.40	12.27	11.37

Table 9: Investment Criteria for DA Investment

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.24	2.14	4.13	5.71	6.94	7.91	8.67
Present value of costs ($m)	1.68	1.68	1.68	1.68	1.68	1.68	1.68
Net present value ($m)	-1.44	0.46	2.45	4.03	5.26	6.23	6.99
Benefit-cost ratio	0.14	1.28	2.46	3.40	4.14	4.71	5.17
Internal rate of return (%)	neg.	11.87	22.92	25.05	25.61	25.78	25.83
Modified IRR (%)	neg.	11.01	15.98	14.77	13.39	12.27	11.37

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 1.

Figure 1: Annual Cash Flow of Total Benefits and Investment Costs in the Project

Sources of Benefits

Estimates of the relative contribution of each benefit valued, given the assumptions made, are shown in Table 10.

Table 10: Contribution to Total Benefits from Each Source

Source of Benefits	Contribution to PVB ($m)	Share of benefits (%)
Benefit 1: Increased MOFC due to replacement of some concentrates with home-grown fodder.	19.36	64.8%
Benefit 2: Decreased feed costs due to research into improved forage management.	10.53	35.2%
Total	29.90	100.0%

Sensitivity Analysis

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 11 presents the results. The results showed a moderate sensitivity to the discount rate.

Table 11: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	**Discount rate**		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	59.54	29.90	17.97
Present value of costs ($m)	5.49	5.78	6.08
Net present value ($m)	54.05	24.11	11.88
Benefit-cost ratio	10.84	5.17	2.95

Further sensitivity analyses of the best case and worse case scenarios were conducted on the key variables of adoption levels for both benefits and the probability of impact of both the benefits (Tables 12 and 13).

Table 12: Sensitivity to Change in Adoption Rates for Both Benefits
(Total investment, 30 years, 5% discount rate)

Investment Criteria	**Maximum Adoption (%)**		
	10% Benefit 1 10% Benefit 2 (Worst case)	**15% Benefit 1 20% Benefit 2 (Base case)**	**20% Benefit 1 30% Benefit 2 (Best case)**
Present value of benefits ($m)	18.18	29.90	41.62
Present value of costs ($m)	5.78	5.78	5.78
Net present value ($m)	12.39	24.11	35.83
Benefit-cost ratio	3.14	5.17	7.20

Table 13: Sensitivity to Probability of Impact
(Total investment, 30 years, 5% discount rate)

Investment Criteria	**Likelihood of Impact Assumed for Farms Adopting (% for both Benefit 1 and Benefit 2)**		
	50%	**75% (Base)**	**95%**
Present value of benefits ($m)	19.93	29.90	37.87
Present value of costs ($m)	5.78	5.78	5.78
Net present value ($m)	14.15	24.11	32.09
Benefit-cost ratio	3.45	5.17	6.55

From the sensitivity analyses reported in Tables 12 and 13, the base results appear robust. Even in the worst-case scenario, the C4 project still has a positive Net Present Value and a Benefit-Cost Ratio that is over 1, for the 30-year period.

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 14). 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 14: Confidence in Analysis of Cluster

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

Coverage of benefits was assessed as high-medium as most benefits were economic in nature relating to decreasing input costs. Some impacts were not valued due to the availability of relevant data, the ability to place credible monetary estimates on the results, and time and resources constraints. The impacts not valued were assessed as being less important than those valued.

Confidence in assumptions was rated as high-medium. While validation of most assumptions was provided subjectively by research personnel, some uncertainty remains regarding the specific levels of impacts captured by producers; the associated adoption levels are necessarily uncertain as these predominantly lie in the future. On the other hand, there have been some on farm adoption and impacts that have already occurred while the project was on-going. These findings, along with the survey results, form the basis of the adoption assumptions that are therefore a mixture of both revealed and stated preferences.

The assumptions that have been made for valuing the benefits from these investments are potentially conservative, with uncertainty factors for adoption and impact being included in the analysis.

8. Conclusions

The findings have led to significant cost reductions for farmers who have adopted the project's findings. The project also exhibited widespread industry participation, allowing for increased networks to develop so providing capacity of the dairy industry to innovate and undertake future change.

Funding for the C4 Milk project totalled $5.8million (present value terms) and produced aggregate total expected benefits of $29.9million (present value terms). This gave a net present value of $24.1million, a benefit-cost ratio of 5.2 to 1, an internal rate of return of 25.9% and a modified internal rate of return of 11.4% discounted for 30 years.

Given the assumptions made, the investment criteria estimated support the conclusion that this has been a most worthwhile investment. In addition to the impacts that were valued, several other impacts were identified and reported only qualitatively. Hence, the resulting investment criteria most likely provide an underestimate of the total value of project impacts.

References

Australian Bureau of Agricultural and Resource Economics, 2014. Productivity in the Australian dairy industry, ABARES.

Australian Bureau of Agricultural and Resource Economics, 2016. Australian dairy: financial performance of dairy farms, 2013–14 to 2015–16. Accessed March 2017 at http://pandora.nla.gov.au/pan/30839/20161004-0002/16.6.pdf

Dairy Australia (DA), 2015. The Northern Dairy Industry Accessed 9 March 2017 at: http://dairyinfo.biz/wp-content/uploads/2014/10/The_Northern_Dairy_Industry_factsheet.pdf

DAWR (2015) Rural Research and Development Priorities, Department of Agriculture and Water Resources, Canberra, ACT, accessed April 2017 at: http://www.agriculture.gov.au/ag-farm-food/innovation/priorities

Department of Agriculture and Fisheries (DAF), 2016a. Balancing dairy production and profits in Northern Australia Queensland Dairy Accounting Scheme Financial and production trends – 2016. Accessed March at: http://dairyinfo.biz/wp-content/uploads/2016/11/QDAS_2016.pdf

Department of Agriculture and Fisheries (DAF), 2016b. Progress Report Number 4

Department of Agriculture, Fisheries, and Forestry (DAFF), 2013a. Successful Dairy Production in the Sub-Tropics. Accessed March at: http://dairyinfo.biz/wp-content/uploads/2014/11/Tropical_feedbase_manual.pdf

Department of Agriculture, Fisheries and Forestry (DAFF), 2013b. http://dairyinfo.biz/wp-content/uploads/2014/11/N04_Factors_affecting_feed_intake.pdf

Edwards, E.J., Osborne, C.P., Strömberg, C.A., Smith, S.A. and C4 Grasses Consortium, 2010. The origins of C4 grasslands: integrating evolutionary and ecosystem science. Science, 328(5978), pp.587-591.

Harper and McNeill, 2015. The Role of iNDF in the Regulation of Feed Intake and the Importance of Its Assessment in Subtropical Ruminant Systems. Agriculture. Accessed 8 March 2017 at: http://www.mdpi.com/2077-0472/5/3/778/htm

OCS (2016) Science and Research Priorities, Office of the Chief Scientist, Department of Industry, Innovation and Science, Canberra, accessed April 2017 at: http://science.gov.au/scienceGov/ScienceAndResearchPriorities/Pages/default.aspx

Office of the Chief Scientist, Queensland Government (2015) Revised Queensland Science and Research Priorities, accessed April 2017 at: http://www.chiefscientist.qld.gov.au/images/documents/chiefscientist/pubs/reports-other/qld-science-n-research-priorities-2015-2016.pdf

Queensland Parliament, 2017. Public hearing—inquiry into the sustainable Queensland dairy production (fair milk price logos) bill 2016. Accessed March 2017 at http://www.parliament.qld.gov.au/documents/committees/AEC/2016/13-FairMilkPriceLogos2016/trns-ph-1Mar2017.pdf

Sub-tropical dairy, 2010. Strategic Plan for Industry Development 2010 to 2015 Accessed March 2017 at http://dairyinfo.biz/wp-content/uploads/2014/10/NDI_SP_Aug_2010_Final.pdf

YouTube, 2017. Queensland Agriculture. Accessed 24th May 2017 at: https://www.youtube.com/user/QldAgriculture/videos

Appendix 5: An Impact Assessment of DAF Investment in Sweetpotato Projects between 1998 and 2018 that address Pests, Diseases, Agronomy and New Varieties

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ASPG	Australian Sweetpotato Growers Inc.
BMP	Best Management Practice
CBA	Cost-Benefit Analysis
CIP	International Potato Centre
CRC	Cooperative Research Centre
CRRDC	Council of Research and Development Corporations
DAF	Department of Agriculture and Fisheries, Queensland
DAL	Department of Agriculture and Livestock (PNG and Solomon Islands)
DAWR	Department of Agriculture and Water Resources (Australian Government)
DPI	NSW Department of Primary Industries
ELISA	Enzyme-Linked Immuno-Sorbent Assay
GDP	Gross Domestic Product
HAL	Horticulture Australia Limited (now HIA)
HIA	Horticulture Innovation Australia
HRDC	Horticulture Research and Development Corporation (now HIA)
IPM	Integrated Pest Management
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NARI	National Agricultural Research Institute (PNG)
NGO	Non-Government Organisation
NSW	New South Wales
OCS	Office of Chief Scientist Queensland
PNG	Papua New Guinea
PT	Pathogen Tested
PVB	Present Value of Benefits
QLD	Queensland
QUT	Queensland University of Technology
RDC	Research and Development Corporation
R&D	Research and Development
RD&E	Research, Development and Extension
SI	Solomon Islands
SPC	Secretariat of the Pacific Community

Executive Summary

The Projects

This report presents the results of an impact assessment of Queensland Department of Agriculture and Fisheries (DAF) investment in eleven sweetpotato projects that address pests, diseases, agronomy and new sweetpotato varieties. The projects have been funded by DAF and a range of project partners over the period 1998 to 2018.

Methods

The projects were analysed qualitatively within a logical framework that included activities/outputs, outcomes, and impacts. Impacts were categorised into a triple bottom line framework. The principal impacts were then valued. Benefits were estimated for a range of time frames up to 30 years from the year of last investment in the project. Past and future cash flows in 2016/17 dollar terms were discounted to the year 2016/17 using a discount rate of 5% to estimate the investment criteria.

Impacts

The major impacts identified were of a financial nature. However, some social and environmental impacts were also identified but not valued. It is expected that both the Australian and Pacific Island Countries' sweetpotato industries will be the primary beneficiaries of the investment. This analysis has focussed on impacts on the Australian sweetpotato industry.

Investment Criteria

Total funding from all sources for the project was $15.3 million (present value terms). The value of benefits was estimated at $133.1 million (present value terms). This gave an estimated net present value of $117.8 million, and a benefit-cost ratio of 8.7 to 1.

1. 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 included both qualitative and quantitative descriptions that are in accord with the evaluation guidelines of the Council of Research and Development Corporations (CRRDC, 2014).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, 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, a high degree of uncertainty surrounding the potential impact, or the likely low relative significance of the benefit compared to those that were valued. The impacts valued therefore are deemed to represent the principal benefits delivered by the project.

2. Background and Rationale

Background

Fresh Australian produced sweetpotatoes are available all year round. Annual production in 2016 was 100,000 tonnes valued at $100 million farm gate. Queensland (QLD) produces 70% of Australia’s sweetpotato output with production being centred on Bundaberg. The second major producing area is Cudgen in far north-eastern New South Wales (NSW). Sweetpotatoes are also grown at Mareeba, Atherton and Rockhampton (QLD), Murwillumbah (NSW), and in Perth, Carnarvon and Kununurra (Western Australia).

By 2020 sweetpotato will be the third most important vegetable grown in QLD behind tomatoes and capsicums. Sweetpotato is the only vegetable category whose retail sales are increasing. All fresh market sweetpotatoes sold in Australia are grown in Australia. A small amount of product is processed and 200 tonnes were exported in 2015. All imports are currently in processed form (e.g. chips) (Nick Macleod, Director Vegetables and Deciduous Fruit RD&E, DAF, written communication, March 2017).

Sweetpotatoes are an essential staple of Pacific Island Communities. In Papua New Guinea (PNG) they account for 64% of the staple foods grown by weight and have a United States (US) dollar value of $450 million per annum. Depending on the PNG region, sweetpotato occupies between 55% and 90% of the land under arable agriculture. In the Solomon Islands, sweetpotatoes have a similar prominence – with production of 280,000 tonnes worth an estimated A$40 million (Bourke 2005).

Rationale for the Projects

Sweetpotato yield and quality have been in decline in both PNG and the Solomon Islands. Pests and diseases were thought to be the major cause of yield loss. Ongoing yield decline threatens food security. Pathogen Tested (PT) virus free planting material held out promise of yield gain in the Pacific and would also benefit the Australian sweetpotato industry. Improved pest control and agronomy could be married to the use of PT material.

PNG and the Solomon Islands have many sweetpotato varieties. The Australian industry is dominated by gold type varieties with Bellevue, Beauregard and Orleans holding a 90% market share. The other significant Australian variety is 'Northern Star' a purple skinned white fleshed variety with approximately 5% market share that was tested and released as a part of a DAF project included in this cluster. Consumer research in Australia shows there is latent demand for alternative varieties with different coloured flesh that are smooth skinned and easy to peel.

The projects have been funded by DAF and a range of project partners over the period 1998 to 2018.The partners included various horticultural industry funding organisations including Horticulture Innovation Australia (HIA) and its antecedents, as well as the Australian Centre for International Agricultural Research (ACIAR).

3. Project Details

A summary of details on the eleven projects that make up the project cluster is provided in Table 1.

Table *1*: Summary of the Projects Subjected to the Impact Assessment

Project ID	**Project Name**	**Start Date**	**Finish Date**
VG97023	Sweetpotato variety improvement	July 1997	July 2000
VG01010	Improving sweetpotato agronomy to meet new market opportunities	July 2001	June 2005
VG02114	Development of smooth skinned easy to peel sweetpotato using smart state technology	Dec 2002	Mar 2006
VG05037	Improving the management of sweetpotato soil insect pests	July 2005	Nov 2009
CP2004-071	Reducing pest and disease related yield decline in selected Papua New Guinea (PNG) sweetpotato production systems	Apr 2006	Mar 2010
CP2005-134	The use of pathogen tested planting materials to improve sustainable sweetpotato production in Solomon Islands and PNG	Sept 2006	Aug 2010
08-14329	Efficacy of Oxamyl for control root knot nematode in sweetpotato	Sept 2008	Feb 2009
VG09009	Evaluating sweetpotato varieties to meet market needs	Jan 2010	Dec 2013
VG09052	Integration of crop and soil insect management in sweetpotatoes	July 2010	Jan 2014
PC2011-053	Identifying appropriate strategies for reducing virus and weevil losses in sweetpotato production systems in PNG and Australia	Sept 2012	Jan 2015
VG13004	Innovating new virus diagnostics and planting bed management in the Australian Sweetpotato Industry	Feb 2014	Mar 2018

Source: Department of Agriculture and Fisheries, Queensland

Logical Framework

Tables 2 to 12 provide a description of the 11 projects in a logical framework.

Table 2: Logical Framework for VG97023

VG97023: Sweetpotato variety improvement	
Project details	Research Organisation: Department of Agriculture and Fisheries Period: July 1997 to July 2000 Principal Investigator: Lester Loader
Rationale	There is opportunity to improve grower productivity and expand the sweetpotato market through the introduction of new varieties.
Objectives	1. Establish a sweetpotato gene bank collection in Australia. 2. Evaluate and release new varieties suitable for Australia.
Activities and Outputs	• Project activities included germplasm acquisition, breeding, preliminary observation and selection, germplasm maintenance and increase, regional trials and virus indexing. • New varieties with different consumer characteristics were released. Only Northern Star captured market share (5%) while Beauregard, an existing variety maintained market dominance (90%). • Releases included: o 'Hernandez' – bright orange flesh, high yielding and sweet. o 'Northern Star' – bright purple skin, white flesh and high yielding. o 'WSPF' – white skin, purple marble flesh. o 'Hawaii' white but slightly purple. o 'Kestle' true white flesh/skin, inconsistent shape and yield. o 2 new lines of Beauregard (L86-33Q7, L86-33Q9) with improved production attributes. Planting material made available that is virus free. • New variety release information was published in the DAF Agri-Link Sweetpotato Manual.
Outcomes	• Varieties that help meet demand for staple (starchy) sweetpotatoes. • Virus free planting material for the market dominating 'Beauregard'. • Release of virus free lines with improved returns for growers.
Impacts	• Additional sweetpotato yield (more productive lines of Beauregard). • Increased grower profitability via increased demand from new varieties. • Increased regional income in Australia (spillover).

Table 3: Logical Framework for VG1010

VG01010: Improving sweetpotato agronomy to meet new market opportunities	
Project details	Research Organisation: Department of Agriculture and Fisheries Period: July 2001 to June 2005 Principal Investigator: Stephen Harper
Rationale	A previous DAF-HIA project VG97023 had produced and released a suite of new sweetpotato varieties. The project highlighted considerable geographic and seasonal variation in existing and new varieties suggesting each appeared to have specific cultural requirements in order to produce more roots of marketable size. Growers have had difficulty in achieving market specifications with some of the new varieties and there was a need to refine agronomic practices to improve marketable yield. Problems included high percentages of over or under sized roots, cracking skin, skin and flesh colour, and shape and number of roots set. The variability in expression of

	these defects was likely to be at least partly related to specific agronomic requirements. Factors including presence of feathery mottle virus, timing and rate of fertiliser application, genetic drift in propagative material, varietal maturation and plant spacing, all potentially impacting on yield and quality traits. In Australia, little was known about these agronomic issues particularly in relation to Beauregard (gold flesh) and the new variety Northern Star (purple skin, white flesh).
Objectives	1. Improve agronomic practices and increase marketable yield. 2. Document and promote the benefits of Pathogen Tested (PT) planting material. 3. Evaluate agronomic response to nutrition, density and maturation. 4. Evaluate new cultivars. 5. Select new accessions of Beauregard. 6. Conduct best management practice (BMP) option trials.
Activities and Outputs	• Survey of retailers – 50% of supply does not meet requirements; consistency of size and shape was the main area for improvement. • Survey of the performance of Beauregard used by growers and the PT tested virus free material. • Evaluation of new varieties with the potential to replace Beauregard. • Planting trial tested row spacing and found spacing to be non-critical. • Nitrogen and potassium application rates tested and current commercial rates can, in some instances, be reduced without yield loss. Excessive nitrogen application results in yield loss and root splitting (poor quality). • DAF BMP recommendations tested and found to be sound. • Extension included presentations to Australian growers by leading US researcher Dr Mike Canon.
Outcomes	• 80% yield improvement achieved for cv. Beauregard using PT planting material. More sweetpotatoes of marketable size and quality also grown. • Beauregard selections made from grower lines did not give greater yield nor confer improved disease resistance compared with DAF Beauregard. There has been limited genetic drift in the Beauregard variety. • Julie Stanton, DAF email Oct 2003: "No germplasm from VG01010 has been sold and no germplasm is likely to be sold. Their comprehensive trials of germplasm material have yielded nothing that can supersede the cultivar, Beauregard". • Grower surveys completed at the end of the project showed universal awareness of the research and identification of the project's greatest outcome being the opportunity to adopt PT planning material.
Impacts	• Increased average yield (through further adoption of PT with more sweetpotatoes of marketable size). • Increased grower profitability via reduced fertiliser rates. • Increased regional income in Australia (spillover).

Table 4: Logical Framework for VG02114

VG02114: Development of smooth skinned easy peel sweetpotato using smart state technology	
Project details	Research Organisation: Department of Agriculture and Fisheries Period: December 2002 to March 2006 Principal Investigator: Eric Coleman
Rationale	Beauregard is known for the variability of its tubers and there is no market for roots that are not even in shape with easy to peel smooth bright skins. Prior to this project, it was hypothesised that pre-plant and transplant

	physiology played a role in determining the quality of sweetpotatoes but no research had been completed to understand the potential link. As a consequence, the project set out to explore the link between pre-plant and transplanting physiology to better understand how plant material, environment and management impact on resultant sweetpotato quality.
Objectives	1. Determine whether improved planting techniques and plant establishment increase the yield of easy to peel sweetpotatoes cultivar Beauregard. 2. Develop new plant establishment protocols/techniques linked to climate and economic conditions that will allow growers to manipulate crop performance and generate higher marketable yields.
Activities and Outputs	• Review of literature and relevant planting technologies. • Field experiments. Seven planting material experiments were completed that addressed: length and thickness of planting material, herbicide effects, planting orientation, planting method, number of nodes underground, seedling potential and irrigation. • Factors important in early plant establishment were shown to be linked to planting material type, planting material length, planting method, temperature, moisture and leaf area at or just after planting. • Important factors in early establishment were incorporated into management protocols and introduced to growers through established extension channels. • The project showed that there is a strong linkage between early plant physiology and final root quality.
Outcomes	• Before this project, the majority of Australian growers used a stick to push the sweetpotato planting material into the soil resulting in a V shape plant. Crops would be irrigated initially and then not attended to until six weeks after planting. • It is now estimated that 80% of the Australian industry has adopted the flat planting technique and frequent early irrigation recommended by this project. • Many growers now use mechanical planters for flat planting and have adopted trickle irrigation. • As a result of the change in planting technique and plant establishment care, a reduction in time to maturity and an improvement in final root shape have been achieved. • In addition, new experimental techniques were pioneered through this project to reduce plant to plant variability and measure changes in root development.
Impacts	• Increased average yield – a 50% improvement in premium grade, sweetpotato yield (more sweetpotatoes of marketable size). • Cost reduction and increased profitability (fertiliser savings in some growing areas). • Increased research capacity (agronomic research techniques). • Increased regional income in Australia (spillover).

Table 5: Logical Framework for VG05037

VG05037: Improving the management of sweetpotato soil insect pests	
Project details	Research Organisation: Department of Agriculture and Fisheries Period: July 2005 to November 2009 (extended to 31 May 2010) Principal Investigator: Russell McCrystal

Rationale	The Australian Sweetpotato Growers (ASPG) group identified soil insect pest management as the industry's number one research priority. Growers are continually reporting increased incidence of major soil insect damage. At the start of this project the only means of controlling these pests was through the application of multiple broad spectrum insecticides incorporated in the soil prior to planting and foliar applied during crop development. Insecticides were often applied as 'insurance cover' when possibly the wrong insecticide was being used or it was not needed at all.
Objectives	Develop management strategies for sweetpotato pests including sweetpotato weevil (*Cylas formicarius*), root-knot nematode (*Meloidogyne* spp.) and both true and false wireworm (Elateridae and Tenebrionidae families).
Activities and Outputs	• Review of the scientific literature. • Assessment of the efficacy of insecticides for the control of sweetpotato weevil (1 insecticide), root-knot nematode (1 nematicide) and wireworm (5 insecticides) in the Australian sweetpotato cropping system. • Identify new 'soft options' which have the potential to contribute to sweetpotato Integrated Pest Management (IPM) systems. • Conduct an insect pest and control practices survey of the sweetpotato industry. • Develop and test improved IPM strategies, which included pheromone technology. • Extension of project results through facilitated sessions in Bundaberg and Cudgen.
Outcomes	• Two minor use chemical permits renewed for wireworm – bifenthrin and chlorpyrifos. • A more effective means of delivering smaller amounts of fipronil through drip irrigation against wireworm was demonstrated. • Oxamyl was shown to be an effective alternative to fenamiphos against root-knot nematode. • Thiamethoxam applied to the soil prior to planting was shown to be effective for the control of sweetpotato weevil. This new insecticide has a low impact on beneficial arthropods and potentially is a good 'IPM fit'. • Use of pheromones for control of sweetpotato weevil was successfully demonstrated on a grower's property. A subsequent survey showed that use of pheromones by growers in Bundaberg increased from 6% in 2006 to 80% in 2010. • The same survey showed that 30% of Bundaberg growers now have nematode surveys done before planting. Previously there was no surveying (i.e. the work has resulted in a practical application of IPM principles). • The grower survey also showed a significant decrease in routine use of insecticides prior to sweetpotato planting. The reduction in insecticide use has been mostly from the group 'organophosphates'.
Impacts	• Increased average yield (wireworm, weevil and nematode control). • Increased profitability (chemical purchase savings i.e. more monitoring with less calendar sprays). • Fewer chemicals in the farm and district environment increasing biodiversity and water quality. • Increased regional income in Australia (spillover).

Table 6: Logical Framework for CP2004-071

CP2004-071: Reducing pest and disease related yield decline in selected PNG sweetpotato production systems	
Project details	Research Organisation: Department of Agriculture and Fisheries Period: April 2006 to March 2010 (with extension to September 2010) Principal Investigator: Eric Coleman (later Michael Hughes)
Rationale	Sweetpotato provides 64% of the food base of the PNG population. Yield and tuber quality has been declining over time. Virus complexes were the suspected cause of yield decline. Consequently, a research project was required to investigate the cause of yield decline and develop solutions based around IPM and PT planting material.
Objectives	1. To understand the causes of PNG sweetpotato yield loss. 2. To develop and test pest and disease control strategies. 3. To encourage adoption of PT planting material as part of an IPM strategy in both PNG and Australia. 4. To apply lessons learned, especially in relation to IPM, to the Australian sweetpotato industry.
Activities and Outputs	• Literature review – pest and disease status in PNG. • Assembly of PNG sweetpotato germplasm for virus testing. • Virus identification and testing in PNG and Australia. • PNG and Australian officers trained in virus indexing. • Knowledge of virus status and the link established between PNG sweetpotato yield decline, viruses and virus complexes. • Introduction, trialling and successful use of PT planting material in PNG and Bundaberg, Australia. • Testing for the presence and damage caused by weevils in PNG. • Trialling of weevil pheromone as a management tool in Australia. • Investigation of biological controls for sweetpotato weevil in PNG including a fungus and a predatory ant. • IPM based control developed for sweetpotato weevil in Australia. • Development of extension networks including the online information sharing tool ‘kaukaunet’ in Australia and the south west Pacific. • Assessment of sixteen sweetpotato varieties on the basis of taste, yield and shorter growing period with two preferred varieties selected by PNG farmers. • Cuttings from preferred varieties taken by more than 200 farmers.
Outcomes	• Systems to mitigate the impact of viruses on sweetpotato yield. • IPM controls for sweetpotato weevil resulting in saved production costs and less chemical in the farm environment. • Preferred varieties selected by farmers for PNG. • New sweetpotato germplasm available in Australia. • Research capacity increased in PNG and Australia e.g. virus testing.
Impacts	• Increased average yield PNG and Australia (from improved virus and weevil control). • Increased profitability through decreased chemical use in PNG and Australia (use of IPM rather than calendar spraying). • Increased research capacity in PNG and Australia (virus control PNG and Australia, weevil pheromone use Australia). • Reduced environmental impact – less broadspectrum chemical use in PNG and Australia. • Improved food security and human health in PNG (linked to increased average yields). • Increased regional income in PNG and Australia.

Table 7: Logical Framework for CP2005-134

CP2005-134: The use of pathogen tested planting materials to improve sustainable sweetpotato production in Solomon Islands and PNG.	
Project details	Research Organisation: International Potato Centre (CIP). Period: September 2006 to August 2010. Principal Investigator: Fernando Ezeta (CIP) and Eric Coleman (DAF).
Rationale	Sweetpotato yield has declined over time in both the Solomon Islands and PNG. Yield decline has been caused by virus affected planting material and poor cultural practices. There was a need to introduce new varieties and planting material that is PT and virus free. The overall aim of the project was to improve food security in the Solomon Islands and PNG by introducing and adapting technologies that produce consistently high yielding and nutritious crops of sweetpotato, satisfying household consumption and human nutrition.
Objectives	1. To describe and evaluate sweetpotato planting material supply systems. 2. To introduce and evaluate improved sweetpotato varieties. 3. To introduce, refine and disseminate technologies for improved sweetpotato planting material supply systems for small holders practising low-input agriculture.
Activities and Outputs	Activities focussed on areas under production stress - the Solomon Islands (SI) where rapid population growth is combining with yield decline and the PNG Lowlands (a previous project has addressed yield loss in the Highlands). SI assessed as the area of greatest need and 70% of project resources were expended in that country. • Farmer surveys to understand how planting material is retained and how new varieties are introduced to the system following yield loss. • Introduction of new planting material from varieties currently held at the Regional Germplasm Centre of the Secretariat of the Pacific Community. • Extension to achieve new variety uptake using NGOs, Community Based Organisations, Department of Agriculture and Livestock (DAL) staff and lead farmers. Extension activities included identification of project coordinators, train the trainer activities, and work through Farmers' Field Schools and selected DAL extension officers. • Complete experiments with Farmers' Field Schools to determine the performance of old and new varieties introduced through the project. • Complete virus indexing and production of PT material. • Introduction of PT material through extension systems developed to introduce new varieties. • Completion of field days, farmer-to-farmer training and farmer visits to secure ongoing adoption of new varieties produced with PT virus free planting material. • Knowledge of SI and PNG sweetpotato production practices. • New sweetpotato varieties and PT planting material.
Outcomes	• Adoption of new varieties in SI with a focus on Guadalcanal, Isabel, Makira, and Malaita. • Adoption of new varieties in the PNG Lowlands. • Introduction and adoption of PT planting material in both PNG and SI.
Impacts	• Increased average yield in both SI and PNG (new varieties). • Improved food security in the SI and PNG from higher yielding new varieties (social). • Improved health – displacing poor quality varieties with nutritious new varieties to improve vitamin intake, antioxidants and dietary fibre.

	• Increased research, extension capacity in SI and PNG – extension officers trained in techniques to encourage uptake of PT material and new varieties. • Increased regional income as a result of improved sweetpotato grower returns – SI and PNG (spillover benefit).

Table *8*: Logical Framework for 08-14329

08-14329: Efficacy of oxamyl for control root knot nematode in sweetpotato.	
Project details	Research Organisation: DuPont Period: September 2008 to February 2009 Principal Investigator: Peter Morris
Rationale	Root knot nematodes adversely affect sweetpotato production. Research was required to determine whether the chemical oxamyl (brand name 'Vydate') was effective in their control.
Objectives	To investigate the efficacy and active life of the nematicide, 'Vydate' on root knot nematode in sweetpotato.
Activities and Outputs	• A trial was required to determine the efficacy of 'Vydate' on root knot in sweetpotato production systems. The trial also provided insight into the duration of time protection was afforded. • Two 1.25 ha trial sites were established at each of Bundaberg QLD and Cudgen NSW. The trial consisted of a control and five treatments with varied nematicide application rates.
Outcomes	• Trial results submitted to APVMA for consideration and the existing registration and label approval for oxamyl was varied to include use on sweetpotatoes for root knot nematode control.
Impacts	• Increased average yield – additional nematode control option (fenamiphos already available). • Increased profitability – oxamyl is a lower cost option for sweetpotato growers. • Environmental – possible negative impacts from use of a soil sterilising chemical that reduces populations of beneficial insects (this impact offset by further reductions in organophosphates associated with VG05037). • Increased regional income in Australia (spillover).

Table 9: Logical Framework for VG09009

VG09009: Evaluating sweetpotato varieties to meet market needs	
Project details	Research Organisation: Department of Agriculture and Fisheries Period: January 2010 to December 2013 Principal Investigator: Sandra Dennien
Rationale	Sweetpotato sales growth in Australia has been based on a single variety – gold fleshed Beauregard. If there is a change to Australian growing conditions, e.g. pest or disease incursion, the sweetpotato growing industry is at risk of production collapse. Furthermore, market research indicates that there are opportunities for additional sales from sweetpotato varieties that produce white, red and purple flesh. Existing white, red and purple flesh varieties are unreliable, producing variable yield and tuber quality. This project identified additional commercial varieties and provided a foundation for growing both the Australian sweetpotato market and export sales.
Objectives	1. Identify new commercial sweetpotato varieties. 2. Grow both the Australian domestic and export sweetpotato markets.

Activities and Outputs	The project builds on VG97023 which identified current commercial varieties and some further variety development work completed as part of VG1010. VG1010 collected a large number of local varieties that had not been productivity or disease/pest tolerance tested. • Market research – wholesalers and retailer priorities for the category. • Grower survey – to identify production concerns with the existing variety. • Genetic resource survey – including the major sweetpotato germplasm repository in the US. • Testing of possible varieties for viruses and other pathogens. • Initial screening trials included propagation of planting materials and testing screened varieties at multiple growing sites. • Completion of detailed variety evaluation using replicated fully randomised split plots. Leading marketers asked to test varieties under evaluation. • Review of potential commercial varieties for their suitability in both Korean and Japanese export markets. • Communication of trial results to growers through field days relevant to Bundaberg QLD and Cudgen NSW, distribution of the project final report via the industry's mailing list and communication of results through the national sweetpotato foundation seed scheme that was managed by a member of the project team.
Outcomes	• A sounder gold sweetpotato supply chain – reduced risk of relying on a single variety that may become susceptible to a pest/disease incursion or changed growing conditions. • Market growth based on new categories - white, red and purple flesh sweetpotatoes of appropriate quality that meet wholesaler, retailer and consumer demand. • Reduced risk of a pest/disease incursion causing a collapse in Australian sweetpotato production. • Possible health outcomes for consumers from additional sweetpotato consumption – antioxidants, vitamins, important dietary fibres and a low glycaemic index all assist with fighting obesity and type 2 diabetes.
Impacts	• Increased preparedness for new viruses from overseas. • Increased profitability from potential latent demand for red and white/purple varieties. • Increased regional income in Australia (spillover).

Table 10: Logical Framework for VG09052

VG09052: Integration of crop and soil insect management in sweetpotatoes.	
Project details	Research Organisation: Department of Agriculture and Fisheries Period: July 2010 to January 2014 (extended to May 2014) Principal Investigator: Eric Coleman
Rationale	VG05037 made significant advances in managing soil borne insects. The challenge then was to integrate these findings into the whole farm system. As a consequence of reducing the number of broad spectrum insecticides used for control of soil borne insects, growers must rethink their approaches to foliar pests that were being controlled by the past approach. As a consequence, approaches adopted in VG05037 were expanded through this project to include foliar chewing and sap sucking pests like tortoise shell beetle, flee beetle and hawk moth.

Objectives	1. Integrate VG05037 findings on soil borne pests into the whole farm system. 2. Develop approaches to manage foliar pests without use of broad spectrum organophosphates.
Activities and Outputs	• Workshops and field walks to deliver an improved awareness and understanding of sweetpotato pest insects including training in pest identification, use of decision support tools, use of predatory insects and best practice pest management strategies (pheromone traps, monitoring using bait foods, crop rotation and use of pest free planting materials). • Trials and field experiments to identify new technologies – testing of alternative/ new chemistry, alternative delivery techniques and genetic tolerances of various cultivars to sweetpotato pests. • Decision support tools that include monitoring and testing approaches. • Ongoing research on soil pests – wireworm, weevil and nematodes – through replicated field and pot trial experimentation. • Participatory learning events to deliver improved human resource capacity through the development of decision support tools for growers, agribusiness suppliers and consultants. • An industry wide pest management extension program that armed growers with the knowledge necessary to implement integrated crop management strategies.
Outcomes	• Improved understanding of pests and predators by growers, agribusiness suppliers and consultants. • New chemicals for the control of wireworm (one new chemical), sweetpotato weevil (three new chemicals) and nematodes (one new chemical). • New chemical application systems that improve the delivery of crop protectants into the root zone, improving crop protection times and reducing dependence on large concentrations of soil incorporated insecticides that need to be applied prior to planting. • Use of cover cropping management strategies between sweetpotato cropping periods to break pest cycles. • Demonstration of pest resistance in some sweetpotato cultivars including the newly imported Evangeline and Bienville. • Improved pest monitoring techniques with high adoption rates.
Impacts	• Increased average yield (wireworm, weevil and nematode control). • Increased profitability (lower input costs in the form of purchased chemicals i.e. more monitoring less calendar sprays). • Capacity building in the sweetpotato industry (IPM techniques). • Fewer chemicals in the farm and district environment with positive impacts on biodiversity and water quality. • Increased regional income in Australia (spillover).

Table 11: Logical Framework for PC2011-053

PC2011-053: Identifying appropriate strategies for reducing virus and weevil losses in sweetpotato production systems in PNG and Australia.	
Project details	Research Organisation: Department of Agriculture and Fisheries Period: September 2012 to January 2015 (variation to June 2015) Principal Investigator: Michael Hughes
Rationale	Sweetpotato is an important subsistence and cash crop in PNG. To support sweetpotato, ACIAR has undertaken projects on varieties (identification of sweetpotato varieties for West Papua Indonesia and PNG), sweetpotato soil

	fertility (SMCN 2004-067), pests and diseases (CP2004-071 – virus identification, CP2005-134 – pathogen tested planting material for Solomon Islands and PNG, CP 2010-026 – a strategy to produce virus free planting material) and the socio-economic aspects of sweetpotato marketing (ASEM2006/035 – marketing efficiency). This project set out to establish pathogen free planting material and develop a better understanding of the weevil problem in PNG. The project was aimed at increasing pest and disease management knowledge and laying the foundations for a fully integrated approach to sweetpotato crop management. The project was consistent with the broader development goal of increasing the resilience of food security systems in PNG. Project goal was to identify the most promising strategies for managing sweetpotato pests and diseases in PNG and Australia.
Objectives	1. Assess the value of pathogen tested planting materials in reducing the impact of virus diseases. 2. Identify the most promising management tactics for weevils in specific production systems.
Activities and Outputs	• Project partners were DAF, National Agricultural Research Institute (NARI), the Australian Sweetpotato Growers Inc. (ASPG), the Secretariat of the Pacific Community (SPC), and the International Potato Centre (CIP), Peru. • Trials conducted in both the PNG Highlands and Lowlands to determine yield decline over successive plantings. • Crop sampling and virus testing at newly equipped centres in NARI and SPC (to build capacity in Pacific Island Communities). CIP provided supplies of unique primers for begomo-viruses and ongoing technical support. Gatton Research Facility provided assay support for previously undetected viruses in Australia and NARI and SPC refined virus diagnostic techniques. • Introduction of qPCR technology to Australian sweetpotato diagnostics. • Surveys of weevil prevalence in both the PNG Highlands and Lowlands. • Training to build awareness of weevil biology and ecology. • Preliminary trials in PNG of Australian weevil management techniques including pheromone trapping. • Formation of a farmer group in Australia under the ASPG to facilitate the adoption of improved decision-making to reduce reliance on broad-spectrum insecticides.
Outcomes	• A clean seed system based on PT for sweetpotato. • Methods for weevil control in PNG. • Methods to achieve weevil control in Australia with less reliance on broad-spectrum chemicals. • Identification of new viruses affecting Australian sweetpotato crops.
Impacts	• Increased average yield PNG (virus and weevil control). • Increased profitability for Australian growers (lower cost weevil control). • For PNG and Australia less use has been made of broad-spectrum chemicals that may impact the farm environment by increasing biodiversity and the population of beneficial insects, as well as improving water quality on and off farm. • Increased research capacity in PNG and Australia. • Improved food security and human health in PNG. • Increased biosecurity capability in Australia. • Increased regional income due to increased grower returns in PNG and Australia.

Table 12: Logical Framework for VG13004

VG13004: Innovating new virus diagnostics and planting bed management in the Australian sweetpotato industry	
Project details	Research Organisation: Department of Agriculture and Fisheries Period: February 2014 to March 2018 Principal Investigator: Sandra Dennien
Rationale	Viruses in planting material are the major factor limiting sweetpotato yield and the production of easy peeling varieties. A major RD&E outcome since the 1990s has been the development and use of the PT scheme for supplying virus free planting material. PT has been so successful in eliminating viruses from planting material that it has been adopted by 100% of Australian growers. However, viruses constantly evolve and there is a risk that the current PT system will break down. The risk of breakdown is exacerbated by the presence in Australia of additional virus vectors e.g. whitefly and the risk of transmission of new viruses through fresh sweetpotato imports. Some 22 known sweetpotato viruses are not present in Australia and are capable of being imported through supply of product from countries with sweetpotato export capacity. Consequently, there is a need to know the virus status of other countries and for Australia to have the ability to diagnose viruses rapidly and accurately. In addition, to produce PT planting material, PT roots are planted into designated planting beds to produce high quality cuttings, which are grown out, cut by hand and transferred to the commercial sector. Efficiency in this process ensures planting stock is available, is virus free and produced at the lowest cost. It is essential that best practice techniques for planting bed management are known and adopted.
Objectives	1. Improve virus diagnostic techniques and maintain the integrity of the PT system. 2. Ensure that best practice planting bed management systems are in place to produce ample high quality low cost planting material.
Activities and Outputs	• Survey literature to identify world virus status, new diagnostic techniques. • Work with growers to determine which viruses are impacting production. • Research relationships between growing bed management and sweetpotato productivity. • Develop, evaluate and implement new virus diagnostic techniques (e.g. ELISA antisera, alternative Ipomoea indicator plants). • Investigate the causes of planting bed losses and develop strategies to minimise the risk of these events (e.g. anaerobic conditions, fungus). • Complete agronomic experiments to determine variables responsible for planting bed performance (e.g. depth and arrangement of PT roots). • Describe the practices that impact on the ability of the planting bed to generate physiologically hardened, yet rapid-growth capable sweetpotato cuttings, which can in turn provide high numbers of marketable sweetpotato roots per cutting. • Describe how to determine the balance between sequential cutting of existing planting beds, and when to switch to a new planting bed. • Outline the desirable equipment and land resource attributes that can best deliver optimal planting bed conditions e.g. row covers, irrigation, soil condition, nutrition status and PT root planting arrangements. • Outputs to date have included virus surveys, virus diagnostic tools, factsheets and web page information. • Extension has included on-farm field walks and workshops, regular updates in the ASPG newsletter and Good Fruit and Vegetable articles.

Outcomes	• Latest virus detection methods are incorporated in industry PT scheme. • Planting material remains virus free. • Growers maintain yields without resorting to excessive chemical use. • Sweetpotatoes produced sustainably in line with consumer expectations. • Future productivity improved by the ability to import varieties without jeopardising production base with viruses. • Productivity of planting beds has been increased (minimum 30% increase forecast in cuttings generated per square metre of growing bed and the cost of generating high yielding pathogen tested cuttings is 30% lower). • Improved sweetpotato cutting practices have contributed to lower pre-farm gate production costs, lower input requirements (chemicals) and reduced environmental risks.
Impacts	• Increased preparedness for new viruses from overseas. • Increased average yield (future/new virus control). • Increased profitability (lower cost planting material). • Increased research capacity in Australia (virus diagnostics). • Increased regional income in Australia (spillover).

4. Project Investment

Nominal Investment

The following tables show the annual investment by project for both DAF (Table 13) and for funding organisations such as HRDC/HAL/HIA, ACIAR and other investors (Table 14) in the cluster of DAF sweetpotato projects. Table 15 provides the total investment by year and from both sources.

Table 13: Investment by DAF in the Sweetpotato R&D Cluster for Years Ending June 1998 to June 2018 (nominal $)

Year	VG97023	VG01010	VG02114	VG05037	CP2004-071	CP2005-134	08-14329	VG09009	VG09052	PC2011-053	VG13004
1998	114,413	0	0	0	0	0	0	0	0	0	0
1999	114,413	0	0	0	0	0	0	0	0	0	0
2000	114,413	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0
2002	0	165,617	0	0	0	0	0	0	0	0	0
2003	0	170,585	64,139	0	0	0	0	0	0	0	0
2004	0	175,701	69,071	0	0	0	0	0	0	0	0
2005	0	180,974	85,056	0	0	0	0	0	0	0	0
2006	0	0	43,804	174,718	64,730	0	0	0	0	0	0
2007	0	0	0	233,423	243,786	12,125	0	0	0	0	0
2008	0	0	0	248,333	253,708	7,043	0	0	0	0	0
2009	0	0	0	126,892	262,642	3,521	10,423	0	0	0	0
2010	0	0	0	126,892	125,409	6,350	2,197	0	0	0	0
2011	0	0	0	0	0	0	0	121,080	537,079	0	0
2012	0	0	0	0	0	0	0	107,791	459,782	0	0
2013	0	0	0	0	0	0	0	112,103	27,767	77,032	0
2014	0	0	0	0	0	0	0	0	27,767	77,032	62,427
2015	0	0	0	0	0	0	0	0	0	8,977	210,949
2016	0	0	0	0	0	0	0	0	0	0	213,252
2017	0	0	0	0	0	0	0	0	0	0	228,631
2018	0	0	0	0	0	0	0	0	0	0	142,274
Total	343,239	692,877	262,070	910,258	950,275	29,039	12,620	340,974	1,052,395	163,041	857,533

Source: DAF Proposals and final budget spreadsheets

Table 14: Investment by Researchers and Others in the Sweetpotato R&D Cluster for Years Ending June 1998 to June 2018 (nominal $)

Year	VG97023	VG01010	VG02114	VG05037	CP2004-071	CP2005-134	08-14329	VG09009	VG09052	PC2011-053	VG13004
1998	34,175	0	0	0	0	0	0	0	0	0	0
1999	31,108	0	0	0	0	0	0	0	0	0	0
2000	33,898	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0
2002	0	128,357	0	0	0	0	0	0	0	0	0
2003	0	159,236	32,895	0	0	0	0	0	0	0	0
2004	0	153,092	45,425	0	0	0	0	0	0	0	0
2005	0	134,975	45,180	0	0	0	0	0	0	0	0
2006	0	0	17,005	83,041	99,779	0	0	0	0	0	0
2007	0	0	0	125,929	295,589	359,939	0	0	0	0	0
2008	0	0	0	126,355	268,896	226,823	0	0	0	0	0
2009	0	0	0	63,373	258,439	217,922	22,818	0	0	0	0
2010	0	0	0	63,372	144,460	214,907	2,711	106,080	0	0	0
2011	0	0	0	0	0	0	0	315,892	263,683	0	0
2012	0	0	0	0	0	0	0	246,601	225,733	0	0
2013	0	0	0	0	0	0	0	205,207	13,633	327,656	0
2014	0	0	0	0	0	0	0	77,180	13,633	430,373	76,096
2015	0	0	0	0	0	0	0	0	0	85,425	261,868
2016	0	0	0	0	0	0	0	0	0	0	273,425
2017	0	0	0	0	0	0	0	0	0	0	283,753
2018	0	0	0	0	0	0	0	0	0	0	139,577
Total	99,181	575,660	140,505	462,070	1,067,164	1,019,591	25,529	950,960	516,681	843,454	1,034,719

Source: DAF Proposals and final budget spreadsheets

Table 15: Annual Investment in the Cluster (nominal $)

Year ended 30th June	DAF ($)	Other ($)	TOTAL ($)
1998	114,413	34,175	148,588
1999	114,413	31,108	145,521
2000	114,413	33,898	148,311
2001	0	0	0
2002	165,617	128,357	293,974
2003	234,724	192,131	426,855
2004	244,772	198,517	443,289
2005	266,030	180,155	446,185
2006	283,252	199,825	483,077
2007	489,334	781,457	1,270,791
2008	509,084	622,074	1,131,158
2009	403,478	562,552	966,030
2010	260,848	531,530	792,378
2011	658,159	579,575	1,237,734
2012	567,573	472,334	1,039,907
2013	216,902	546,496	763,398
2014	167,226	597,282	764,508
2015	219,926	347,293	567,219
2016	213,252	273,425	486,677
2017	228,631	283,753	512,384
2018	142,274	139,577	281,851
Totals	**5,614,321**	**6,735,514**	**12,349,835**

Program Management Costs

The DAF investment in Table 15 includes an allowance for program management, administration and corporate infrastructure costs.

For other investment, including HRDC/HAL/HIA and ACIAR contributions a management multiplier of 1.12 has been applied. The management multiplier is based on the HIA reported share of overhead costs in total expenditure (HIA 2016). This multiplier was applied to 'Other' nominal investment shown in Table 15.

Real Investment and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2016/17 $ terms using the GDP deflator index. 'Extension' costs were included in budget totals – projects were completed in Australia in partnership with ASPG and in PNG and the Solomon Islands with local farmer groups. Hence, no additional allowance has been made for extension.

5. Impacts

From the project descriptions in Section 3, the principal potential impacts for the investment in sweetpotato R&D were identified. Table 16 summarises the key potential impacts identified for Australia and the contribution to each potential impact by each of the 11 projects. Table 17 summarises impacts for PNG and the Solomon Islands.

Table 16: Contribution by Project to Principal Potential Cluster Impacts - Australia

Project Code	Increased preparedness for new viruses from overseas	Increased average yields	Increased profitability[(a)]	Increased research, extension or industry capacity	Reduced environmental impact - less broadspectrum chemical use	Increased regional income in Australia (spillover)
VG97023		√	√			√
VG01010		√	√			√
VG02114		√	√	√		√
VG05037		√	√		√	√
CP2004-071		√	√	√	√	√
CP2005-134						
08-14329		√	√			√
VG09009	√		√	√		√
VG09052		√	√	√	√	√
PC2011-053			√	√	√	√
VG13004	√	√	√	√		√

(a) Includes increased sweetpotato demand and production cost savings

Table 17: Contribution by Project to Principal Potential Cluster Impacts – PNG and the Solomon Islands

Project Code	Increased average yields	Increased profitability[(a)]	Increased research, extension or industry capacity	Reduced environmental impact - less broadspectrum chemical use	Improved food security	Improved human health	Increased regional income (spillover)
CP2004-071	PNG	PNG	PNG	PNG	PNG	PNG	PNG
CP2005-134	PNG & SI		PNG & SI		PNG & SI	PNG & SI	PNG & SI
PC2011-053	PNG	PNG	PNG	PNG	PNG	PNG	PNG

(a) Includes increased sweetpotato demand and production cost savings

From the logical frameworks in Section 3 and the key impacts described in Table 16 and Table 17, potential impacts of the 11 projects were then condensed and described in a triple bottom line context in Table 18.

Table 18: Triple Bottom Line Categories of Impacts from Sweetpotato Investment

Economic	• Increased average yields through PT planting material, seedbed technology, insect control, agronomy and selection of more productive genetic material. • Increased profitability through increased prices received for sweetpotatoes that better meet consumer requirements as well as input cost savings - planting material, chemicals and fertiliser.
Environmental	• Fewer chemicals in the farm and district environment with positive impacts on biodiversity and water quality.
Social	• Increased research capacity including virus testing and biological control strategies for weevils (Australia and PNG), crop sampling (PNG), new agronomic experimental techniques (Australia), and virus diagnostic methods (Australia). • Increased extension capacity including new skills and techniques for the successful uptake of new varieties and production technologies (PNG). • Increased industry capacity including understanding and implementation of sweetpotato IPM techniques (Australia). • Improved food security – sweetpotatoes are an important staple and increased yield addresses declining sweetpotato output combined with population growth (PNG and Solomon Islands). • Improved human health - new varieties established in PNG and the Solomon Islands have displaced poor quality varieties and offer improved vitamin intake, antioxidants and dietary fibre. • Increased regional incomes resulting from the increased profitability of sweetpotato production in both PNG and Australia.

Public versus Private Impacts

The majority of benefits identified in this evaluation are sweetpotato industry related and therefore are considered private benefits. Public benefits have also been delivered, including environmental benefits and social benefits.

Environmental and social impacts were reported in Tables 16, 17 and 18. A principal environmental and social benefit was decreased use of broadspectrum organophosphates which, if released to the environment, are potentially hazardous to human (social) and fauna (environmental) health. Social benefits delivered by the research included increased capacity (research, extension and industry), improved food security, nutrition and human health in PNG and the Solomon Islands as well as additional regional incomes resulting from the increased profitability of sweetpotato production in PNG and regional income spillovers to Australian producing areas.

Distribution of Private Impacts

The benefits to the sweetpotato industry from investment in this project will be shared along the supply chain with growers, packers, transporters, wholesalers and retailers all sharing impacts produced by the project. These impacts are relevant to sweetpotato industries in Australia, PNG and the Solomon Islands.

Impacts on other Australian Industries

Impacts on industries other than the sweetpotato industry and its associated sectors may include potential gains to other industries via any future spillovers from the increases in research and extension capacity.

Impacts Overseas

The primary impacts overseas will arise from the three projects that target yield gain in sweetpotato production in PNG and the Solomon Islands. Potential impacts include improved food security, human health, research and extension capacity and regional income.

Match with National and State Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 19. Investment in sweetpotato PT planting material, seedbed technology, insect control, agronomy and more productive genetic material contributes to Rural RD&E Priorities 1, 2, 3 and 4 and to Science and Research Priority 1.

Table *19*: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities (est. 2015)	**Science and Research Priorities (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

Sources: DAWR (2015) and OCS (2016)

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 20. Sweetpotato investments addressed Science and Research Priorities 1 and 3. In terms of the guides to investment, the projects will have a real future impact through additional profitable sales of sweetpotato, was supported and funded by others external to Queensland, had a distinctive angle with the targeting of the only increasing fresh vegetable sector in Australia and is scaling towards critical production mass on a year-round basis.

Table 20: 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

Investment analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved. Sensitivity analyses were undertaken for those variables where there was greatest uncertainty or for those that were identified as key drivers of the investment criteria.

Impacts Valued

Valuation focusses on impacts on the Australian sweetpotato industry as well as on the general Australian community. This is consistent with CBA processes used by the CRRDC whereby costs and benefits refer to those usually incurred or captured within Australian borders. A separate evaluation of project impacts on PNG and the Solomon Islands was completed in June 2017 and was commissioned by ACIAR (Dr Andrew Alford, Research Program Manager – Impact Assessment, ACIAR, personal communication, March 2017).

Three sets of impacts were valued in this assessment:

- Increased average yield - through PT planting material, seedbed technology, insect control, agronomy and selection of more productive genetic material.
- Increased profitability through higher prices achieved for better quality sweetpotatoes along with input cost savings including planting material, chemicals and fertiliser.
- Increased area of sweetpotato grown due to the increased profitability of the crop.

Impacts Not Valued

Not all impacts identified in Table 17 could be valued in the assessment. This was for various reasons including time and resources, availability of baseline data, difficulty in quantifying the causal relationships between the research outputs and the specific impact, and the difficulty of placing credible monetary values on some of the environmental and social benefits.

The environmental impacts identified but not valued included:

- Increased biodiversity and improved water quality from the increased and more effective use of IPM that has reduced the quantity of agro-chemicals used.

The social impacts identified but not valued included:

- Increased research capacity including virus testing, identification of biological controls, crop sampling and experiment design.
- Increased industry capacity including understanding and implementation of sweetpotato IPM techniques.
- Increased regional incomes resulting from the increased profitability of sweetpotato production.

Valuation of Benefit 1: Increased Average Yields

Investments in this cluster span the period 1998 to 2018. At the commencement of DAF investment in year ending June 1998, the Australian sweetpotato industry had an annual GVP of $4.5 million. Beauregard planting material was virus affected and usually sourced on-farm. Sweetpotatoes were not widely consumed and some regarded the product as only suitable for pig food. Average industry yield was 1,600 cartons/ha (650 cartons/ acre) (Eric Coleman, ASPG, pers. comm., June 2017).

The industry had an annual GVP that had risen from $4.5 million in 1998 to $100 million in 2016. Virus free planting material, pest control and selection of more productive lines of gold varieties has resulted in an average industry yield of 6,175 cartons/ha (2,500 cartons/acre) and the product is well regarded by Australian consumers and enjoys growing domestic demand (Sandra Dennien, Experimentalist, DAF Gatton, pers. comm., April 2017).

Valuation of Benefit 2: Increased Profitability

In addition to yield increases, investment in this cluster has improved the profitability of growing sweetpotato through other mechanisms. Improved quality and an even shape with easy to peel smooth bright skins, has enhanced consumer willingness to pay for the product and the average price received by growers has increased. The profitability of growing sweetpotatoes has also benefited from research outcomes that have resulted in production cost savings including lower cost planting material and savings in chemicals and fertilisers. Overall gross margin per hectare is estimated to have increased 25% between 2007 and 2016.

Valuation of Benefit 3: Increased Area Grown

The increase in the profitability of growing sweetpotatoes has resulted in an increase in sweetpotato production area. The area of sweetpotato production has increased from an estimated 210 ha in 1998 to 900 ha in 2016. The benefit of this additional area of production is the gross margin for sweetpotatoes less the value of the next best use of the land resource. In this instance, the next best use is the district average horticultural return and was assessed at a gross margin of $2,500/ha after considering a range of DAF and NSW Department of Primary Industries (DPI) vegetable enterprise gross margins.

Counterfactual

If these projects had not been funded some progress with yield, profitability and area grown would have been made. ACIAR would have funded projects in PNG and the Solomon

Islands, where sweetpotato is an essential staple with falling yields. It is a requirement of ACIAR funding that there are also benefits for Australia. Under the counterfactual, it is assumed that 15% of the yield, profit and area increase would have occurred regardless of investment by DAF in the cluster. An alternative counterfactual is that 25% of the gain in Australian sweetpotato yield, profit and area grown would have occurred anyway.

Attribution

There was some additional research that contributed to the impacts defined including prior research and other research projects completed in PNG that were relevant but not included in the cluster. Attribution of quantified benefits to the projects being assessed has been assumed at 75%.

Summary of Assumptions

A summary of the key assumptions made for valuation of the impacts is shown in Table 21.

Table 21: Summary of Assumptions

Variable	Assumption	Source
BASE COUNTERFACTUAL: In the absence of DAF investment in sweetpotato projects, only 15% of the increase in industry yield, profitability and area grown would have been realised.		
Benefit 1: Increased Average Yields		
Average industry sweetpotato yield prior to DAF investment in projects	28.8 t/ha	1,600 cartons/ha with 18kg of sweetpotato in each carton (Michael Hughes, pers. comm., June 2017).
Average industry sweetpotato yield post DAF investment in projects	111.2 t/ha	6,175 cartons/ha with 18kg of sweetpotato in each carton (Michael Hughes, pers. comm., June 2017).
Year in which yield gain due to cluster investment commences	2001	1 year after completion of the first DAF project (VG97023) which delivered more productive lines of Beauregard to growers.
Year in which yield increase stabilises	2019	1 year after completion of the last DAF project (VG13004).
Value of additional yield	$400/tonne	Derived from the DAF sweetpotato gross margin updated 2016 (DAF 2016) and based on a farm price $756/tonne adjusted to $400/tonne after considering additional harvesting, packing and transport costs.
Benefit 2: Increased Profitability		
Profit from sweetpotato production	$2,717/ha	DAF sweetpotato gross margin updated 2016 (DAF 2016).
Increase in sweetpotato profitability due to DAF investment	25%	Consultant assumption after consideration of both sweetpotato price increases and decreased production costs.
Year in which profit improvement commences	2007	1 year after completion of the first DAF project (VG02114) which specifically addressed cost saving.

Year in which profit increase stabilises	2019	1 year after completion of the last DAF project (VG13004) which is expected to deliver lower cost planting material.
Benefit 3: Increased Area Grown		
Area of sweetpotato grown prior to DAF investment in projects in 1998	210 ha	Sweetpotato production of 6,000 tonnes with an average industry yield of 28.8t/ha (Michael Hughes pers. comm., June 2017).
Area of sweetpotato grown in 2016	900 ha	Sweetpotato production of 100,000 tonnes (Nick Macleod, written comm., March 2017) with an average industry yield of 111.2 t/ha (Sandra Dennien, pers. comm., April 2017).
Profit from sweetpotato production	$2,717/ha	DAF sweetpotato gross margin updated 2016.
Profit from 'next best' enterprise	$2,500/ha	Consultant estimate after considering DAF and NSW DPI vegetable enterprise gross margin budgets.
Increased return on the additional area of sweetpotato grown	$217/ha	$2,717/ha less $2,500/ha
Attribution for Benefit 1, 2 and 3	**75%**	Consultant estimate and based on the knowledge that there was prior research and other research projects completed in PNG that were relevant to cluster impacts but not included in the cluster.
ALTERNATIVE COUNTERFACTUAL: In the absence of DAF investment in the sweetpotato industry, 25% of the increase in yield, profitability and area grown would have been realised.		
Benefit: Increased sweetpotato yield, profitability and area grown	Same assumptions as for the Base Counterfactual.	

7. Investment Criteria

All past costs were expressed in 2016/17 dollar terms using the Implicit Price Deflator for Gross Domestic Product. As described earlier, the Hort Innovation and ACIAR components of project investment costs were multiplied by a factor of 1.12 to accommodate program management costs. The DAF investment costs already had program management costs included.

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

Investment Criteria using Base Counterfactual

Tables 22, 23 and 24 show the investment criteria estimated for different periods of benefits for the total investment, the DAF investment and the Hort Innovation's investment respectively. The project is characterised by varying R&D investment by year up to 2018 combined with early benefits that vary in magnitude in relation to investment costs for each year. The resulting annual net cash flow has multiple sign changes and hence there are multiple estimates of the internal rate of return. The internal rate of return therefore is not reported in these three tables.

The present value of benefits (PVB) attributable to DAF investment only, shown in Table 23, has been estimated by multiplying the total PVB by the DAF proportion of real investment (44%). Hort Innovation's share of benefits has been determined on the same basis (34%) and is shown in Table 24. The balance of benefits is attributable to ACIAR and other project contributors (e.g. ASPG).

Table 22: Investment Criteria for Total Investment in the Project Cluster

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	62.17	82.14	97.79	110.05	119.65	127.18	133.08
Present value of costs ($m)	15.25	15.25	15.25	15.25	15.25	15.25	15.25
Net present value ($m)	46.92	66.89	82.54	94.80	104.41	111.93	117.83
Benefit-cost ratio	4.08	5.39	6.41	7.22	7.85	8.34	8.73
Modified IRR (%)	2355.6	120.1	60.6	41.9	32.8	27.3	23.6

Table 23: Investment Criteria for DAF Investment in the Project Cluster

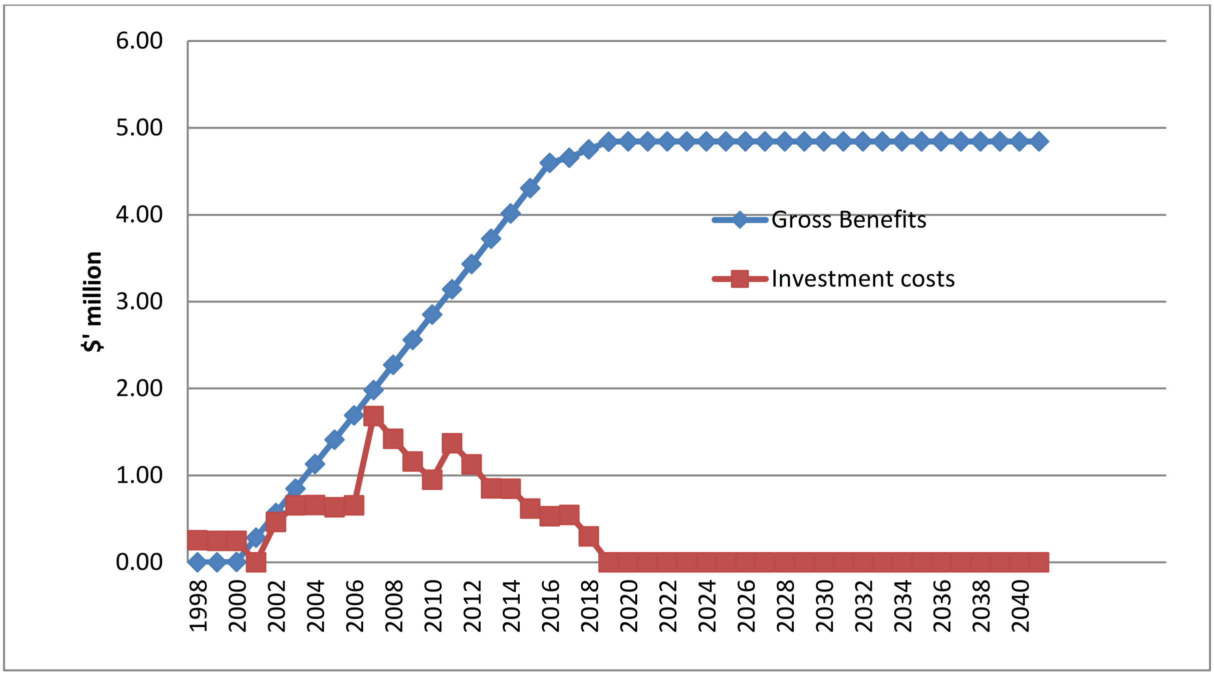
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	27.16	35.89	42.73	48.08	52.28	55.57	58.15
Present value of costs ($m)	6.67	6.67	6.67	6.67	6.67	6.67	6.67
Net present value ($m)	20.50	29.22	36.06	41.42	45.62	48.90	51.48
Benefit-cost ratio	4.07	5.38	6.41	7.21	7.84	8.34	8.72
Modified IRR (%)	2961.8	97.2	51.3	36.2	28.7	24.1	21.0

Table 24: Investment Criteria for Hort. Innovation Investment in the Project Cluster

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	21.14	27.93	33.25	37.42	40.68	43.24	45.25
Present value of costs ($m)	5.18	5.18	5.18	5.18	5.18	5.18	5.18
Net present value ($m)	15.95	22.74	28.06	32.23	35.50	38.06	40.06
Benefit-cost ratio	4.08	5.39	6.41	7.22	7.85	8.34	8.73
Modified IRR (%)	2355.6	120.1	60.6	41.9	32.8	27.3	23.6

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 1.

Figure 1: Annual Cash Flow of Undiscounted Total Benefits and Total Costs



Sources of Benefits for Base Counterfactual

Estimates of the relative contribution of each benefit valued, given the assumptions made, are shown in Table 25.

Table *25*: Contribution to Total Benefits from Each Source

Source of Benefits	**Contribution to PVB ($m)**	**Share of benefits (%)**
Increased average yields (Benefit 1)	127.55	95.8
Increased profitability (Benefit 2)	1.98	1.5
Increased area grown (Benefit 3)	3.54	2.7
Total	133.08	100.0

Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate for the base counterfactual scenario. 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 26 presents the results. The results showed a moderate sensitivity to the discount rate.

Table 26: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	**Discount rate**		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	193.57	133.08	124.34
Present value of costs ($m)	15.25	15.25	15.25
Net present value ($m)	178.32	117.83	109.09
Benefit-cost ratio	12.69	8.73	8.15

Given the importance of yield gain to assessment results (Table 25), a second sensitivity analysis was completed on this benefit – Table 27. Even at 25% attribution of base yield gain to cluster research, a positive benefit-cost ratio is achieved.

Table 27: Sensitivity to Yield Gain
(Total investment, 30 years)

Investment Criteria	Attribution of Sweetpotato Yield Gain to Research Completed in this Cluster		
	25% of base	50% of base	Base
Present value of benefits ($m)	37.41	69.30	133.08
Present value of costs ($m)	15.25	15.25	15.25
Net present value ($m)	22.17	54.05	117.83
Benefit-cost ratio	2.45	4.55	8.73

Investment Criteria using the Alternative Counterfactual

A second analysis was conducted using the alternative counterfactual as specified in Table 21. In this scenario, it was assumed that in the absence of DAF investment in the sweetpotato industry 25% of the increase in yield, profitability and area grown would have been realised. In this alternative scenario, the same assumptions as for the base counterfactual were used, except that a lower share of benefits was attributed to the cluster. Results are provided in Table 28.

Table 28 shows that the discounted benefits are lower under the alternative counterfactual. The benefit-cost ratio for the total investment dropped from 8.7 to 7.7 under the alternative counterfactual.

Table *28*: Investment Criteria for Total Investment in the Project using the Alternative Counterfactual
(Total investment, 30 years, 5% discount rate)

Investment criteria	Number of years from year of last investment						
	0	5	10	15	20	25	30
Present value of benefits ($m)	54.86	72.48	86.28	97.10	105.58	112.22	117.42
Present value of costs ($m)	15.25	15.25	15.25	15.25	15.25	15.25	15.25
Net present value ($m)	39.61	57.23	71.04	81.85	90.33	96.97	102.18
Benefit-cost ratio	3.60	4.75	5.66	6.37	6.92	7.36	7.70

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 29). 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 29: Confidence in Analysis of Project

Coverage of Benefits	Confidence in Assumptions
High	High

Coverage of benefits was assessed as high as most benefits were economic in nature and related to increased grower returns. While some impacts were not valued, their contribution was considered minor compared with those valued.

Confidence in assumptions was rated as high. Principal assumptions around yield gain, increased profitability and additional sweetpotato area grown have already been realised.

8. Conclusions

Investment in this cluster of projects has led to growth and further development of the Australian sweetpotato industry. The industry is now positioned to become the third largest vegetable industry in Queensland.

Under the base counterfactual scenario, funding for this cluster of projects totalled $15.3 million (present value terms) and produced aggregate total expected benefits of $133.1 million (present value terms). This gave a net present value of $117.8 million, a benefit-cost ratio of 8.7 to 1 and a modified internal rate of return of 23.6%.

Using the alternative counterfactual, that in the absence of DAF investment in the sweetpotato industry, 25% of the increase in yield, profitability and area grown would have been realised, the benefit-cost ratio was estimated as 7.7 to 1. Hence, it can be concluded that the performance of the investment as measured by the benefit-cost ratio was probably at least 7.7 to 1, and potentially as high as 8.7 to 1.

In addition to benefits quantified for the Australian economy, this same cluster of projects has benefited sweetpotato production in PNG and the Solomon Islands. Benefits include an increase in yield and profitability, increased research, extension and industry capacity, environmental gain, improved food security, improved human health and increased regional income. Quantification of these benefits was the subject of a separate impact assessment commissioned by ACIAR.

This assessment provided a good example of a long-term commitment to industry development by DAF that has provided strong returns for Queensland, Australia and, potentially, contributed to positive impacts on two Pacific Island countries.

References

CRRDC (2014) Impact Assessment Guidelines – Version 1, May 2014, CRRDC, Canberra http://www.ruralrdc.com.au/wp-content/uploads/2016/04/CRRDC-Impact-Assessment-Guidelines-V.1-070514.pdf

Bourke RM (2005) The Continuing Ipomoean Revolution in Papua New Guinea. in The Sweetpotato in Oceania: a reappraisal. Eds Ballard c, Brown P, Bourke RM & Harwood T. Oceania Monograph 56. University of Sydney, NSW, Australia. pp 171-179

Coleman (2002) Retail Buying Preferences Surveyed and Evaluated: A HAL Project Report VG01010 Sweetpotato Market Evaluation Report. Queensland Horticulture Institute

DAF (2016) Gross Margin for Sweetpotato – Washed https://publications.qld.gov.au/dataset/agbiz-tools-plants-vegetables/resource/cb917e46-dcd8-4510-b7ee-1ed2a8fc1a42

DAWR (2015) Rural Research and Development Priorities, Department of Agriculture and Water Resources, Canberra, ACT, accessed January 2016 at: http://www.agriculture.gov.au/ag-farm-food/innovation/priorities

HIA (2016) Horticulture Innovation Australia Annual Report 2015-16 http://horticulture.com.au/wp-content/uploads/2016/10/Hort-Innovation-Annual-Report-2015-16-Web.pdf

OCS (2016) Science and Research Priorities, Office of the Chief Scientist, Department of Industry, Innovation and Science, Canberra, accessed 02 November 16 at: http://science.gov.au/scienceGov/ScienceAndResearchPriorities/Pages/default.aspx

Office of the Chief Scientist, Queensland Government (2015) Revised Queensland Science and Research Priorities, accessed 17 February 2017 at: http://www.chiefscientist.qld.gov.au/images/documents/chiefscientist/pubs/reports-other/qld-science-n-research-priorities-2015-2016.pdf

Appendix 6: An Impact Assessment of DAF Investment in Plum Breeding 1981-2007

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Abbreviations

CBA	Cost-Benefit Analysis
CRRDC	Council of Research and Development Corporations
DAF	Department of Agriculture and Fisheries
GDP	Gross Domestic Product
IRR	Internal Rate of Return
HIAL	Horticulture Innovation Australia Limited
HRDC	Horticultural Research and Development Corporation
MIRR	Modified Internal Rate of Return
NPV	Net Present Value
PEG	Plum Evaluation Group
PVB	Present Value of Benefits
PVC	Present Value of Costs
R&D	Research and Development
RD&E	Research, Development and Extension
QG	Queen Garnet
QAAFI	Queensland Alliance for Agriculture and Food Innovation
QDPI	Queensland Department of Primary Industries
WADA	Western Australian Department of Agriculture

Executive Summary

Introduction

This report presents the results of an impact assessment of an investment the by the Queensland Department of Agriculture and Fisheries (DAF) (previously known as the Department of Primary Industries) and others in plum breeding over the years ending June 1981 to June 2007. Apart from funding by DAF, other funding was provided by the Horticulture Research and Development Corporation (HRDC) (now Horticultural Innovation Australia Limited (HIAL)), the Australian Fresh Stone Fruit Growers Association, and Agriculture Western Australia.

There was a considerable time lag between the early, formative breeding investment involving various crosses of parental material and the eventual successful commercialisation of a new plum variety, the Queen Garnet plum. Much of the breeding and assessment investment for the commercialisation was completed by June 2000 when a principal breeding project ended. There was then some additional funding up to 2007.

Methods

The investment was analysed qualitatively within a logical framework that considered project rationale, objectives, activities/outputs, outcomes, and impacts. Much of the early material used was sourced from the Final Report for Project SF 97005 (Topp et al., 2000). From 2000 to 2007 information was sourced mainly from personal communications with DAF personnel and from Nutrafruit, the company that is DAF's commercial licensee for the Queen Garnet plum. The most significant impact of the Queen Garnet plum was then valued. Benefits were calculated for a range of time frames up to 30 years from the last year of Research and Development investment (2007).

The early development of the Queen Garnet took over twenty years of investment. The total annual investment costs that were involved in its development were available from the year ended June 1981 to June 2000 and some smaller investments after that up to 2007. Past and future cash flows were expressed in 2016/17 $ terms and were discounted to the year 2016/17 using a discount rate of 5% to estimate investment criteria.

Impacts

The major impact from the plum breeding investment has emanated from the one plum variety developed by the investment. The Queen Garnet plum was commercialised in 2010. This impact assessment focuses on the commercial benefits from this plum variety. However, it is likely there will be some minor commercial benefits from other plum releases due to the investment, as well as some social benefits associated also with the commercialisation of the Queen Garnet.

Benefits will be captured by Australian and potentially overseas growers of the Queen Garnet plum, the Australian commercialising company, and the investors in the plum breeding investment including the Queensland Government. Potential royalties from overseas plantings will be a further source of benefits to Australia.

Investment Criteria

Total funding from all sources for the investment totalled $19.7 million (present value terms). The benefits from the investment were valued at $255.7 million (present value terms). This gave an estimated net present value of $236 million, and a benefit-cost ratio of approximately 13 to 1.

1. Methods

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

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, 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, a high degree of uncertainty surrounding the potential impact, or the likely low relative significance of the benefit compared to benefits that were valued. The impacts valued therefore are deemed to represent the principal benefits delivered by the investment.

2. Background and Rationale

Background

The Australian plum industry is part of the summerfruit industry that also includes nectarines, peaches and apricots. Queensland is a relatively small producer compared to other states, producing only 5% of all Australian plums in the year ended June 2015 (Table 1).

Table 1: Production of Fresh Plums by State
(Year ended June 2015)

State	**Production (tonnes)**
Victoria	11,997
Western Australia	4,692
New South Wales	4,476
South Australia	1,221
Queensland	1,197
Tasmania	66
Imported	62
Total	23,711

Source: HIAL, 2015

The 23,000 tonnes of plums produced in 2015 compares with about 19,000 tonnes produced in 1993, so national growth in production has been slow. Statistics for production, production value and the average unit price for plums over the past three years are shown in Table 2. Most production is consumed fresh in Australia with only 15% exported (Table 3).

Table *2*: Australian Fresh Plum Production and Value (2013 to 2015)

Year ended June	Production (tonnes)	Production value ($m)	Unit price all production ($/tonne)	Fresh Supply (tonnes)
2013	24,199	43.1	1,781	11,965
2014	26,749	59.5	2,224	13,019
2015	23,649	51.9	2,195	13,809
Simple Average	24,866	51.5	2,067	12,931

Source: HIAL, 2015

Table 3: Disposal of Australian Fresh Production of Plums (2013 to 2015)

Year ended June	Fresh domestic supply (tonnes)	Fresh export (tonnes)	Processing domestic (tonnes)	Total production (tonnes)
2013	11,965	3,268	8,966	24,199
2014	13,019	4,205	9,525	26,749
2015	13,809	3,586	6,316	23,711
Simple Average	12,931	3,686	8,269	24,886

Source: HIAL, 2015

Rationale for the Investment

Applethorpe in the Queensland Granite Belt near the NSW border is Queensland's major temperate deciduous fruit growing region. The aim of the early stonefruit breeding programs based at Applethorpe was to emphasise early ripening and high quality. In 1990, a change occurred to a focus on bacterial spot resistance as a major breeding priority for plums. This was because the imported plum varieties from California were often susceptible to this disease. Also, from 1994-1996 the breeding objective had been to produce plums with qualities suitable for exports to Asia.

A review of stonefruit breeding in Australia was undertaken in 1996 (Marshal et al, 1996). The review was funded by the Australian Fresh Stone Fruit Growers Association and the Horticultural Research and Development Corporation (HRDC) (now Horticultural Innovation Australia Limited (HIAL)). This review concluded that breeding for early (high chill) peaches and nectarines was unnecessary as imported germplasm was well adapted to Australian conditions. However, imported plum genetics were not well adapted to Australia. Moreover, Australia had different requirements in plums destined for export to Asia.

As a result of the review, the National Plum Breeding Program (SF 97005) was established to be carried out by the Queensland Department of Primary Industries (QDPI). The project was established to breed new Japanese cultivars that were suited to the Asian export market. These characteristics included a large plum size, a high level of firmness to ostensibly provide a longer shelf life, a bright skin colour and a sweet and juicy flesh.

During the final period of project SF 97005 (1997-2000), it was reported that exports of Australian fresh stonefruit had increased more than 170% over the five years to 1998/99, with plums contributing 56% of the export crop. However, increases in Australian plum exports had been limited by the availability of only a narrow range of varieties with characteristics favoured by Asian consumers. This reinforced the need for continuing with the stated priority for breeding to meet Asian export market requirements.

3. Description of the Plum Breeding Investment

Table 4 provides a description of the investment with an emphasis on Project SF 97005

Table 4: Description of Investment in Plum Breeding

Activities and Outputs	• In the initial period of the investment (1981 to 1996), the plum breeding program at Applethorpe was a part of the more inclusive stonefruit breeding program that included peaches, nectarines, plums and apricots. At this stage the superior high anti-oxidant plum germplasm was identified. • Project SF 97005 was funded from July 1997 up to June 2000 with Dougal Russell and Bruce Topp as Principal Investigators • The overall aim of the project was to produce new plum cultivars that were resistant to bacterial spot disease, of high quality and of a quality suited to the export market to Asia. Specific objectives included: o To carry out a core breeding and selection program for plums to benefit Australian growers. o To produce new cultivars for a range of high and low chill environments with both wet and dry summer climates to ensure superior varieties are available for most Australian growing regions. o To conduct an efficient breeding program using quantitative genetics and molecular biology and to develop linkages with overseas breeders. • In each of the three years of the project SF 97005, various plum seedlings were produced and planted out in nurseries at Applethorpe and Maroochy in Queensland and at Manjimup in Western Australia. • A total of 17,733 seedlings were planted in 1997, 1998 and 1999, with the majority planted at Applethorpe. • The above number of seedlings was very large compared with previous years; by contrast, only 25,000 seedlings had been planted in the previous 25 years from 1971 until 1996. • The spread of sites was chosen to provide a range of temperature and rainfall conditions to test the adaptation of the lines. • As seedlings usually take 3 to 4 years to begin fruiting, the seedlings that were evaluated from 1997 to 2000 were created prior to the commencement of the three- year project (SF 97005). • The seedlings were evaluated with regard both tree and fruit characteristics and their associated potential for direct commercialisation or use as parents in future breeding. • The seedling material that had fruited during the three years combined various characteristics from a range of plums such as local adaptation, bacterial spot resistance, early and late and high-quality from Californian plums, and low chill plums from the University of Florida. • An industry steering committee and Plum Evaluation Groups (PEGs) were established in each State to facilitate the evaluation process from a national perspective. • The intellectual property for all trees was protected under QDPI's non-propagation agreement.

	• The Granite Belt PEGs met frequently during the three-year project and rated prospective selections on attractiveness, eating quality, fruit size, tree health, tree habit and overall commercial potential. • Consumer assessments were provided on those plum selections considered as having commercial potential by the Granite Belt PEGs; consumer assessment was obtained on attractiveness, eating quality and comparisons made with existing cultivars. • Seven superior plum selections were identified by the PEGs as having commercial potential and were evaluated for bacterial spot resistance and cross compatibility. • In the last year of the project some of the seedlings evaluated exhibited Asian export quality requirements of high fruit sugar, a dark red-purple skin colour, clear firm yellow flesh, and low acid in both skin and flesh. • The most promising plum selections identified on the Granite Belt were close to being named at the end of the project in the year 2000. However, information on their performance at other locations was still required before release was recommended, and this was not completed until after the project ended in June 2000. Some combinations of parents produced more outstanding progeny than others, and this allowed the researchers to produce seedlings with large fruit size, high fruit sugar levels, and other desirable characteristics. • The final seedling populations fruited from 2000 to 2005 and then these were propagated for testing across various locations and seasons. • Final hybridisations were in September 2005 and final progeny planting in winter 2006. These were assessed for anti-oxidant properties (Dougal Russell, pers. comm., May 2017). • The Queen Garnet (QG) originated from a cross made in 1997. From the original seedlings, trees were propagated in 2001 and planted for second stage testing. Subsequent grower evaluations and trial plantings at Applethorpe Research Station proved the trees produced fruit that were true to type. • Between 2000 and 2010 funding was via grower group participation as well as via contributions from DAF, HRDC, and others (e.g. in anti-oxidant testing).
Outcomes	• Apart from the QG plum, a few other selections of stonefruit were named and released including the Granite Supreme Peach in the early 1980s; Queensland Earlisweet (plum)in the early 1980's; Queensland Bellerosa (plum) in the 1990's; and Rubycot plumcot in 2006 (Dougal Russell, pers. comm., May 2017). • DAF entered into an exclusive worldwide commercialisation license with Nutrafruit to exploit the QG plum in 2010. Nutrafruit sublicenses nurseries to produce the trees and sub-licenses orchardists for a fee to grow the fruit. • There was an additional Expression of Interest released by DAF in April 2010 for 16 superior stonefruit lines which included Rubycot. The Rubycot commercialisation was awarded to Nutrafruit. Little activity has occurred with these lines since then, except for Rubycot now starting to be grown (Jodie Campbell, pers. comm., July 2017). • The QG plum has been the most successful commercialised plum that had its origin in the DAF plum breeding program.

	• Various sized Australian plantings of the QG under licence have been made across a number of Australian states. • The plum is being trialled in a range of overseas countries. • Claims of human health benefits that can be attributed to the QG plum are being researched.
Impacts	• Net gain in profitability of Australian plum growing through a higher price for the QG plum compared to other plum types. • Potential income to Australia from trees licensed to be grown overseas. • Increased investment in horticultural R&D from Queensland Government licensing income from QG. • Enhanced capacity in plum breeding research. • Potential for health benefits to consumers due to the high levels of anti-oxidants and anthocyanins in the QG. • Increased community well-being through the spillover effects of increased stonefruit farm profitability.

4. Project Investment

Nominal Investment

Table 5 shows the annual investment for the project funded by DAF (and its antecedents), HRDC (now HIAL), and the Western Australian Department of Agriculture (WADA), now known as the Western Australian Department of Agriculture and Food. The project funded was SF 97005 (1998-2000). However, while this project undertook the crossing that led to the QG plum variety being identified and commercialised, there had been earlier crossing and evaluations carried out. These earlier investments in plum breeding did lead to several other varieties being released but none of these varieties have been commercially successful. For the purposes of the impact assessment, the total investment since 1981 up the end of Project SF 97005 in 2000, together with the additional investment costs from 2001 to 2007 by DAF and others, have been compared to the expected benefits from the QG plum.

Table 5: Annual Investment in Plum Breeding by Year
(nominal $ with overheads included)

Year ended 30th June	DAF ($)	WADA and other(a) ($)	HRDC/HIAL ($)	TOTAL ($)
1981	37,112	0	0	37,112
1982	44,109	0	0	44,109
1983	48,773	0	0	48,773
1984	52,965	0	0	52,965
1985	62,124	0	0	62,124
1986	67,220	0	0	67,220
1987	70,135	0	0	70,135
1988	72,771	0	0	72,771
1989	76,760	0	0	76,760
1990	80,444	0	0	80,444
1991	88,803	0	0	88,803
1992	145,920	0	21,893	167,813
1993	145,920	0	19,367	165,287
1994	145,920	0	27,437	173,357
1995	145,920	91,000	46,929	283,849

1996	145,920	91,000	46,357	283,277
1997	145,920	91,000	46,357	283,277
1998	200,448	58,500	44,908	303,856
1999	200,448	0	44,908	245,356
2000	200,448	0	44,908	245,356
2001	48,640	5,000	0	53,640
2002	48,640	5,000	0	53,640
2003	89,600	21,000	0	110,600
2004	92,160	22,000	0	114,600
2005	92,160	5,000	0	97,160
2006	46,080	0	0	46,080
2007	48,640	0	0	48,640
Total	2,644,001	389,500	343,063	3,376,565

Source: DAF, 2017; Dougal Russell and Rod Edmonds, pers. comm., May 2017
(a) 'Other' includes contributions from Royal Sat Company, Spain.

Program Management Costs

For the DAF investment, the management and overhead costs for the investment are already built into the nominal $ amounts appearing in Table 5.

For HRDC investment the cost of managing their contribution also are already built into the $ nominal amounts that appear in Table 5. The Table 5 estimates were derived by applying a management cost multiplier (1.1227) to the original nominal cash expenditure. The multiplier was estimated based on the reported share of overhead costs including 'employee benefits' in total HIAL expenditure (HIAL, 2016). The assumption is made that the HRDC management multiplier in the past investment period would have been roughly equivalent to that of HIAL today.

Real Investment and Extension Costs

The investment costs in Table 5 are in nominal $ terms. For the purposes of the investment analysis, the investment costs of all parties were expressed in 2016/17 $ terms using the Implicit Gross Domestic Product (GDP) deflator index. No additional costs of extension were included as the QG plum has been commercialised and any further extension or promotional costs would be incurred by and recouped by Nutrafruit.

5. Impacts

The principal impact of the research and development (R&D) investment in plum breeding has been from the commercialisation of the QG plum in the year 2010. The plum is already being grown in various locations in Australia and potential contracts are being developed for it to be grown overseas in a range of locations. The plum is commanding a premium price in the Australian fresh stonefruit market and added value products are being developed. The higher prices to growers are only marginally offset by the licensing costs per tree paid by growers. In addition to the increase in profitability of growing this plum in Australia, there is likely to be benefits to Australia for royalties paid by growers outside Australia to Nutrafruit with a royalty passed on to the Queensland Government

The existing and potential impacts have been identified in a triple bottom line context. Table 6 provides a summary of the principal types of impacts associated with economic, environmental and social impact categories.

Table 6: Triple Bottom Line Categories of Principal Impacts from the Development of the Queen Garnet Plum

Economic	• Increased profitability for Australian growers of the QG plum when sold fresh in domestic and potentially export markets, or when transformed into added value products; such added value products can provide a market for plums not suitable for the fresh market, so reducing wastage compared with other stonefruit. • Potential licensing income for the Queensland Government and Nutrafruit from overseas plantings of QG.
Environmental	• Nil
Social	• Licensing income to Queensland Government leading to benefits from increased investment in horticultural R&D; this is because Queensland Government royalties are reinvested into horticulture R&D, often leveraging other external funding resources. • Enhanced capacity in plum breeding research. • Increased community well-being through the spillover effects of increased stonefruit farm profitability. • Potential health benefits to consumers from the high anti-oxidant and anthocyanin properties of the QG plum.

Public versus Private Impacts

The principal impacts generated from the plum breeding investment are associated with the commercialisation of the QG plum. The impacts accrue predominantly to the private sector. Some private sector to public sector transfers are being delivered via royalty payments to the Queensland Government. Some public benefits also are expected in the form of increased income spillovers to Australian regional communities where the new plum is being grown. Also, there could be potential health benefits to Australians and others from consumption of the plum.

Distribution of Private Impacts

The private beneficiaries of the development of the QG plum will be Australian and overseas growers of the plum and Nutrafruit (the Australian commercialising company). The distribution of these private benefits will be influenced by the commercial licensing agreements between the commercialising company and growers in Australia and elsewhere. Some of the Australian grower benefits will be distributed along the supply chain to distributors, potential exporters and Australian and overseas consumers.

Impacts on other Australian Industries

It is assumed that project impacts will be confined to both existing and new growers in the Australian stonefruit industry. The manufacturing of added value products has already commenced.

Impacts Overseas

Potential benefits will accrue to overseas licensees of the QG plum due to its higher price and potential/perceived health benefits.

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 7. The improved plum industry performance contributes primarily to Rural RD&E Priority 1 and 4 (via the successful commercialisation policy) and to Science and Research Priority 1 and, to a lesser degree at this stage, Research Priorities 6 and 8.

Table 7: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities (est. 2015)	**Science and Research Priorities (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

Sources: DAWR (2015) and OCS (2016)

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 8. The plum breeding investments addressed Science and Research Priority 1 and potentially 7. In terms of the guides to investment, the project is likely to have a real future impact in Australia and overseas through the availability of the superior plum. The investment was supported and funded by others external to Queensland and had a distinctive angle as the Queensland Government will be a significant recipient of the impacts via royalty payments.

Table 8: 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. Investment in planting QG plums has provided, and will continue to provide in future, increased profit to both existing and new plum growers through the higher price attained. This is despite slightly higher costs than for other plums due to the royalty paid to the rights holder for the planting of QG plums. The licensing regime applies to all tree plantings in Australia and overseas. Royalties paid by Australian interests are $2 per tree on ordering and $2 per tree per annum on bearing trees thereafter.

This royalty payment provides income to Nutrafruit (an Australian company) but it is a cost to the grower and therefore can be considered a transfer payment. Hence, royalties on Australian production of QG plums influence the distribution of benefits within Australia, but not total benefits, and therefore are not valued as a separate benefit or cost.

A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved. Sensitivity analyses were undertaken on the discount rate, the price for GG plums and the inclusion of some overseas plantings and associated licensing income.

Impacts not Valued

Not all impacts identified in Table 6 were valued in this impact assessment. This was for various reasons including uncertainty, time and resources and the difficulty of placing credible monetary values on some impacts.

Licensing of trees to overseas growers of the plum will probably eventuate and this will provide a potential income stream to Nutrafruit. This would not be a transfer payment and such royalties can be considered an additional benefit to Australia. However, as will be described later, oversees plantings of the QG are somewhat uncertain at present and the potential royalties from overseas therefore have not been valued in the basic assessment model.

The social impacts identified but not valued included:

- The impact of the investment of additional R&D resources for horticultural R&D have not been valued due to a lack of readily available information on these investments as well as the limited time and resources available in the current economic evaluation.
- The research and industry capacities built by the investment have not been valued due to the difficulty of valuing such capacity.
- The Increased community well-being through the spill-over effects of a more profitable plum industry in regional areas of Australia has not been valued due to a lack of readily available data on the distribution of the QG trees in Australia, as well as time and resource constraints.
- The potential health benefits to consumers via any specific disease amelioration and health provision activity. These prospective health benefits are still uncertain as research is currently ongoing, hence their value is not estimated. Also, the past and current demand and prices paid for the QG plum are likely to include some perceived health benefits anyway.

Total Tree Plantings

The QG plum already has been planted in the major plum growing areas of Australia (mainly Victoria and NSW). Table 9 provides the number of trees planted by year and expected to be planted up to 2018 (Nutrafruit, 2017). Two further years of planting at 25,000 trees per year were assumed by Agtrans Research for 2019 and 2020 based on current profitability of, and interest in, the QG plum. No plantings have been assumed after 2020 due to price uncertainty further into the future. However, it is likely that further QG tree plantings will occur so the current assumptions on tree numbers can be viewed as conservative.

Only trial plantings as opposed to commercial plantings have been made to date overseas and any royalty payments have yet to be received (Nutrafruit, 2017). However, as with future Australian plantings post 2020, some plantings overseas are expected but assumptions have not been made in this base evaluation. If commercial plantings are made in the future, the associated royalties would provide another source of benefits to Australia from the QG development. Some exploration of overseas royalty payments has been made in the sensitivity analysis associated with this impact assessment.

Table *9*: Number of New QG Plum Trees Planted in Australia by Year from 2010

Year	**New trees planted (a)**	**Fruit bearing trees**
Actual		
2010	14,900	0
2011	63,838	0
2012	3,646	0
2013	1,109	14,900
2014	9,000	78,738
2015	10,230	82,384
2016	123,630	83,493
2017	38,110	92,493
2018	61,000	102,723
Subtotal	325,463	
2019 estimated	25,000	226,353
2020 estimated	25,000	264,463
2021 estimated	0	325,463
2022 estimated	0	350,463
2023 estimated	0	375,463
2024 onwards	0	375,463

(a) Source: Nutrafruit (2017)

Additional Profits from Growing the Queen Garnet Plum in Australia

Additional profits will be derived from the higher prices for QG plums compared to other plum varieties. The retail price for QG plums has varied by year from about $11-$12 per kg in 2015 to $15-$16 in 2016 (Fruity Capers, Toowong, Brisbane). Nutrafruit (2017) reported retail prices of $17 to $20 per kg in 2017. Retail prices for non-QG black plums have been in the order of $4 to $8 per kg in 2017. This suggests a retail price ratio of about 3 to 1 in favour of QG plums.

Wholesale prices for the QG plum in 2017 have averaged $10.10 per kg (Nutrafruit, 2017). The average wholesale price for all plums over the period 2013 to 2015 had been $2.10 per kg. Although this suggests a higher price ratio than 3 to 1, wholesale prices for the QG plum before 2017 may have been lower. Due to the uncertainty of the future price, a wholesale price ratio of 3 to 1 has been used in the analysis.

The extent of the profitability gain will vary according to the method and rationale for establishment of the QG. Three methods are considered.

1. Existing aged plum trees are replaced by QG trees as opposed to another plum type. It is assumed that this change will result in a net gain to growers due to the higher price but low establishment costs are included as the planting cost would have been incurred anyway. The exception is the licensing fee but this is minor compared to the capital costs of establishing new trees.
2. It is understood that some plantings to date have been via topworking or grafting existing trees.
3. Other plantings have been on new areas of land and the profits from these trees will depend on the opportunity value of the land, the capital investment required for the new planting and the gross margin from growing the QG plum.

Of the new plantings of QG plums made or planned in Australia, 20% are assumed to be in the category of replacement trees for aged plum or stonefruit trees, 10% from topworking/grafting, and 70% established on new land areas. General assumptions for the valuation of benefits and specific assumptions for valuing profits for each of the three types of plantings are provided in Table 10.

Counterfactual

Without the investment in plum breeding led by DAF, the Queen Garnet plum would not have been produced. While the breeding program was targeting a type of plum with the QG colour and quality for the Asian market, the potential health benefits were not specifically targeted and could be viewed as a serendipitous outcome and of additional potential value.

Summary of Assumptions

A summary of the key assumptions made for valuation of the impacts is shown in Table 10.

Table 10: Summary of Assumptions

Variable	Assumption	Source
General Assumptions		
Year of commercialisation	2010	Nutrafruit website (2017)
Number of new tree plantings of QG plum in Australia	See Table 9	Nutrafruit and Agtrans Research
QG tree planting density	1,000 trees/ha	Based on DAF (2012) and discussions with Dougal Russell
Years to first bearing	3	
Average yield for QG plum trees	20 tonnes per ha	
Attribution of benefits to the DAF-led plum breeding investment	100% to total investment; 80% to DAF investment; 9.5% to HRDC investment; 10.5% to WADA and other investment	Agtrans Research, based on relative investment proportions in real terms
Average wholesale market price for existing plums	$2.10 per kg	See Table 2

Average wholesale market price assumed for QG plums	$6.30 per kg	Conservatively based on 3x the average historical wholesale price for plums
Cost of tree licensing (royalty)	$2 per tree on ordering and $2 per tree per annum (applied on and after the first fruit bearing year)	Nutrafruit (2017)
Benefit 1A: Increased Profitability from QG Plantings – Replacing Existing Stonefruit Trees with QG		
Proportion of new plantings replacing existing plum trees that would have been replaced anyway	20% of QG trees planted as per Table 9	Agtrans Research after discussions with Hugh Macintosh
Cost of new planting development	Negligible	The majority of the cost of new plantings would have been incurred anyway (exception is the tree licensing cost)
Benefit 1B: Increased Profitability from QG Plantings – Topworking Existing Trees with QG		
Proportion of new QG trees from topworking	10% of QG trees planted as per Table 9	Agtrans Research after discussions with Hugh Macintosh
Marginal capital cost of topworking	$15,000 per ha	Agtrans Research after discussions with Hugh Macintosh
Benefit 1C: Profitability from QG Plantings - New Areas in Australia		
Proportion of new plantings on new land	70% of QG trees planted as per Table 9	Agtrans Research after discussions with Hugh Macintosh
Opportunity cost of land	$5,000 per ha per annum	Agtrans Research, based on opportunity cost of suitable horticultural land
Capital cost of planting QG trees	$60,000 per ha	Agtrans Research, based on past stonefruit gross margin budgets and allowing for some infrastructure already present
Total variable operating costs	$55,000 per ha	Agtrans Research, based on past stonefruit gross margin budgets

7. Results

All past costs reported in Table 5 were expressed in 2016/17 dollar terms using the Implicit Price Deflator for GDP. All benefits after 2016/17 were expressed in 2016/17 dollar terms. All costs and benefits were discounted to 2016/17 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for some of the assumptions. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2006/07) to the final year of benefits assumed.

The extended period of relevant investment in breeding the QG plum (1981 to 2007), the lag period between the last year of investment and commercialisation in 2010, and the use of real dollar terms, all worked against the investment performance.

Investment Criteria

Tables 11, 12 and 13 show the investment criteria estimated for different periods of benefits for the total investment and for the DAF and HRDC investments respectively. The present value of benefits (PVB) attributable to the DAF investment only, shown in Table 12, has been estimated by multiplying the PVB for the total investment by the DAF proportion of the total investment in real terms (80.0%); a similar approach was applied to estimate the HRDC investment criteria.

Table 11: Investment Criteria for Total Investment

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	-14.53	-14.33	37.69	128.63	199.88	255.71
Present value of costs ($m)	19.71	19.71	19.71	19.71	19.71	19.71	19.71
Net present value ($m)	-19.71	-34.24	-34.03	17.98	108.92	180.17	236.00
Benefit-cost ratio	0.00	-0.74	-0.73	1.91	6.53	10.14	12.97
Internal rate of return (IRR) (%)	negative	negative	negative	7.1	10.9	12.0	12.4
Modified IRR (%)	negative	negative	negative	11.8	18.1	16.4	14.7

Table 12: Investment Criteria for DAF Investment

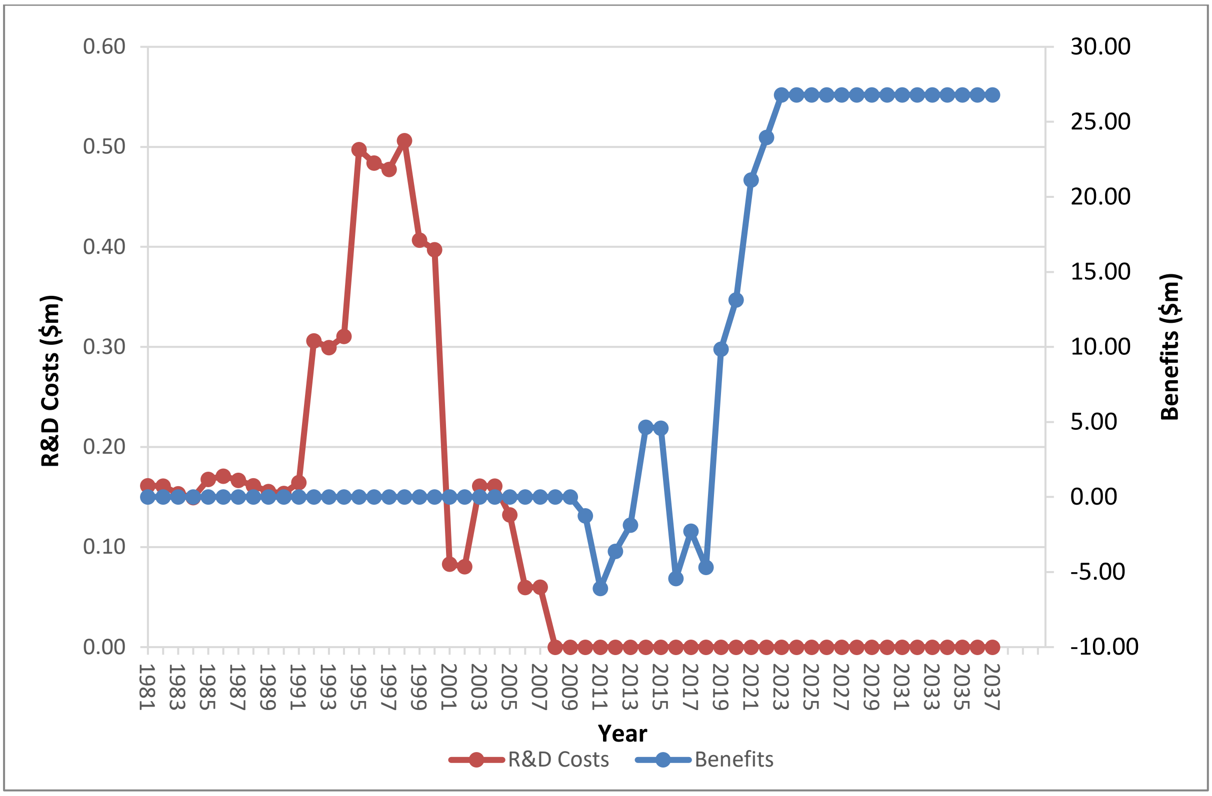
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	-11.63	-11.47	30.16	102.95	159.99	204.67
Present value of costs ($m)	16.39	16.39	16.39	16.39	16.39	16.39	16.39
Net present value ($m)	-16.39	-28.02	-27.85	13.78	86.56	143.60	188.28
Benefit-cost ratio	0.00	0.00	-0.70	1.84	6.28	9.76	12.49
Internal rate of return (%)	negative	negative	negative	6.9	10.7	11.7	12.2
Modified IRR (%)	negative	negative	negative	11.4	17.9	16.3	14.6

Table 13: Investment Criteria for HRDC Investment

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	-1.38	-1.36	3.57	12.17	18.92	24.20
Present value of costs ($m)	1.72	1.72	1.72	1.72	1.72	1.72	1.72
Net present value ($m)	-1.72	-3.09	-3.07	1.85	10.46	17.20	22.49
Benefit-cost ratio	0.00	-0.80	-0.79	2.08	7.09	11.02	14.10
Internal rate of return (%)	negative	negative	negative	7.7	12.4	13.7	14.2
Modified IRR (%)	negative	negative	negative	8.5	16.3	15.2	13.8

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 1. The negative period of benefits from 2010 to 2013 in Figure 1 is due to the cost of establishing the initial QG trees before any revenues were derived from plum bearing trees. The negative benefits from 2016 to 2018 were due to the costs of the large number of trees planted in that period compared to revenue being generated from the smaller number of trees planted earlier.

Figure 1: Annual Cash Flow of Undiscounted Total Benefits and R&D Costs



Sources of Benefits

Estimates of the relative contribution of each benefit valued, given the assumptions made, are shown in Table 14. For the Australian planting benefits, Benefit 1C (the new area of trees) provided 56% of all benefits despite making up 70% of all trees planted. Where QG plums were planted instead of other new plantings (Benefit 1A, 20% of all QG trees planted) they provided 30% of the benefits. These results were due to costs of different methods for establishing the QG plantings.

Table 14: Contribution to Total Benefits from Each Source

Source of Benefits	Contribution to PVB ($m)	Share of Benefits (%)
Benefit 1A: Replacing old trees	75.73	29.6%
Benefit 1B: Topworking existing trees	37.29	14.6%
Benefit 1C: New area of trees	142.69	55.8%
Total Benefit: A+B+C	255.71	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 15 presents the results. The results showed a very high sensitivity to the discount rate, largely due to the long lag time between the beginning of the investment and the incidence of benefits.

Table 15: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	454.28	255.71	151.43
Present value of costs ($m)	6.19	19.71	65.29
Net present value ($m)	448.09	236.00	86.13
Benefit-cost ratio	73.41	12.97	2.32

A sensitivity analysis was undertaken with assumptions associated with scenarios where some trees are licensed and planted overseas with royalties returned to Australia. This additional benefit scenario was based on 100,000 to 200,000 trees planted per annum commencing 2018 and extending to 2021.

The sensitivity of the investment criteria to a scenario that includes overseas plantings is provided in Table 16. Each 100,000 trees planted in each of these four years provided an increase in the PVB of $7.6 million in present value terms.

Table 16: Sensitivity to a Scenario that includes Overseas Plantings (post 2017)
(Total investment, 30 years, 5% discount rate)

Investment Criteria	Trees planted overseas per annum from 2018 to 2022		
	0	100,000	200,000
Present value of benefits ($m)	255.71	263.29	270.87
Present value of costs ($m)	19.71	19.71	19.71
Net present value ($m)	236.00	243.58	251.16
Benefit-cost ratio	12.97	13.36	13.74

Table 17 shows the sensitivity of the investment criteria to the assumed QG plum price. The investment criteria reported in Table 19 demonstrate the critical importance of the QG plum price. The breakeven price ratio for the investment is about 1.75 x. However, it should be noted that Benefits 1A and 1B still contribute positive benefits even at 1.75 times the average plum price. The negative net present value in Table 17 at this reduced price is driven by the higher capital costs that are incurred by the new areas of fully planted QG trees (Benefit 1C) and the associated potential losses that could have been incurred.

Table 17: Sensitivity to Australian QG Plum Price
(Total investment, 30 years, 5% discount rate)

Investment Criteria	Price Relativity to Existing Plum Varieties			
	1.75x	2x	3x (Base)	4x
Present value of benefits ($m)	19.62	66.38	255.71	445.03
Present value of costs ($m)	19.71	19.71	19.71	19.71
Net present value ($m)	-0.09	46.68	236.00	425.33
Benefit-cost ratio	1.00	3.37	12.97	22.58

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 has not been 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 18). 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 18: Confidence in Analysis of Cluster

Coverage of Benefits	Confidence in Assumptions
Medium	Medium

Coverage of benefits was assessed as Medium as the overseas licensing of trees was not included. Also, any future benefits from confirmation of health benefits, adding value opportunities and potential exports of fresh plums have not been included. Confidence in assumptions that were used in the valuation were considered medium, largely due to uncertainty regarding future prices.

8. Conclusions

The plum breeding investment can be regarded as a most rewarding R&D investment by DAF and others. The market success of the QG plum to date has demonstrated that persevering with a targeted objective over a long period of time can result in outcomes that are successful and surprising.

Funding for the investment in DAF’s plum breeding program over the period 1981 to 2007 totalled $19.7 million (present value terms) and produced aggregate total expected benefits of $255.71 million (present value terms). This gave a net present value of $236 million, a benefit-cost ratio of approximately 13 to 1, an internal rate of return of 12.4% and a modified internal rate of return of 14.7 %.

The longevity of the price premium for the QG plum is a key assumption and may erode over time due to increased planting if imbalances in demand and supply occur. However, such imbalances can be minimised due to Nutrafruit’s licensing arrangements whereby they can manage the supply side for the QG. Also, the scenario of additional Australian plantings post-2019, could increase the performance of the investment to a high extent if supply is managed to meet the perceived demand. If significant numbers of trees are planted overseas, the resulting royalty stream also could significantly increase investment performance.

The investment criteria are likely to represent a conservative estimate of the value of the plum breeding investment as the explicit potential health benefit from the consumption of the QG plum has not been included explicitly in the evaluation. Health benefits based on the development of processed products also could utilise QG plums not suitable to the fresh market, so further increasing returns to growers.

References

CRRDC (2014) Impact Assessment Guidelines – Version 1, May 2014, CRRDC, Canberra http://www.ruralrdc.com.au/wp-content/uploads/2016/04/CRRDC-Impact-Assessment-Guidelines-V.1-070514.pdf

DAF (2012) Harvesting and Yields of Stonefruit, Accessed April 2017 at https://www.daf.qld.gov.au/plants/fruit-and-vegetables/fruit-and-nuts/stonefruit/harvesting-and-yields

DAWR (2015) Rural Research and Development Priorities, Department of Agriculture and Water Resources, Canberra, ACT, accessed January 2016 at: http://www.agriculture.gov.au/ag-farm-food/innovation/priorities

HIAL (2015) 2014/15 Australian Horticulture Statistics Handbook, Sydney.

HIAL (2016) Horticulture Innovation Australia Annual Report 2015-16 http://horticulture.com.au/wp-content/uploads/2016/10/Hort-Innovation-Annual-Report-2015-16-Web.pdf

Marshall D., Greenhalgh W., and Heighway, C. (1996) Review of Fresh Stonefruit Breeding and Varietal Evaluation. HRDC Final Report SF616. Horticultural Research and Development Corporation (HRDC), Gordon, NSW, HRDC ISBN 1 86423 505 5.

Nutrafruit (2017) Queen Garnet Commercialisation: Progress Report Prepared for Department of Agriculture and Fisheries, Queensland (Commercial in Confidence).

OCS (2016) Science and Research Priorities, Office of the Chief Scientist, Department of Industry, Innovation and Science, Canberra, accessed 02 November 16 at: http://science.gov.au/scienceGov/ScienceAndResearchPriorities/Pages/default.aspx

Office of the Chief Scientist, Queensland Government (2015) Revised Queensland Science and Research Priorities, accessed 17 February 2017 at: http://www.chiefscientist.qld.gov.au/images/documents/chiefscientist/pubs/reports-other/qld-science-n-research-priorities-2015-2016.pdf

Topp B.L., Russell D.M., Banks A.G., and Stephens P.M. (2001) National Plum Breeding Program, Final Report, Project SF97005, Queensland Horticulture Institute, Applethorpe Research Station, Stanthorpe, Q 4380.