Final Report to

Cotton Research and Development Corporation

Cost Benefit Analyses of Research

Funded by the

Cotton Research and Development Corporation

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BDA Group

Economics and Environment

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FOREWORD

The Cotton Research and Development Corporation (CRDC) engaged BDA Group to undertake a triple bottom line evaluation of two of their recently completed projects that were known to have had a significant industry impact. While this evaluation forms part of a broader examination of investment projects funded by Australian Rural Research and Development Corporations, it also provides an indication of the nature and extent of gains that the CRDC has been able to achieve on the funds that they manage. Although the CRDC's primary investment focus is to enhance the international competitiveness of the Australian cotton industry, they have been able to deliver significant environmental and broader social gains to the Australian community.

This report presents the triple bottom line evaluation of CRDC's investment in managing pest resistance in transgenic cotton and the development and commercialisation of the Irrimate technology.

In undertaking this study considerable support was provided by CRDC staff, and in particular Bruce Pyke. CSIRO's Dr Rod Mahon, Jim Purcell from Aquatech Consulting Pty Ltd and Erik Schmidt and Steven Raine from the National Centre for Engineering in Agriculture also provided considerable support and background material to BDA Group. Their assistance and support is gratefully acknowledged.

David Collins
Director
BDA Group

EXECUTIVE SUMMARY

BDA Group was engaged by the Cotton Research and Development Corporation (CRDC) to complete a cost benefit analysis (CBA) of two completed investment projects. The CBA considered economic, environmental and social benefits that could be attributed to the CRDC investment and provides an objective assessment of the returns that the CRDC has been able to generate for its levy payers, the cotton industry and Australia more broadly. CBA results will also be used by the Council of Rural Research and Development Chairs to demonstrate the value of the Federal government's support of rural research and development initiatives.

Hero Project 1 – Resistance Management for Transgenic Cotton

This project involved research inputs across a number of scientific areas on a collaborative basis with other public and private organisations. Through the CRDC investment development of resistance to the transgenic varieties by major pest species has been successfully managed and the "shelf life" of transgenic cotton extended. Main benefits include:

- ***Economic*** – cost savings to cotton growers from reduced chemical sprays.
- ***Environmental*** – reduced volumes of chemicals in the environment and increased biodiversity of natural predators of pests of cotton and grains.
- ***Social*** – increased economic opportunities in regional Australia and support of scientific expertise in resistance management.

BDA Group estimated that the CRDC investment has delivered a return of $201 for every dollar of levy payers funds invested or $87 for every dollar invested across the entire supply chain. The return on matching funds provided by the Federal government was estimated at $488 for every dollar invested.

DISTRIBUTION OF RETURNS FROM CRDC INVESTMENT ACROSS DIFFERENT SECTORS

	Net Present Value	*Benefit Cost Ratio*	*Internal Rate of Return*
Levy Payers →	$284m	201	15%
Industry →	$587m	87	14%
Australia →	$692m	488	14%

Hero Project 2 – Irrimate Suite of tools and techniques for Management of Water Resources On-Farm

This project provided a foundation upon which water savings have subsequently been realised. CRDC supported the successful development and ultimate commercialisation of the Irrimate™ technology which has enabled cotton growers to more effectively "measure and manage" their water resources. Main benefits include:

- ***Economic*** – variable and capital cost savings from reduced water applications on cotton crops.
- ***Environmental*** – reduced deep drainage in cotton growing areas.
- ***Social*** – increased economic opportunities in regional Australia, support of scientific and extension expertise in water management on farms and support of small and medium sized businesses that provide services direct to primary producers.

BDA Group estimated that the CRDC investment has delivered a return of $131 for every dollar of levy payers funds invested or $22 for every dollar invested across the entire supply chain. The return on matching funds provided by the Federal government was estimated at $184 for every dollar invested.

DISTRIBUTION OF RETURNS FROM CRDC INVESTMENT ACROSS DIFFERENT SECTORS

	Net Present Value	*Benefit Cost Ratio*
Levy Payers →	$36m	131
Industry →	$34m	22
Australia →	$50m	184

Overall Value of the CRDC

When compared to CRDC's total investment portfolio, the two hero projects examined in this study provide an indication of the *minimum average return* on funds invested across all projects and activities supported by the CRDC. It was estimated that the pay off from CRDC investment over four years of operation was considerable, both on levy payer funds and matching funds provided by the Federal government.

- ***Levy Payers*** – an estimated return of $13 for every dollar invested.
- ***Industry as a whole*** – an estimated return of $12 for every dollar invested.
- ***Australia*** – an estimated return of $30 for every dollar of matching funds provided.

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1 INTRODUCTION

The Council of Rural Research and Development Corporation Chairs (CRRDCC) is developing a framework for the evaluation of research and development investments across Australian based research and development corporations. This will enable individual research and development corporations to develop improved in-house evaluation systems as well as enabling evaluation results to be aggregated across all these corporations. The evaluation framework is based on cost benefit analysis (CBA) methods with standardised time frames, discount rates and treatment of investment risk.

As part of the development of the CRRDCC evaluation framework, each corporation was asked to undertake a CBA of selected "hero" projects from within their investment portfolio. The "hero" projects selected by each corporation represent completed investment projects that have delivered significant gains to industry and the Australian community more broadly. Individually, the CBA results presented in this report will demonstrate the triple bottom line returns that have been achieved by the Cotton Research and Development Corporation (CRDC) on their R&D investments. When compared to the total investment portfolio the combined CBA's reflect the minimum return that has been achieved by the CRDC on all dollars invested. Once each corporation has completed their CBA's of individual "hero" projects the CRRDCC will manage the aggregation of evaluation outcomes to report overall investment returns from Australian research and development corporations more broadly.

In response to the CRRDCC request the CDRC selected two "hero" projects and engaged BDA Group to complete a CBA for each. The two projects selected were:

(1) Support provided for the successful deployment of Bt transgenic cotton.

This project involved research inputs across a number of scientific areas on a collaborative basis with other public and private organisations. Through the CRDC investment development of resistance to the transgenic varieties by major pest species has been successfully managed.

(2) Development of tools and techniques for more accurately measuring water use efficiency.

This project provided a foundation upon which water savings have subsequently been realised. CRDC supported the successful development and ultimate commercialisation of the Irrimate™ technology which has enabled cotton growers to more effectively "measure and manage" their water resources.

This report is divided into three main sections. The first two sections provide details of the individual CBA completed for each selected "hero" project. For each project the industry outcome is discussed as well as the counterfactual, or what would have otherwise occurred in the absence of CRDC funding. Triple bottom line benefits are derived and financial sustainability measures calculated. The final section of the report presents financial sustainability measures across the entire CRDC investment portfolio.

HERO PROJECT 1 – RESISTANCE MANAGEMENT

Transgenic (Bt) cotton was first planted on a commercial basis in Australia in 1996. The first Bt cotton technology introduced was a single gene product by Monsanto Australia Ltd called Ingard® that expressed the insecticidal toxin Cry1Ac. This product was replaced by a two gene product in 2004, also produced by Monsanto Australia Ltd, and called Bollgard® II that expressed the two insecticidal toxins Cry1Ac and Cry2Ab. These transgenic cotton varieties provide protection against insect pests of cotton in Australia, particularly the Heliothis grub (*H. armigera and H. punctigera*) as each gene enables the cotton plant to produce a different toxin that kills grubs when plant tissue is digested. There has been a strong demand by industry for these varieties as they provide economic, environmental and social benefits to growers and can be easily integrated into overall pest management strategies on-farm[1].

Supporting the introduction of Bt cotton in Australia has been a considerable investment by CRDC and others, particularly CSIRO Entomology and NSW Agriculture (now NSW DPI), in managing the potential development of resistance to the transgenic varieties by the major pest species. This investment largely commenced in 1994 when pre-release research was undertaken by CSIRO on some key ecological aspects of *Helicoverpa* populations in relation to the successful management of Ingard® cotton, including the deployment of refuge crops for resistance management and efficacy of these Bt transgenic plants on the two *Helicoverpa* species that attack cotton in Australia. For the purpose of this evaluation the investment concluded in 2004 when the two-gene product was introduced. The broad focus of the investment under CRDC's Hero Project 1 was the management of Ingard® to ensure that the efficacy of Bollgard® II could be sustained for a long period following its introduction. Had resistance to Ingard® developed before Bollgard® II was introduced, Bollgard® II would effectively have become a single gene product with limited shelf life. Roush (1998)[2] concluded that the combined (pyramiding) effect of two genes in a transgenic crop would confer large advantages in terms of the usefulness of the genes before resistance develops over sequential use of single toxins and thus would be the most effective way to manage resistance to transgenic cotton. Therefore, strategies were required that would enable the efficacy of Ingard® to be preserved until Bollgard® II was made commercially available.

By 1993 Australia had developed considerable scientific expertise in pest population ecology (in CSIRO) and resistance management (in NSW DPI and CSIRO), both for cotton and other crops. Much of the work in resistance management was based around the development of industry wide strategies (for example, chemical rotations, spraying windows and pupae busting) to limit the build up within *H. armigera* populations of insects that

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1 Pyke, B. 2007, The impact of high adoption of Bollgard® II cotton on pest management in Australia. In Proc. World Cotton Research Conference 4. Lubbock Texas. September 10-14, 2007.

2 Roush, R. T. 1998, Two-toxin strategies fro management of insecticidal transgenic crops: can pyramiding succeed where pesticide mixtures have not?, Phil. Trans. R. Soc. Lond. B 353: 1777-1786

were resistant to the major classes of available control chemicals, such as pyrethroids and endosulfan. However, these strategies were not easily transferable to transgenic cotton, because for Bt cotton crops, pest populations have continual exposure to the toxin that is produced by the plant. Consequently, with CRDC support, CSIRO and NSW DPI developed resistance management strategies for Bt cotton crops and their successful implementation has resulted in the efficacy of the one gene product being maintained.

1 CRDC Investment

The main research organisations involved in this work were CSIRO Entomology and NSW Agriculture (now NSW DPI) for chemical insecticide resistance monitoring and until 2002 for the Bt resistance monitoring when CSIRO took over this research. In addition to the leadership provided by several key researchers, the State Departments of Agriculture also provided industry extension and support for the monitoring of resistance in the field. Resistance management investment remains a key element of on-going integrated pest management in Australian cotton production.

A timeline of investment for resistance management of Bt cotton by CRDC in Australia is shown in Table 1.

Table 1: BT RESISTANCE INVESTMENT THROUGH TIME: CRDC PROJECTS

1991	1993	1996	2000	2004
	Pre-release evaluation		Monitoring and strategy refinement	
	CSE34C			
		CSE44C		
		CSE52C		
		DAN94C		
		CSE53C		
			CSE64C	
			Administration / extension (TIMS)	
			DAN118C	
			CSE73C	
			DAN152C	
				CSE102C

The key elements of the investment program included:

⇒ Pre-release evaluation of the efficacy of Ingard® and ecological studies to determine the refuge crop requirements for Australian conditions. Based on these data, a resistance management plan was developed. Investment in the development of resistance management strategies for conventional insecticides used on both Bt and non-Bt varieties was also undertaken[3].

⇒ Monitoring of resistance to Bt once Ingard® had been released commercially.

⇒ Ongoing research that has enabled an understanding of Bt resistance in the major pest (*H. armigera*) and examination of the characteristics of resistance present in field isolates and colonies of H. armigera that

[3] Early work under CSE34C looked at resistance issues more broadly (IPM with conventional varieties)

have been selected in the laboratory to be resistant to toxins. Such research underpins the resistance management plan.

⇒ On-going development and adjustment of resistance management strategies once Ingard® had been released, with the primary aim of limiting the build up of resistance to the Cry1Ac toxin so that the full benefits of Bollgard® II as a two gene product could be maintained once it was released.

⇒ Administration of industry adopted strategies for the use of Ingard®. This involved extension work and the development of an industry-approved resistance management strategy through the Transgenic and Insect Management Strategy Committee (TIMS), a special sub-committee established by the Australian Cotton growers Research Association in 1995. A number of key researchers provided strong support and leadership for the technical decisions made on resistance management and extension activities of the TIMS committee both prior to and following the release of Ingard® cotton. These included Drs Gary Fitt, Ray Akhurst, Rod Mahon and Sharon Downs (CSIRO), Drs Neil Forrester, Jonathan Holloway and Robin Gunning (NSW DPI) and Professor Rick Roush (now University of Melbourne).

2 Industry Outcome

The CRDC and partner investment can be attributed to the target outcome of managing resistance in Ingard® so that the "shelf life" of Bollgard® II could be extended. Apart from this investment there was also considerable investment in the management of resistance in conventional cotton varieties as well as the pre-release evaluation of Bollgard® II. Other benefits can be attributed to this investment and hence have not been included here.

The combination of investment by CRDC and partners (particularly CSIRO Entomology and NSW DPI) resulted in two significant industry interventions, the first was the introduction of a 30% cap on total plantings of Ingard®. This occurred in the 2000 season. Up to that date adoption had been less than 30% (due to a staged introduction of the technology regulated by the National Registration Authority), but there was increasing grower and community acceptance of Ingard® and from 2000 it was expected that adoption would be more widespread because the introduction of the double Bt gene Bollgard® II cotton was expected in 2001. However, when Monsanto decided not to release the first double Bt gene product due to possible yield drag, release of Bollgard® II was delayed by several years. Modelling of the resistance risk posed by several additional years relying on single Bt gene Ingard® raised the concern that unconstrained plantings of Ingard® could result in a rapid build up of resistance in the pest population. Consequently the 30% cap on plantings was introduced as an extra precaution. On equity grounds, the 30% cap was achieved by limiting the area planted by any single grower to 30%.

The second industry intervention was based on research conducted by CSIRO Entomology (Dr Gary Fitt and others) which led to the adoption of a refuge area equivalent to 10% of unsprayed cotton rather than a 5% area strategy that was adopted in the USA as part of their resistance management strategy for the single Bt gene product (traded as Bollgard in USA). The main reason for this departure from the USA strategy was the concern that, unlike the situation in the USA, Ingard® cotton did not provide control of larvae of Australian pest species season-long (October – March) and efficacy started to deteriorate by mid January in most areas. The reduced efficacy of the single, Cry1Ac varieties in Australia relative to the situation in the USA was due to greater levels of innate tolerance to Cry toxins by the Australian pests. Thus Australian research indicated that a larger refuge for managing resistance in *H. armigera* was needed*.* A further factor was the tendency of *H. armigera to* "over-winter" within the cropping areas which increases the potential for exposure of sequential generations of the pest to Bt and therefore for resistance to develop. The other major pest *H. punctigera* (or equivalent US cotton pests *Heliothis virescens* and *Helicoverpa zea*) do not over-winter in cropping areas and thereby have populations that are not continuously exposed to selection by the toxins because their initial populations on cotton each summer are established by immigrants that were not exposed to Bt toxins[4]

Investment into research that determined the relative efficacy of alternative refuges also resulted in non-cotton refuge crops (eg. pigeon pea) being identified that enabled a greater area of transgenic cotton to be grown, or higher profits to be earned on the refuge crop sown (eg. conventionally sprayed cotton), without compromising the role of the refuge – to provide a source of non-selected insects. The strategy adopted for refuge areas was that for every 100 ha sown to Ingard® the following crop areas had to be sown[5].

- 10 ha of unsprayed cotton, or
- 100 ha of sprayed cotton, or
- 15 ha of unsprayed sorghum, or
- 20 ha of unsprayed corn, or
- 5 ha of unsprayed pigeon pea.

Other interventions of the resistance management plan agreed to by industry was the use of pupae busting and the adoption of planting windows. The pupae busting strategy has been proven to be successful in reducing *H. armigera* populations during the most vulnerable life stage – overwintering pupae and importantly targets the population of pest species most likely to contain Bt resistant insects. This strategy would have developed anyway under the use of conventional cotton varieties. The use of a restriction on the length of the planting

4 Fitt, G.P. (2003). Deployment and impact of transgenic Bt cottons in Australia. PP. 141 - 164 In *The Economic and Environmental Impacts of Agbiotech: A Global Perspective*, Kalaitzandonakes, N.G. (Editor), Kluwer, New York.

5 Printed copies of the management plan was made available through the Australian Cotton Cooperative Research Centre.

period for Bt cotton was introduced to reduce the number of consecutive generations of the pest exposed to the Bt toxin. Neither of these practices are components of the US resistance management strategy for Bt cotton.

Mahon et al (2007[6]) reported that the current frequency of resistance to the first transgenic Bt gene is less than 3 in 10,000. As the frequency of resistance to Cry1Ac remains low, the benefit of the two gene product should be fully appreciated (Roush 1998[7]) and the efficacy of Bollgard® II is likely to be maintained for a long period with plantings up to 95% of available crop area. This is likely to be the case despite the frequency for resistance to the second transgenic Bt gene (Cry2Ab) being more common than expected (around 33 in 10,000).

These figures are examined in more detail in the following section, but based on data from the Bt monitoring program it can be concluded that resistance in the field to the first gene is rare, despite the deployment of Ingard for 7 years. The frequency of resistance to the second gene is more common (Mahon et al, 2007). The frequency of resistance to Cry2Ab is perhaps surprising and it is important to note that the resistance was present at near current frequencies prior to the use of Cry 2Ab in Bollgard® II. Therefore, the impact of the 30% planting cap for Ingard® and the on-going resistance management strategy adopted for Bollgard® II can be viewed as successful in ensuring that the efficacy of transgenic cotton varieties has been maintained to date and can be expected to continue well into the future.

3 The Counterfactual or Without Investment Scenario

While it is evident that the efficacy of transgenic cotton varieties has been maintained, the level of benefits that can be attributed to the CRDC investment will depend on what would have happened had not the CRDC become involved.

The counterfactual or "without" investment scenario can mainly be described in terms of the area that would have otherwise been sown to transgenic cotton varieties. In the "without" scenario the total area planted to transgenic cotton would have been 95% from 2000. This scenario is based on the assumption that the resistance management strategy adopted in the USA would have been followed in Australia. With the CRDC investment the area sown to Ingard® was contained to 30% up to the introduction of Bollgard® II. From that time on Bollgard® II would have been sown to 95% rather than 90% under the "with" investment scenario[8].

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6 Mahon, RJ, Olsen, KM, Downes, S and Addison, S. 2007, Frequency of alleles conferring resistance to the Bt toxins Cry1Ac and Cry2Ab in Australian populations of *H. armigera*. J. Economic Entomology (in press).

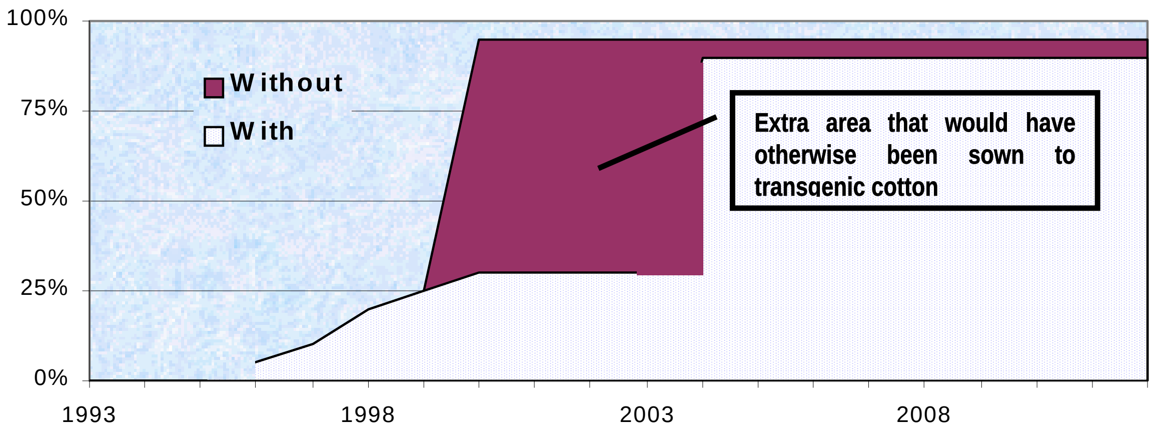
7 Roush, R. T. 1998, Two-toxin strategies fro management of insecticidal transgenic crops: can pyramiding succeed where pesticide mixtures have not?, Phil. Trans. R. Soc. Lond. B 353: 1777-1786

8 Research on refuge areas has resulted in growers being able to sow up to 95% of total area depending on the refuge crop. This is examined under triple line benefits. The relevant fact here is that a 95% area under some refuge crops was found to deliver the same

The difference in areas planted under the "with" and "without" investment scenarios is shown in Figure 1. Instead of the area being capped at 30% between 2000 and 2003 production would have increased to 95%. From the 2004 growing season production would have remained at 90% for the with scenario and increased to 95% in the without scenario. Recently, the US Environmental Protection Agency granted most cotton growing states the option of exploiting the natural refuge within the agroecosystem rather than planting a dedicated refuge crop when a Bollgard® II crop is grown. This means that growers in those states who plant Bollgard® II are able to plant 100% of the area available to grow cotton. This scenario (0% refuge) has not been modeled for the Australian situation in this analysis, but clearly it would lead to the development of resistance more rapidly than under the 5% refuge option.

Without the investment, pest populations would have, in time, developed resistance to Cyry1Ac the toxin in Ingard® and then to Cry2Ab the additional toxin in Bollgard® II. Estimating the rate at which resistance would have occurred can only be determined using population models such as those developed by Roush (1998).

Figure 1: AREA OF TRANSGENIC COTTON SOWN IN AUSTRALIA (%)



The influence of different factors on the rate of resistance development in a pest has been derived from Roush (1998). Resistance was assumed to occur when 50% of individuals in the pest population carried a resistant gene to the toxin produced by the transgenic cotton variety. The time period until resistance developed was measured in the number of (non- overlapping) generations. His main conclusions were that:

1. resistance builds up at an exponential rate through time;

2. resistance will build up faster the higher the initial frequency of resistance within the pest population;

effect on pest populations as a 90% area. Because this section is concerned with the assessment of resistance development a 90% area is used to model resistance build up.

3. increasing the size of the refuge area slows down the rate at which resistance develops; and
4. the more dominant the resistant trait is in the pest then the faster resistance will develop across the entire population.

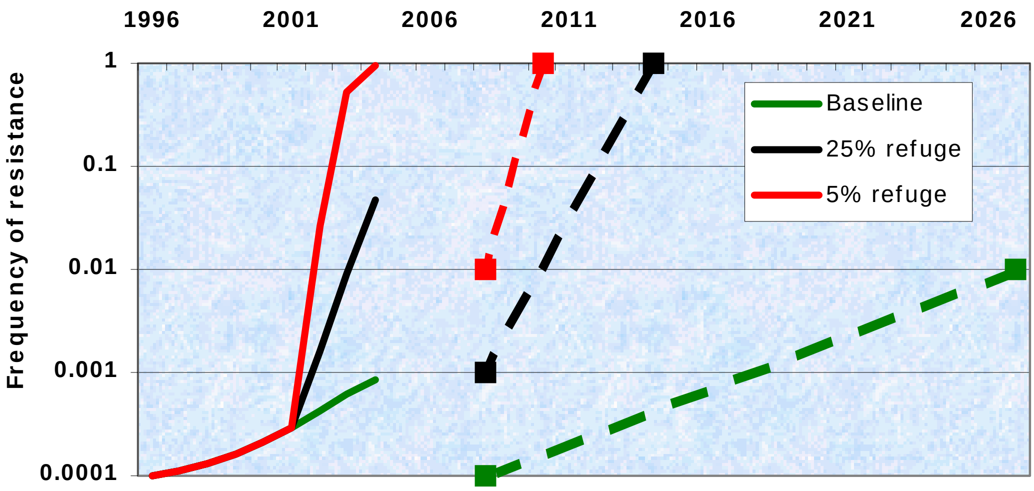
The degree of dominance of the resistant trait within a pest population was expressed by Roush (1998) as "mortality of heterozygotes". Using an initial frequency of resistance of 1 in 1,000 he concluded that a refuge area of greater than 20% would be required to delay resistance for more than 20 generations if mortality of heterozygotes was less than 90%. He also concluded that the refuge area would need to be greater than 10% to delay resistance for more than 20 generations if mortality of heterozygotes was less than 90% and the initial frequency was 1 in 100,000.

CRDC project CSE73c, with CSIRO's Dr Daly as the Principal Researcher, found that the survival of heterozygotes with resistance to Ingard® was significant and concluded that resistance showed some dominance. On these findings, together with evident capacity of *H. armigera* to develop resistance and a refuge area of only 5%, it can be concluded that resistance would have developed in less than 20 generations had not the 30% cap been imposed. As there are around 3 to 4 generations of *H. armigera* each season, it is likely that resistance to Ingard® would have developed before the 2004/05 season when it was replaced by Bollgard® II. Likewise, with the build up of resistance to Ingard® the pyramiding effect of Bollgard® II would have been lost.

To gauge some appreciation of the build up in resistance to Cry1Ac for the purpose of this evaluation, CSIRO researcher Dr Mahon provided some simulations using similar models to those developed by Roush (1998). Using a starting frequency of 1 in 10,000 for resistance to Cry1Ac, dominance based on CSIRO's Cry1Ac resistant colony selected by Dr Ray Akhurst[9] and an area planted of 95% (5% refuge area) it was estimated that the efficacy of the Cry1Ac toxin would have broken down in the 2002/03 season. Dr Mahon also ran simulations using a 25% refuge area and estimated that resistance to the Cry1Ac toxin would have been widespread by the end of the 2003/04 season. The rate of build up in resistance under these two scenarios is shown in FIGURE 2. The dashed lines depict the rate of build up of resistance to Bollgard® II. These estimates were derived from Roush (1998) by assuming different starting frequencies of resistance in 2007 as reported by Mahon et al (2007). Under the 5% refuge scenario it was assumed that no pyramiding benefit would be achieved. The baseline scenario depicts the current situation where Bollgard® II is expected to be effective for 20 years or more. Under the 5% refuge area scenario it is estimated that Bollgard® II would breakdown after 5 years. Under the 25% refuge area scenario it is estimated that Bollgard® II would breakdown after 10 years.

9 Based on Bird, L.J. & Akhurst, R.J., 2004, The relative fitness of Cry1A- resistant and susceptible *Helicoverpa armigera* (Lepidoptera: Noctuidae) on conventional and transgenic cotton, J. Econ. Entomol., 97, 1699-1709 and Bird, L.J. & Akhurst, R.J., 2005, The fitness of Cr1A-resistant and susceptible *Helicoverpa armigera* (Lepidoptera: Noctuidae) on transgenic cotton with reduced levels of Cry1Ac, J. Econ. Entomol. 98, 1311-1319

FIGURE 2: ESTIMATED BUILD UP OF RESISTANCE IN TRANSGENIC COTTON



4 Triple Bottom Line Benefits

In this section the benefits generated on CRDC's Bt resistance management investment is reported. Benefits are described as economic, environmental or social and the distribution of benefits between levy payers and the Australian community at large is identified. Benefits are estimated as the incremental gain between the "with" and "without" investment scenarios.

It should be noted that the "without" CRDC investment scenario is based on the CRDC diverting R&D expenditure to other priority areas. It is not a representation of what would happen in the absence of government matching funds. Under this situation it is likely that there would be widespread changes in the structure of industry supported R&D and such changes can not be identified from consideration of completed R&D investments alone. Nonetheless, the extent of social gains generated on government matching funds can be estimated using the "with" and "without" investment scenarios considered here. Whether or not such benefits justify government investment would require a determination of the opportunity cost of government investing in other areas outside the cotton industry specifically and the rural sector more broadly.

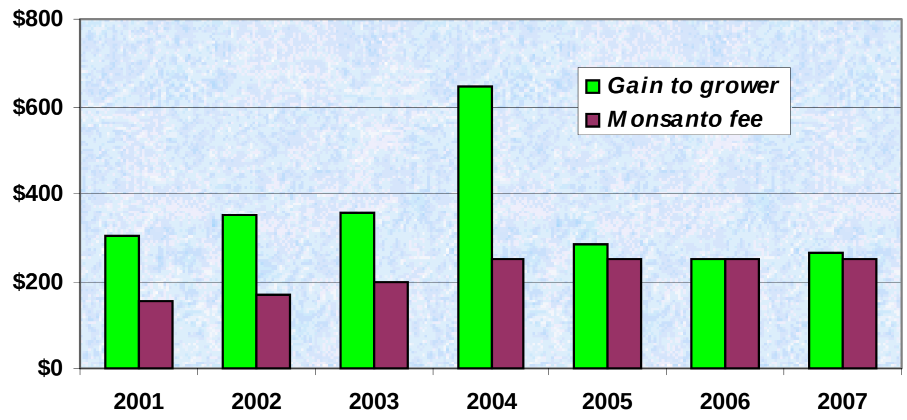
4.1 Economic

The economic benefit generated on CRDC's investment has two components. The first relates to the economic advantage to cotton growers from growing Bt cotton and the second relates to the cost saving achieved on the planted refuge area.

Because Bt cotton produces a toxin that kills susceptible pests, fewer sprays are required during the growing season. Consequently the cost of growing cotton can be reduced. The economic advantage to cotton growers is the reduction in control costs less the licence fee paid to Monsanto Australia Ltd[10]. The licence fee paid to Monsanto represents an increase in their revenue stream. The economic advantage to growers and Monsanto's licence fee is shown in FIGURE 3. Data is shown on an average per hectare basis and was sourced from surveys conducted by Cotton Consultants Australia[11]. For the 2006/07 season an average of the two preceding seasons was used.

The cost saving achieved through R&D targeted at refuge type has been examined by Longworth and Doyle[12] using gross margin analyses prepared by the NSW Department of Primary Industries. Typically, growing a refuge area results in a net loss to growers. For unsprayed cotton gross margins are around negative $1,200 per hectare. Instead of being restricted to unsprayed cotton, growers are able to reduce their loss by $550 per hectare by growing unsprayed pigeon pea. Given that the difference between the refuge areas for these two crops are set at 5% of the area of transgenic cotton grown, the cost saving per hectare would be around $27.50. However, this saving would only be realised in those years where Bollgard® II was effective in controlling pests. In those years where it is estimated that Bollgard® II would have otherwise *broken down* (due to development of resistance), the impact of the refuge would be to increase costs compared to growing conventional cotton. In these years the cost under the "with" investment scenario would be based on a loss of $650 per ha across 5 ha for every 100 ha of transgenic cotton grown ($32.50 per ha).

Figure 3: Economic Advantage of Bt Cotton over Conventional Cotton and Licence Fee: $ per ha



[10] Recent CRDC supported work by the Cotton Catchment Communities CRC has shown that some water savings might also be realised with Bollgard® II where moisture stress occurred close to cut out. While the variable costs associated with any water saving would be included in the reported economic advantage no account would be made for any capital cost saving.

[11] CRDC funds these surveys to measure the performance of transgenic cotton varieties over conventional varieties. Pyke and Doyle (2006) have reported summary data in their Cotton Conference paper *Changes in production due to Bollgard and roundup ready cotton*.

[12] Longworth R. and B. Doyle. 2006. Calculating the cost of your refuge. Hands-on-research session. 13th Australian Cotton Conference. Broadbeach Qld. August 8-10, 2006.

Estimated economic impacts under the "with" and "without" investment scenarios are reported in TABLE 2. Levy payer benefits include the economic advantage of growing Bt cotton when it would have otherwise been susceptible to resistant pest populations (and not grown) as well as the cost saving / cost on refuge areas planted. Gains to Australia include both the economic benefit to levy payers as well as the benefit to Monsanto.

TABLE 2: ESTIMATED ECONOMIC BENEFITS THROUGH TIME

Year	Area[a]	Bt Area Planted		Levy Payers			Australia		
	('000ha)	With	Without	Bt Gain	Refuge	Total	Growers[b]	Industry	Total
2001	527	30%	95%	-$104m		-$104m	**-$90m**	**-$53m**	**-$143m**
2002	409	30%	95%	-$94m		-$94m	**-$82m**	**-$45m**	**-$127m**
2003	225	30%		$24m		$24m	**$21m**	**-$29m**	**-$8m**
2004	418	30%		$81m		$81m	**$70m**	**-$68m**	**$2m**
2005	321	75%	95%	-$18m	$7m	-$12m	**-$10m**	**-$16m**	**-$26m**
2006	336	85%	95%	-$8m	$8m			**-$8m**	**-$9m**
2007	143	95%	95%		$4m	$4m	**$3m**		**$3m**
2008	190	95%	95%		$5m	$5m	**$4m**		**$4m**
2009	226	95%	95%		$6m	$6m	**$5m**		**$5m**
2010	260	95%		$66m	-$8m	$58m	**$50m**	**$62m**	**$112m**
2011	304	95%		$77m	-$9m	$68m	**$59m**	**$72m**	**$131m**
2012 +[c]	356	95%		$90m	-$11m	$79m	**$69m**	**$85m**	**$153m**

(a) Sourced from ABARE Australian Commodity Statistics and Forecasts (b) Levy payer benefits were multiped by 87% to reflect the amount of benefits captured by overseas consumers. See Appendix (c) Benefits expected to last until 20026.

4.2 Environmental

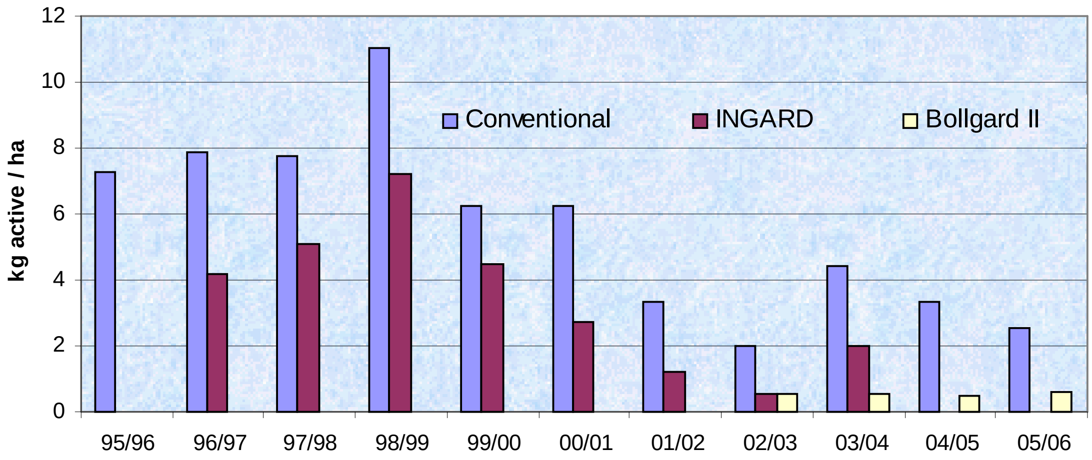
The Australian cotton industry has implemented a voluntary Best Management Practices (BMP) program to ensure that environmental impacts from cotton growing are minimised. Pesticides can enter the environment through: the application process; the soil into groundwater then into waterways; absorption onto soil particles and then movement through erosion into drains and streams; and uptake by plants and then into land and water food-webs[13]. Apart from the adoption of BMP there has also been a reduction in the application rate of active

13 Lovett, S., Price, P. & Lovett, J. 2003, Managing riparian lands in the cotton industry, CRDC.

ingredients per hectare as a result of the adoption of integrated pest management (IPM) strategies and transgenic cotton varieties.

Data on the volume of pesticides (active ingredients) moving from cotton farms to the environment is limited, and BDA Group in their 2004 evaluation for the Australian Cotton CRC estimated that around 1% of active ingredients applied found their way into the environment[14]. In 1995 the application rate for pesticides was around 7 kg of active ingredient per ha, as shown in FIGURE 4[15]. While application rates through time will vary depending on pest pressure it is clear that IPM has had a major influence on application rates for both conventional and Ingard® cotton. Pesticide use under Ingard® compared to conventional cotton is around 50% while for Bollgard® II it is around 25% of conventional cotton.

FIGURE 4: PESTICIDE APPLICATION BY DIFFERENT COTTON VARIETIES: KG ACTIVE INGREDIENT PER HA.



Lovett *et al* (2003) reported that detections of a pesticide (endosulfan) in a number of cotton growing areas had declined in 2002 to around 10% of the reported detections in 1995 and 1996[16]. If this fall is assumed to be proportional to the reduction in pesticide movement to water ways over the same period then the environmental pesticide load would be around 0.1% of 7 kg per ha or 7 grams per ha. Further, if it is assumed that the reduction in pesticide use in transgenic cotton against conventional cotton translates to a similar reduction in the volume of pesticide moving into the environment then the environmental advantage (from 2002) of Bollgard® II would be around 5.3 grams per ha sown and 3.5 grams per ha for Ingard®.

The environmental impact of pesticide run off has been quantified using the NSW Load Based Licensing (LBL) fee structure. Although cotton growing operations do not come under the LBL regime as they represent a diffuse

[14] Estimate based on a UK study using 1995 data that reported that 1% to 1.5% of all pesticides applied found their way into rivers.

[15] Pyke, B. 2007 The impact of high adoption of Bollgard II cotton on pest management in Australia, In Proc. World Cotton Research Conf. 4. Lubbock Texas. Sept. 10-14, 2007.

[16] This reduction was not a result of less area sown to cotton, Areas planted in 1996/97 was less than that planted in 2001/02.

source of pollutants and implement their own BMP strategies, the LBL can provide a minimum environmental cost estimate of pesticides. The LBL fee for pesticides is $3,255 per kg for volumes entering waterways. This estimate is similar to Kovach's[17] estimate of US$11 per pound of pesticide active ingredient applied. Using a 1% run off and converting to 2007 Australian dollars this is equivalent to $4,500 per kg entering waterways.

By prolonging the shelf life of transgenic cotton reduced pesticide run off to the environment can be achieved. The environmental benefits under the "with" and "without" CRDC investment scenarios are shown in TABLE 3.

TABLE 3: ESTIMATED ENVIRONMENTAL BENEFITS THROUGH TIME

Year	Area[a]	Bt Area Planted		Environmental Gain	
	('000ha)	With	Without	Tonnes	Value
2001	527	30%	95%	**-1.20**	**-$3.9m**
2002	409	30%	95%	**-0.93**	**-$3.0m**
2003	225	30%		**0.24**	**$0.8m**
2004	418	30%		**0.44**	**$1.4m**
2005	321	75%	95%	**-0.34**	**-$1.1m**
2006	336	85%	95%	**-0.18**	**-$0.6m**
2007	143	95%	95%		
2008	190	95%	95%		
2009	226	95%	95%		
2010	260	95%		**1.31**	**$4.3m**
2011	304	95%		**1.53**	**$5.0m**
2012 +[a]	356	95%		**1.79**	**$5.8m**

(a) Benefits expected to last until 2026 at a minimum.

It should also be recognised that the use of transgenic cotton varieties enables cotton growers to better manage chemicals applied on conventional cotton or grain crops. Growers often locate transgenic cotton crops in their most sensitive areas and hence are better able to manage potential adverse impacts (such as run-off or spray drift to neighbouring areas) from chemical use on their conventional cotton and grain crops. Consequently, there might be further environmental benefits from possible reductions in chemical discharges from farms that could be attributed to transgenic cotton, but have not been quantified in this study.

[17] Kovach, J. 2002 Putting an environmental price to pesticide use, Ohio State University website.

Another environmental benefit that can be attributed to the prolonged shelf life of transgenic cotton varieties is the increase in biodiversity that has occurred through time. This is observed through the increase in abundance of a large range of spiders, predatory or "beneficial" and benign non-pest insects as a result of less chemical sprays and the maintenance of refuge areas. Apart from the direct increase in biodiversity that has occurred, there will also be increased efficiencies in Integrated Pest Management strategies that utilise natural enemies of cotton and grain pests. The CRDC has supported research into the development of best management practices of all pests of transgenic cotton and how populations of natural enemies of cotton and non-cotton crops can be more effectively managed[18]. This work is likely to deliver on-going dividends in the future.

4.3 Social

Apart form the economic and environmental benefits of growing transgenic cotton, cotton growers have indicated that wider social benefits have also been realised. These include less time required for spraying, especially during the summer school vacation, and reduced exposure and handling of chemicals[19]. Some 3.1% of injuries on a cotton farm are associated with long term contact with chemicals or substances[20], and a reduction in the use of pesticides as a result of transgenic cotton would lead to less injuries. However, any reduction would need to be considered against the widespread uptake of pesticide BMPs and other initiatives such as Drum muster.

While no attempt is made here to quantify potential lifestyle and OH&S benefits, the impact of a more profitable cotton growing sector on regional economies is assessed. BDA Group (2004) estimated that every additional dollar in added profitability on cotton farms would lead to an increase in cotton production valued at 80 cents. This increase in production would have an impact on regional economies in terms of additional demand for goods and services and increased employment opportunities. These benefits are reported in TABLE 4.

The final area where social benefits would be realised is in the support of scientific expertise in resistance management. It was only as a result of having an internationally recognised scientific expertise and capacity in resistance management that industry management plans were able to be successfully introduced. Likewise, the support of R&D for Bt resistance will enable future challenges to be successfully addressed in cotton and other agricultural commodities. Given the long time lag for benefits to be realised, and indeed the short term cost imposed on industry from the implemented resistance management strategy, it is unlikely, without government support by the CRDC, through its partners CSIRO and NSW DPI, that Australia would have developed its current level of expertise. Indeed, the recent decision by the Grains Research & Development Cooperation to invest in the insecticide resistance monitoring work carried out by Dr Louise Rossiter (with CRDC support) recognises that most of Australia's expertise has been built up around resistance issues in the cotton industry. Furthermore, this expertise will enable non-cotton industries to better address any resistance issues that might arise in the future. This is of particular significance for the grains industry as the relative importance of selection pressure for

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18 The work of Murray, Scholz and Parker under CRDC project DAQ127C concluded that there are potential economic and environmental benefits from supporting populations of "beneficials" in transgenic cotton crops.

19 The CCA 2006 Bollgard Comparison Report

20 GHD 2003 Second Australian Cotton Industry Environmental Audit, CRDC

resistance from chemical applications to protect grain yields is now higher due to the replacement of most of the conventional cotton area planted by Bollgard II .

TABLE 4: ESTIMATED SOCIAL BENEFITS THROUGH TIME: $M

Year	Grower Benefits	Increased Production	Additional Demand	Increased Employment
2001	-$90	-$72	-$27	-$3.6
2002	-$82	-$65	-$25	-$3.2
2003	$21	$17	$6	$0.8
2004	$70	$56	$21	$2.8
2005	-$10	-$8	-$3	-$0.4
2006				
2007	$3	$3	$1	$0.1
2008	$4	$3	$1	$0.2
2009	$5	$4	$2	$0.2
2010	$50	$40	$15	$2.0
2011	$59	$47	$18	$2.3
2012 +[a]	$69	$55	$21	$2.7

(a) Benefits expected to last until 2026 at a minimum. Note: Demand and employment impacts based on ABS input / output tables for cotton production

5 Financial Sustainability Measures

As part of the support to the CRDC in undertaking the cost benefit analysis of hero projects ACIL Tasman provided a standardised excel spreadsheet for calculation of financial sustainability measures. Unfortunately the spreadsheet could not accommodate the evaluation parameters derived for CRDC's Bt resistance management investment. Consequently, a dedicated spreadsheet was built and submitted to ACIL Tasman for incorporation into their aggregated evaluations.

Financial sustainability measures derived included the net present value (NPV), benefit cost ratio (BCR) and internal rate of return (IRR) on CRDC's investment. A discount rate of 5% was used and all dollar values were converted to 2007 dollars using the consumer price index. A summary of investment cost incurred by different parties is provided in Table 5. The following sections present estimated measures by different segments of the Australian community.

Table 5: Funds Invested in Hero Project – Bt Resistance Management: $'000

Year	CRDC			Others	All Funds
	Levy	Matching	Total		
1995	$38	$38	$76	$96	$173
1996	$141	$141	$283	$405	$687
1997	$140	$140	$279	$400	$679
1998	$150	$150	$300	$432	$731
1999	$184	$184	$367	$520	$887
2000	$182	$182	$363	$514	$877
2001	$110	$110	$220	$308	$528
2002	$105	$105	$210	$294	$504
2003	$220	$220	$440	$533	$973
2004	$227	$227	$455	$552	$1,007
2005	$110	$110	$220	$0	$220

5.1 Levy Payers

Financial sustainability measures were derived first for levy payers. Relevant costs include payments made by growers via the output levy on cotton production and relevant benefits include only those gains to cotton growers. Financial sustainability measures are reported in the table below along with a breakdown by benefits realised to date and by 5, 10 and 20 years from now.

The payoff to levy payers was estimated at $284m in present value terms. The low IRR reflects the long time period over which benefits will be realised. The present value of benefits earned to date includes the cost to cotton growers of implementing the 30% cap on area sown to transgenic cotton. This cost was substantial, but justified by the future returns that are likely to be generated from having access to Bollgard® II for a longer period of time than would have otherwise been the case.

TABLE 6: FINANCIAL SUSTAINABILITY MEASURES: RETURNS TO LEVY PAYERS

Measure	To date	5 years out	10 years out	20 years out
PVB	-$82.5m	$1.2m	$146.4m	$284.3m
PVC	$1.4m	$1.4m	$1.4m	$1.4m
NPV	-$83.9m	-$0.3m	$144.9m	$282.9m
BCR	-58	1	103	201
IRR	na	1%	12%	15%

Note: PVB is the present value of benefits and PVC is the present value of costs

5.2 Supply Chain

The next segment of the Australian community for which financial sustainability measures were derived was the cotton industry and associated industries along the supply chain. Benefits include the gains to cotton growers as well as to Monsanto Australia Ltd. Investment costs include expenditure by CRDC (both levy and matching funds) and CRDC partners. Derived measures are reported in TABLE 7.

TABLE 7: FINANCIAL SUSTAINABILITY MEASURES: RETURNS TO SUPPLY CHAIN

Measure	To date	5 years out	10 years out	20 years out
PVB	-$240.9m	-$62.3m	$261.2m	$568.6m
PVC	$6.5m	$6.5m	$6.5m	$6.5m
NPV	-$247.5m	-$68.9m	$254.7m	$562.1m
BCR	-37	-10	40	87
IRR	na	na	10%	14%

Note: PVB is the present value of benefits and PVC is the present value of costs

The estimated pay off to the cotton and associated industries was substantial, at nearly $570m in present value terms. Again, there have been significant industry costs associated with restricting areas planted to transgenic cotton. It is unlikely that individual economic agents acting alone would have had the appetite to bear these costs in the short term. Through the CRDC investment an industry wide approach has been successfully adopted.

5.3 Australian Community

The final segment for which financial sustainability measures were derived was the Australian community at large. The Australian government invests across a wide range of activities to increase the "social good". That is, government investment is justified if the pay off to the Australian community exceeds the cost of the intervention (necessary condition) and the opportunity cost of investing funds elsewhere (sufficient condition). As noted earlier, the opportunity cost of government investment outside the cotton industry (and the rural sector more broadly) is unknown and would require evaluation of investment returns across many areas of government activity. This is clearly beyond the scope of the exercise here. However, an assessment of the "necessary condition" for government investment can be made by comparing the benefits generated across the wider Australian community against the intervention costs (matching funds). Financial sustainability measures are reported in TABLE 8.

TABLE 8: FINANCIAL SUSTAINABILITY MEASURES: RETURNS TO AUSTRALIA

Measure	To date	5 years out	10 years out	20 years out
PVB	-$274.3m	-$60.5m	$325.3m	$691.8m
PVC	$1.4m	$1.4m	$1.4m	$1.4m
NPV	-$275.8m	-$61.9m	$323.8m	$690.4m
BCR	-194	-43	229	488
IRR	na	na	10%	14%

Note: PVB is the present value of benefits and PVC is the present value of costs

The estimated pay off on the government investment was estimated at $690m in present value terms. Again, the low IRR reflects the significant cost imposed on the community by capping areas sown to transgenic cotton, but is justified given the extended period over which Bollgard® II is likely to remain effective in controlling cotton pests.

6 Conclusion and Sensitivity Analysis

The estimated payoff from CRDC's investment in Bt resistance management is summarised in TABLE 9 across different sectors of the Australian community. While gains to levy payers are likely to be substantial, greater gains to the industry and the wider community will be generated through increased licence revenues, lower environmental costs and greater economic activity in regional areas.

The sensitivity of investment pay off was undertaken on the main determinant of investment benefits – the refuge area chosen for Ingard® cotton which effectively caps the allowable area of production. In Section 3 the scenario of a 25% refuge area was considered. Under this scenario it was assumed that CRDC would continue to operate, and divert investment from resistance management to other priority areas. If this were the case it might be expected that the industry would accept some limitation on areas planted. Under a 25% refuge area it was estimated that Ingard® cotton would remain effective in controlling pests, but the build up of resistance would limit the effective shelf life of Bollgard® II to ten years. The net present value under this scenario for different sectors is reported in TABLE 9.

TABLE 9: ESTIMATED INVESTMENT PAY OFF UNDER DIFFERENT "WITHOUT" INVESTMENT SCENARIOS: NPV

Without Scenario	Levy Payers	Supply Chain	Australia
30% cap	$284 m	$567m	$692m
75% cap	-$44m	$242m	$251m

If a more conservative refuge area than that adopted overseas had been agreed upon in Australia without CRDC investment then the pay off to levy payers is estimated to be negative. The increased short term cost that would have otherwise been incurred would have exceeded the longer term benefits generated. However, the pay off to the industry as a whole and Australia more broadly would have still been substantial.

HERO PROJECT 2 – IRRIMATE TECHNOLOGY

The Irrimate™ technology involves a commercial agreement between the National Centre for Engineering in Agriculture (NCEA) and the firm Aquatech Consulting Pty Ltd. The technology involves the delivery of a commercial system to measure the water balance on an irrigated agricultural operation and to use this data in conjunction with developed software packages to simulate water savings from potential changes in irrigation management. These technologies are currently being used to identify water saving strategies in agriculture (both surface irrigation and storage components) and storage components in mining operations.

The CRDC became involved in the development of the Irrimate technology in 1997 when it funded an NCEA project (NEC2C) to develop best management practices for maximising whole farm irrigation efficiency in the Australian cotton industry. The NCEA is an unincorporated joint venture between the Queensland Department of Natural Resources and Water and the University of Southern Queensland.

Prior to 1997 there was a widely held view that the water use efficiency in irrigated cotton was high. Much of the irrigated agricultural production was on clay soils where deep drainage was not seen as an important issue. Further, reforms in water markets were only slowly evolving and access to low cost water supplies provided sufficient incentives for irrigators to over-water their crops rather than risk suffering yield losses from under-watering.

In 1996 NCEA staff reported that water use efficiency in irrigated agriculture was probably over-stated and that significant water savings (up to 50%) could be achieved in furrow based systems by modifying furrow length, irrigation cut-off time, water application rate, furrow shape or cultivation practices[21]. At a similar time the CRDC had commissioned Cameron Agriculture Pty Ltd, in association with Dr Hearn[22], to assess the agronomic and economic efficiency of irrigation water use in the Australian cotton industry. They found that the mean irrigation efficiency for cotton was around 54%, much lower than the widely held view within industry.

At the 1996 workshop at Goondiwindi the NCEA put forward a proposed research program for the cotton industry. NCEA had already developed some expertise in surface irrigation models and suggested that the way forward for the cotton industry would be to develop technologies that enabled water use efficiency to be more accurately measured on-farm under normal commercial irrigation practices. Their hypothesis was that once water use efficiency could be measured, farmers were more likely to adopt improved practices if the economic viability of such practices could be demonstrated.

The CRDC appreciated that a coordinated effort between researchers and commercial parties would be required if water use efficiency gains were to be realised. Consequently, CRDC provided an industry focus and funded the NCEA to undertake work in this area. This investment has provided the platform from which considerable public and private investment has been made to increase water use efficiency in the cotton industry.

[21] Raine, S. R. & Smith, R. J. 1996 Improving the efficiency of surface irrigation: The view from USQ, Irrigation water use efficiency workshop, Goondiwindi, 29 November.

[22] CRDC (1997) Agronomic and economic aspects of water use efficiency in the Australian cotton industry, Report prepared by Cameron Agriculture in association with A. B. Hearn

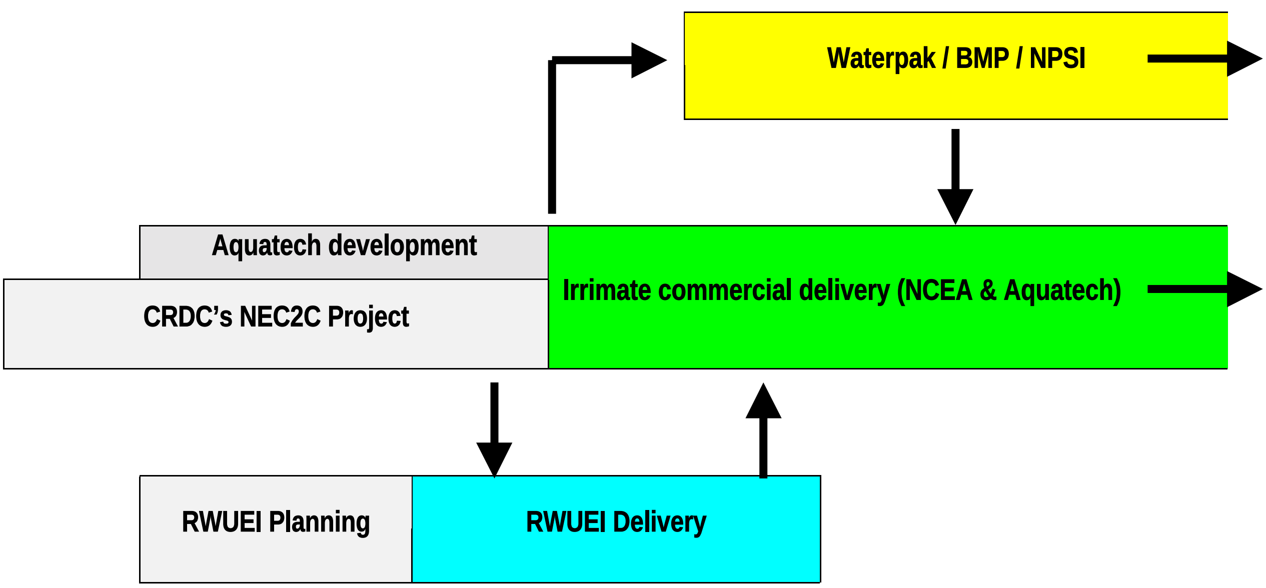
1 CRDC Investment

The main research organisation involved in this work was the NCEA. Alongside the CRDC investment was expenditure by Aquatech Consulting Pty Ltd in the development of commercial technology to measure water balances on farm. A timeline for the CRDC investment is shown in TABLE 10. The key linkages include:

1. Aquatech consulting Pty Ltd worked alongside NCEA in the development of an on-farm system that enabled cotton growers to "*measure to manage*" their water resource. At the conclusion of NEC2C the Irrimate and associated technologies were delivered to industry by Aquatech and the NCEA and involved a number of Irrimate agents (in QLD, NSW, Vic and SA).
2. Project outputs were used in the development of several extension activities based around Waterpak (CRDC led), Best Management Practices manuals and the National Program for Sustainable Irrigation (NPSI) "*knowledge management in cotton and grain project*" (GRDC support with CRDC as NPSI partner). These activities provided broader support for on-going water use efficiency gains across the industry.
3. The Queensland government developed and implemented the Rural Water Use Efficiency Initiative where the cotton and grains program had ownership through Cotton Australia and AgForce and had representatives from all industry stakeholder groups. The considerable grower awareness of water use issues generated through this initiative has provided on-going input into the commercial delivery of the Irrimate and associated technologies.

TABLE 10: IRRIMATE INVESTMENT THROUGH TIME: CRDC AND ASSOCIATED INVESTMENTS

1998	1999	2000	2001	2002	2003	2004	2004	2005



2 Industry Outcome

This project was successfully completed, and at its conclusion had achieved several key outputs. These included[23]:

- Detailed measurement of the performance of individual components of the whole farm water system under commercial conditions that led to the development of a range of monitoring devices (Irrimate) and associated software and calibration technologies. These technologies have provided an industry standard for evaluating water use efficiency. By 2001 over 60 Irrimate devices had been used to evaluate water use efficiencies across 25 farms.
- Average water use efficiency on-farm was found to be low, up to 65%, with major losses identified in storages and in-field application, including significant deep drainage losses (11% to 33% over a season).
- Water logging of crops had the potential to reduce cotton yields by up to 20%.
- Strategies to increase water use efficiency might require a mix of design and management improvements.

The main industry outcome from adoption of the Irrimate suite of technologies has been to reduce water consumption in the growing of cotton on irrigated operations.

With improvements in water use efficiency the Australian cotton industry has been able to reduce the volume of water applied to growing crops. In an average year water use in cotton production would be around 2,000 GL, assuming production on 350,000 ha, 84% of production irrigated and irrigation of 6.8 ML per ha[24]. Under the RWUE initiative 51,000 ML had been saved by the end of the 2001/2002 season and a further 16,855 ML by the end of the 2003/2003 season[25]. Indeed, the success of the cotton and grains program led to the program team being awarded the 2003 Queensland Primary Industry Achievement Award – environment category. The total water saved was just over 10% of water used.

Realisation of water savings in NSW has developed more slowly, mainly because there was no initiative in NSW similar to the RWUE initiative in QLD, which had considerable industry backing and financial incentives to change water management practices. By 2007 it has been estimated[26] that water savings in NSW reached 10%, largely due to the efforts of Waterpak extension materials and networks, NPSI activities and on-going commercial delivery of Irrimate technologies by Aquatech Consulting Pty Ltd.

On-going adoption of water saving strategies will enable further water savings to be achieved in the future. Although the CRDC has set a target water saving of 20% by 2008 (based on bales per ML which could be achieved by an increase in yields per ML as well as a reduction in ML per ha), a more conservative adoption profile has been assumed for this evaluation. Based on adoption rates in NSW (10% over seven years) it is likely that the next 10% saving will be achieved by 2014 in NSW and 2010 in QLD. On an average annual industry

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[23] CRDC Project NEC2C Final Report

[24] ABARE Commodity statistics, Cotton Australia Water Fact Sheet and Waterpak.

[25] RWUEI Milestone 4 Report for the Cotton / Grains adoption program, June 2003

[26] Personal communication with Aquatech staff and industry representatives.

water demand of 2,000 GL, it is expected that water savings will reach 400 GL by 2014 across the cotton industry.

Achieving a 20% water saving across the industry appears promising, given the savings achieved to date and the level of support being provided to the industry. The findings under CRDC Project NEC2C found that average water use efficiency across cotton farms was up to 65% and significant savings were possible. The extent to which savings can be made has also been confirmed by results achieved by Aquatech to date (20% savings over 107 optimised irrigations) and by Smith et al (2005[27]), who reported current losses of up to 2.5 Ml per ha.

3 The Counterfactual or Without Investment Scenario

While NEC2C has only been a modest part of the total investment in water saving initiatives since the mid-1990's, research, extension and technology outcomes from the project have had a major contribution to the water savings achieved to date and that likely to be realised in the future. During the project Jim Purcell from Aquatech provided a strong commercial focus with the NCEA ,and invested separately in the development of the Irrimate technology. However, without the investment by CRDC, it could be expected that Aquatech and the NCEA would have pursued other sources of funding. Consequently, similar technologies and extension material would have been developed, albeit at a later date, and modified for application in the cotton industry.

The importance of the project NEC2C in the success of the RWUEI is noted in the Milestone 4 report (page 31[25]) – *the work* [under project NEC2C] *in the Border River Region, which was being completed at the commencement of the Adoption Program had a major influence on the Program's activities and success*.

The counterfactual or "without" CRDC investment scenario can be described by the period over which water savings have been brought forward. The "with" and "without" scenarios are shown in TABLE 11. In the "without" case it is assumed that:

- Only 50% of the achieved water savings under the RWUEI would be realised by 2003. As a comparison, savings in the sugar industry, which also uses furrow irrigation systems, only achieved a 2.5% improvement[28].
- Water savings of 10% in Queensland would have been achieved by 2007 (rather than 2003) - by the same time the 10% saving was achieved in NSW.
- Water savings in NSW would have been achieved at the same rate, but initial uptake would have been delayed by 2 years.

Water savings are expressed in ML in the year that the saving was (or expected to be) realised. These savings once achieved would be realised every year. The total water saving through time has been estimated at 400 GL – with 136 GL in Queensland and 264 GL in NSW.

27 Smith, R. J., Raine, S. R. & Minkevich, J. 2005, Irrigation application efficiency and deep drainage potential under surface irrigated cotton, Agricultural Water Management 71 , 117-130

28 Final Report – Evaluation of the RWUEI adoption program by Dr Coutts and Kerry Bell 2003

TABLE 11: WATER SAVINGS REALISED THROUGH TIME: WITH AND WITHOUT SCENARIOS: ML

Year	Queensland		NSW	
	With	Without	With	Without
1998				
1999				
2000				
2001				
2002	51,000	25,500	18,878	
2003	16,855	8,428	18,878	
2004	9,694	8,482	18,878	18,878
2005	9,694	8,482	18,878	18,878
2006	9,694	8,482	18,878	18,878
2007	9,694	8,482	18,878	18,878
2008	9,694	9,694	18,878	18,878
2009	9,694	9,694	18,878	18,878
2010	9,694	9,694	18,878	18,878
2011		9,694	18,878	18,878
2012		9,694	18,878	18,878
2013		9,694	18,878	18,878
2014		9,694	18,878	18,878
2015			18,878	18,878
2016				18,878
2017				18,878
Total	**136 GL**	**136 GL**	**264 GL**	**264 GL**

Note: Annual savings may not equal the total due to rounding for presentation in the Table.

4 Triple Bottom Line Benefits

In this section the benefits generated on CRDC's water saving investment is reported. Benefits are described as economic, environmental or social and the distribution of benefits between levy payers and the Australian community at large is identified. Benefits are estimated as the incremental gain between the "with" and "without" investment scenarios.

It should be noted that the "without" CRDC investment scenario is based on the CRDC diverting R&D expenditure to other priority areas. It is not a representation of what would happen in the absence of government matching funds. Under this situation it is likely that there would be widespread changes in the structure of industry supported R&D and such changes can not be identified from consideration of specific R&D investments alone. Nonetheless, the extent of social gains generated on government machining funds can be estimated using the "with" and "without" investment scenarios considered here. Whether or not such benefits justify government investment would require a determination of the opportunity cost of government investing in other areas outside the cotton industry specifically and the rural sector more broadly.

4.1 Economic

In this section the economic benefits from water savings on-farm are estimated. Achieving water savings on-farm will lead to reduced water pumping costs and less water actually applied to cotton crops. These benefits will accrue to levy payers and are estimated here using a representative farm approach to quantify benefits in dollars per ML saved. Benefits are expressed in terms of the capitalised value per ML of water saved.

Pumping costs are estimated by the NSW Department of Agriculture at $16 per ML (gross margin budgets for surface irrigated cotton in 2005/06). This value capitalised over 20 years using a discount rate of 5% is $200 per ML.

The value of the water saved can be given by the price at which water trades in established water markets. Trades in permanent water entitlements in 2004 were around $1,500 per ML in Queensland and up to $2,205 per ML in the Gwydir catchment[29]. Given the severe drought conditions the industry has experienced since 2000 and the lack of trade in permanent water rights we decided to use more recent price data on trades of seasonal allocation to test the robustness of prices used in BDA Group's 2004 evaluation of CRC outcomes. An average annual price of $200 per ML of water was used for this purpose[30]. The capitalised value of this price over 20 years with a discount rate of 10% (for cotton growers) was calculated at $1,700. Therefore, for every ML of water saved the average economic benefit would be a one-off gain of $1,900.

Against the $1,900 economic benefit realised per ML of water saved needs to be deducted the costs of achieving that saving. In the RWUEI program evaluation it was noted that 55% of cotton growers made use of the financial incentive provided by the Queensland government. The financial incentive formed part of the total $4.3m in expenditure on water saving strategies. This cost is equivalent to $115 per ML saved (or $130 per ML in current dollars).

In addition, there would have been costs absorbed by other agencies in providing some measurement of water balances on-farm and extension services direct to growers. While these costs are unknown an estimate has been derived using Irrimate technology and consultancy prices on a 500 ha cotton growing area. A 500 ha cotton area would need a water storage volume of some 4,000 ML with 3,400 ML applied each season. At a cost of $35,000[31] for the Irrimate in-field evaluation equipment, meters and software the cost per ML saved, assuming a 10% saving, would be approximately $100. Therefore the total cost of achieving a 10% water saving would be in the order of $230 per ML.

It is also reasonable to assume that the second 10% water saving would be harder to achieve than the first 10% saving. Initial water savings are likely to be from simple on-farm changes, such as changes in irrigation timing and flow rates through siphons. Reducing evaporation rates from storages would possibly require changes to the

[29] BDA Group 2004 Evaluation of CRC outcomes

[30] Weekly prices of temporary water were sourced from www.waterexchange.com.au.

[31] This cost is reflective buying the whole Irrimate range of technologies. It should be noted that component parts can be purchased or rented with packages tailored to meet individual requirements.

design of storage area. To account for an increasing cost of achieving water savings, it was assumed that the cost of the second 10% water saving would require earthworks such as increasing the depth of a storage facility. Dalton et al (2001) in a case study example estimated that going from a 5m depth to a 7.5m depth water storage would require earthworks of some 300,000 m3 and reduce evaporation losses by 22% (734 ML). If an earthwork cost of $1.5 per m3 is used, the cost per ML saved would be nearly $620. This value and the Irrimate technology cost was used as an indicative cost for achieving the second 10% water saving – a value of $720 per ML.

Economic benefits are reported in TABLE 12 below. For the first 10% of water savings achieved in each State the economic benefit is calculated at $1,670 per Ml while for the second 10% saving the economic benefit is calculated at $1,180 per mL. The difference between benefits generated under the "with" and "without" CRDC investment represents the economic benefit that can be attributed to investment project.

TABLE 12: ECONOMIC BENEFITS THROUGH TIME: WITH AND WITHOUT SCENARIOS: $M

Year	Queensland			NSW		
	With	Without	Difference	With	Without	Difference
1998						
1999						
2000						
2001						
2002	$85	$43	$43	$32		$32
2003	$28	$14	$14	$32		$32
2004	$11	$14	-$3	$32	$32	
2005	$11	$14	-$3	$32	$32	
2006	$11	$14	-$3	$32	$32	
2007	$11	$14	-$3	$32	$32	
2008	$11	$11		$32	$32	
2009	$11	$11		$22	$32	
2010	$11	$11		$22	$32	
2011		$11	-$11	$22	$22	
2012		$11	-$11	$22	$22	
2013		$11	-$11	$22	$22	
2014		$11	-$11	$22	$22	
2015				$22	$22	
2016					$22	-$22
2017					$22	-$22

4.2 Environmental

A major research finding from the CRDC project NEC2C was that deep drainage represents a significant source of water lost from cotton irrigation activities. Water savings that reduce deep drainage will have long term impacts on ground water recharge and water table rise. No attempt is made here to quantify these impacts because:

- *Time scales for ground water systems to respond to increased drainage are reasonably long, of the order of decades* [32] and would fall outside our 20 year time horizon;
- Salinity is not seen as a major issue in most cotton growing areas[33]; and
- BDA Group estimated that the present value of benefits from reduced deep drainage as a result of water savings under the QLD RWUEI program was less than $1m.

4.3 Social

Water savings deliver a direct economic benefit to cotton growers. Such benefits increase the profitability of cotton production and acts as an incentive to increase production, which in turn stimulates regional economies. BDA Group (2004) estimated that for every additional dollar in added profitability across the Australian cotton industry output would increase by 80 cents. This increase in production would have an impact on regional Australia in terms of additional demand for goods and services and increased employment opportunities. These benefits are reported in Table 13. It should be noted that in some years a negative impact will occur. This is because in some years benefits under the "without" scenario are more than under the "with" scenario. That is, benefits are generated sooner in time rather than later.

Table 13: ESTIMATED SOCIAL BENEFITS THROUGH TIME: $M

Year	Grower Benefits	Increased Production	Additional Demand	Increased Employment
2002	$74.1	$59.3	$22.5	$7.7
2003	$45.6	$36.5	$13.9	$4.7
2004	-$2.7	-$2.2	-$0.8	-$0.3
2005	-$2.7	-$2.2	-$0.8	-$0.3
2006	-$2.7	-$2.2	-$0.8	-$0.3
2007	-$2.7	-$2.2	-$0.8	-$0.3
2008				
2009	-$9.3	-$7.4	-$2.8	-$1.0
2010	-$9.3	-$7.4	-$2.8	-$1.0
2011	-$11.4	-$9.1	-$3.5	-$1.2
2012	-$11.4	-$9.1	-$3.5	-$1.2
2013	-$11.4	-$9.1	-$3.5	-$1.2
2014	-$11.4	-$9.1	-$3.5	-$1.2
2015				
2016	-$22.3	-$17.8	-$6.8	-$2.3
2017	-$22.3	-$17.8	-$6.8	-$2.3

(a) Benefits expected to last until 2026 at a minimum. Note: Demand and employment impacts based on ABS input / output tables for cotton production

32 Silburn, D.M. & Montgomery, J. 2001, Deep drainage under irrigated cotton in Australia – A review, Cotton Consultants Assoc. Meeting, Dalby 21-22 June 2001

33 Cotton Australia Water Fact Sheet

Another area where social benefits have been realised is in the development of scientific expertise and extension skills in water management on cotton farms. There is considerable support provided by both State and federal governments in water market reforms, including the implementation of strategies to increase environmental flows in stressed river systems. The CRDC has taken a lead role in supporting scientific and extension efforts across the cotton industry and has provided an effective inter-face with industry members. This will enable more effective policies to be introduced and the productivity of cotton farms to be maintained in the face of on-going reforms.

The final area where social benefits will be generated is in the development of businesses supplying consultancy services in water management to Australian businesses. These firms are mainly small to medium sized enterprises, have direct links with cotton growers and provide both employment opportunities in regional areas and increase regional economic activity. Their services also target other agricultural commodities and sectors such as mining. While the provision of Irrimate services to other industries will generate significant economic and social benefits, no attempt has been made to quantify the magnitude of such benefits in this study.

5 Financial Sustainability Measures

As part of the support to the CRDC in undertaking the cost benefit analysis of hero projects ACIL Tasman provided a standardised excel spreadsheet for calculation of financial sustainability measures. Unfortunately the spreadsheet could not accommodate the evaluation parameters derived for CRDC's Irrimate investment as benefits were expressed as a one-off rather than an on-going gain. Consequently, a dedicated spreadsheet was built and submitted to ACIL Tasman for incorporation into their aggregated evaluations.

Financial sustainability measures derived include the net present value (NPV), benefit cost ratio (BCR) and internal rate of return (IRR) on CRDC's investment. A discount rate of 5% was used and all dollar values were converted to 2007 dollars using the consumer price index. A summary of investment cost incurred by different parties is provided in Table 14. The following sections present measures by different segments of the Australian community.

Investment by "others" includes the considerable development work by Aquatech Consulting Pty Ltd (estimated at $0.5m) and contributed inputs by the NCEA. It is not necessary to include costs of other organisations (such as the QLD RWUEI program) as it is assumed that these costs would have been incurred under the "without" investment scenario. This also raises the issue of what industry structure might have existed had there been no matching funds provided to the CRDC. Apart from how the CRDC might be structured and operated, it is likely that without the CRDC in its current form other research and development organisation may have indeed adopted different structures and priorities.

Table 14: Funds Invested in Hero Project – On-Farm Water Management: $'000

Year	CRDC			Others	All Funds
	Levy	Matching	Total		
1998	$63	$63	$125	$250	$375
1999	$63	$63	$125	$250	$375
2000	$63	$63	$125	$250	$375
2001	$63	$63	$125	$250	$375

5.1 Levy Payers

Financial sustainability measures were derived first for levy payers. Relevant costs include payments made by growers via the output levy on cotton production and relevant benefits include only those gains to cotton growers. Financial sustainability measures are reported in the table below along with a breakdown of the present value of benefits realised to date and by 5 and 10 years from now. A 20 year time horizon was not considered as all benefits will be captured within 10 years from now.

TABLE 15: FINANCIAL SUSTAINABILITY MEASURES: RETURNS TO LEVY PAYERS

Measure	To date	5 years out	10 years out
PVB	$84.8m	$63.5m	**$36.1m**
PVC	$0.3m	$0.3m	**$0.3m**
NPV	$84.6m	$63.2m	**$35.8m**
BCR	308	231	**131**

Note: PVB is the present value of benefits and PVC is the present value of costs. The stream of benefits and costs reported earlier were discounted a rate of 5% with 2002 taken as the starting period.

The payoff to levy payers was estimated at $36m in present value terms. Caution should be exercised when interpreting measures under the to-date and 5 year time horizon. Because benefits result from adoption occurring sooner than would otherwise be the case and that benefits are described in terms of a once off gain, at some point in time benefits will be assigned a negative value because under the "without" scenario a greater level of adoption would have occurred. This will result in the PVB being higher than it would be when a longer time period is considered. The IRR has not been calculated because it has no sensible interpretation when benefits are reported as they have been in this cost benefit analysis.

5.2 Supply Chain

The next segment of the Australian community for which financial sustainability measures were derived was the cotton industry and associated industries along the supply chain. Investment costs include expenditure by CRDC (both levy and matching funds) and CRDC partners. Derived measures are reported in TABLE 16. Only the 10 year measures have been reported.

TABLE 16: FINANCIAL SUSTAINABILITY MEASURES: RETURNS TO SUPPLY CHAIN

Time Frame	PVB	PVC	NPV	BCR
10 Years out	$36.1	$1.6	$34.4	22

Note: PVB is the present value of benefits and PVC is the present value of costs. The stream of benefits and costs reported earlier were discounted a rate of 5% with 2002 taken as the starting period.

The estimated pay off to the cotton and associated industries was again substantial, at nearly $35m in present value terms. There was considerable investment by Aquatech Consulting Pty Ltd and it is unlikely that they would have had the appetite to make this investment when they did if the CRDC had not been involved.

5.3 Australian Community

The final segment for which financial sustainability measures were derived was the Australian community at large. The Australian government invests across a wide range of activities to increase the “social good”. That is, government investment is justified if the pay off to the Australian community exceeds the cost of the intervention (necessary condition) and the opportunity cost of investing funds elsewhere (sufficient condition). As noted earlier, the opportunity cost of government investment outside the cotton industry (and the rural sector more broadly) is unknown and would require evaluation of investment returns across many areas of government activity. This is clearly beyond the scope of the exercise here. However, an assessment of the “necessary condition” for government investment can be made by comparing the benefits generated across the wider Australian community against the intervention costs (matching funds). Financial sustainability measures are reported in TABLE 17. Again, only measures for the 10 year period are reported.

TABLE 17: FINANCIAL SUSTAINABILITY MEASURES: RETURNS TO AUSTRALIA

Time Frame	PVB	PVC	NPV	BCR
10 Years out	$50.8m	$0.3m	$50.5m	184

Note: PVB is the present value of benefits and PVC is the present value of costs. The stream of benefits and costs reported earlier were discounted a rate of 5% with 2002 taken as the starting period.

The estimated pay off on the government investment was estimated at $51m in present value terms. A considerable pay off on funds invested.

6 Conclusion and Sensitivity Analysis

It was estimated that the payoff to levy payers and to the government matching funds was considerable, $36m and $49m respectively in present value terms. The driver of pay off to funds invested will be the extent to which water savings can be brought forward in time as a result of the CRDC investment. It was acknowledged that there had been considerable investment made by other parties in pursuing water savings in cotton and other agricultural industries more broadly. Under the assumed counterfactual it was argued that the rate of water use efficiency gains in Queensland would have been slower, while the gains in NSW would have been delayed by two years.

To test the sensitivity of the estimated investment pay off under a different counterfactual it was assumed that there would be no impact from the CRDC investment on water use savings in Queensland, and that benefits might only be attributed to the earlier savings achieved in NSW. Financial sustainability measures for different groups under this “scenario” are reported in TABLE 18 below.

TABLE 18: SENSITIVITY ANALYSIS : FINANCIAL SUSTAINABILITY MEASURES ASSUMING NO IMPACT OF CRDC INVESTMENT IN QUEENSLAND.

Sector	PVB	PVC	NPV	BCR
Levy Payers	$21.0m ($36.1m)	$0.3m ($0.3m)	$20.7m ($35.8m)	76 (131)
Industry	$21.0m ($36.1m)	$1.6m ($1.6m)	$19.3m ($34.4m)	13 (22)
Australia	$29.5m ($50.8m)	$0.3m ($0.3m)	$29.2m ($50.5m)	107 (184)

Note: PVB is the present value of benefits and PVC is the present value of costs. Financial sustainability measures derived previously for the counterfactual described in Sections 3 is given in brackets as a comparison.

If it were assumed that the CRDC investment in the development of the Irrimate technology had no impact on water use savings in Queensland, and only brought forward adoption by two years in NSW, the estimated payoff would still be significant with an estimated net present value of $20m to almost $30m.

THE VALUE OF THE CRDC

This project, under guidelines from ACIL Tasman (representing the RRDC Chairs), sought to demonstrate the returns that can be achieved from CRDC investment in R,D&E. Two projects were selected on the basis that they were known to have had a major industry impact and delivered substantial value to cotton growers and Australia more broadly.

If the pay off from the two hero projects are compared to the total CRDC expenditure over the period in which benefits were realised (2002 to 2006) this would provide an estimate of the *minimum average payoff* on all investments made by the CRDC. A research lag of 5 years was assumed between funds invested and when benefits are first realised as this was indicative of the two hero projects evaluated in this study. Therefore, the period of CRDC investment that should be considered should be between 1997/98 and 200/01. Over this period CRDC expenditure was $48m with matching funds of $23m. Financial sustainability measures using total CRDC expenditure across all projects are reported in TABLE 19.

TABLE 19: FINANCIAL SUSTAINABILITY MEASURES ON FOUR YEARS OF CRDC TOTAL INVESTMENT

Sector	PVB	PVC	NPV	BCR
Levy Payers	$319m	$25m	$294M	13
Industry	$599m	$50m	$549m	12
Australia	$741m	$25m	$716m	30

Note: PVB is the present value of benefits as reported in earlier sections and PVC is the present value of costs. CRDC costs were converted to 2006/07 dollars and discounted from 1998.

As shown in the table above, the two hero projects selected in this study would provide a minimum average return of $13 for every levy payer dollar invested over four years of CRDC's operation examined in this report. Returns to Australia at large on the Commonwealth's matching funds were estimated to be considerably higher as benefits generated outside the cotton growing sector are included. While these returns demonstrate that the CRDC has been able to deliver significant industry impacts from its investment portfolio, the estimated financial sustainability measures do not provide any indication of the value of the Australian government's matching funds.

The hero projects evaluated in this study considered a counterfactual where it was assumed that the CRDC would still operate, but would have diverted funds to other priority areas. Using historical returns as estimated here to assess the value of the matching contribution by the government is problematic. While the estimated pay off demonstrates that a significant return has been generated it does not indicate whether on-going investment of matching funds is justified or not in the future. Conclusions regarding the justification of using matching government funds through the CRDC would require an assessment of the likelihood that without government funds the CRDC would still operate in its current form and merely increase the levy on cotton growers to make up the shortfall.

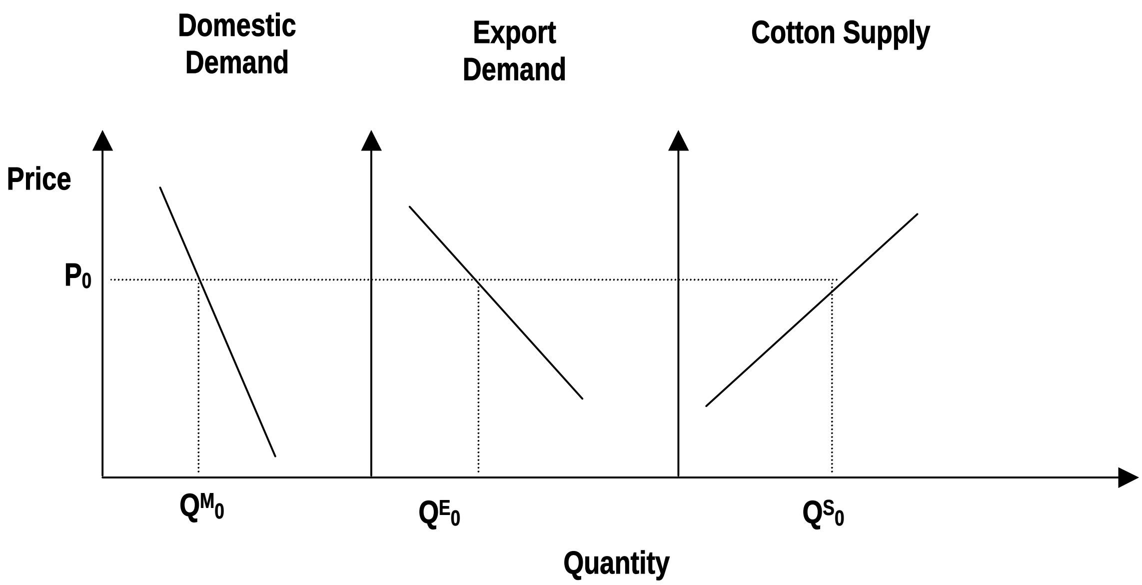
APPENDIX 1: CAPTURE OF BENEFITS BY LEVY PAYERS

This appendix describes the economic model used to derive the share of benefits captured by cotton growers (87%) following a productivity gain on-farm. The model was first used to assess price impacts for the Australian Cotton CRC and has been updated to reflect current market conditions.

Investment in Research and Development can result in productivity gains in an industry or increase the demand for commodities or services produced. In the cotton industry R&D benefits will ultimately be distributed between farmers, processors, input suppliers and consumers. Because the focus of the evaluation is on the CRDC's investment in R,D&E, it is necessary to determine the distribution of benefits across different industry participants so that those benefits which accrue to overseas consumers can be identified.

Much of the literature on the distribution of benefits from R&D is based on the early work of Freebairn, Davis and Edwards (1982)[34]. Their work illustrated an approach to measuring R&D benefits in terms of the changes in economic surplus as a result of productivity gains or demand shifts at various stages from primary production to consumption. The fundamental concept to this approach is that in a competitive market increased production efficiency, or increased product demand, will have an impact on prices.

FIGURE 5: ECONOMIC MODEL OF COTTON DEMAND AND SUPPLY



For the purpose of this evaluation, a model of cotton demand and supply was constructed to determine the distribution of economic gains between cotton farmers and consumers of cotton products. An economic model was constructed to represent cotton demand and supply at the farm gate, and is depicted in FIGURE 5.

34 Freebairn, J.W., Davis, J.S. and Edwards, G.W. (1982), "Distribution of Research Gains in Multistage Production Systems", *American Journal of Agricultural Economics*, 64, 39-46.

The partial equilibrium model is based on the (derived) demand for cotton on the domestic market and export markets. Supply is aggregated across all production regions of Australia.

Demand and supply are given by:

Domestic Demand Equation:

(1) $P_0 = \beta^M Q^M{}_0 + \gamma^M$

where P_0 = Initial equilibrium price
$\beta^M = (P_o/Q^M{}_0)(1/e^M)$
$Q^M{}_0$ = Initial equilibrium demand
e^M = Demand elasticity
$\gamma^M = (P_o - \beta^M Q^M{}_0)$

Export Demand Equation:

(2) $P_0 = \beta^E Q^E{}_0 + \gamma^E$

where P_0 = Initial equilibrium price
$\beta^E = (P_o/Q^E{}_0)(1/e^E)$
$Q^E{}_0$ = Initial equilibrium demand
e^E = demand elasticity
$\gamma^E = (P_o - \beta^E Q^E{}_0)$

Supply Equation:

(3) $P_0 = \beta^S Q^S{}_0 + \gamma^S$

where P_0 = Initial equilibrium price
$\beta^S = (P_o/Q^S{}_0)(1/e^S)$
$Q^S{}_0$ = Initial equilibrium supply
e^S = supply elasticity
$\gamma^S = (P_o - \beta^S Q^S{}_0)$

Initial Producer Surplus (PS_o)*:*

(4) $PS_o = 0.5 Q^S{}_0 (P_o - \gamma^S)$

Initial Consumer Surplus (CS_o) *:*

(5) $CS_o = CS^D{}_0 + CS^E{}_0$

(6) $CS^D{}_0 = 0.5 Q^D{}_0 (\gamma^D - P_0)$

(7) $CS^E{}_0 = 0.5 Q^E{}_0 (\gamma^E - P_0)$

R&D will result in an outward shift in the derived demand for cotton or a downward shift in the supply of cotton. New equilibrium prices and production / consumption are given by:

Post-Shift Price

(8) $P_1 = [-\beta^S(\gamma^D-a)/ \beta^D-\beta^S(\gamma^E-b)/ \beta^E +\gamma^S-c]/[(1-\beta^S(1/\beta^D+1/\beta^E))]$

where P_1 = Post shift equilibrium price
a = shift in domestic derived demand (price)
b = shift in export derived demand (price)
c = shift in supply (price)

Post-Shift Production / Consumption

(9) $Q^S{}_1 = +Q^D{}_1+Q^E{}_1$

where $Q^S{}_1$ = Post shift equilibrium supply
$Q^D{}_1$ = Post shift equilibrium production for domestic market
$Q^E{}_1$ = Post shift equilibrium production for export market

(10) $Q^D{}_1 = (P_1-\gamma^D+a)/ \beta^D$

(11) $Q^E{}_1 = (P_1-\gamma^E+a)/ \beta^E$

Post-Shift Producer Surplus (PS_1) *:*

(12) $PS_1 = 0.5Q^S{}_1(P_1-\gamma^S-d)$

Post-Shift Consumer Surplus (CS_1)*:*

(13) $CS_1 = CS^D{}_1+ CS^E{}_1$

(14) $CS^D{}_1 = 0.5Q^D{}_1(\gamma^D-P_1+b)$

(15) $CS^E{}_1 = 0.5Q^E{}_1(\gamma^E-P_1+c)$

Change in Producer Surplus (ΔPS) *:*

(16) $\Delta PS = PS_1 – PS_0$

Change in Consumer Surplus (ΔCS) *:*

(17) $\Delta CS = CS_1 – CS_0$

Change in Economic Welfare (TS)*:*

(18) $TS = \Delta PS + \Delta CS$

Change in Surplus - Australia (TS^A):

(19) $TS^A = \Delta PS + CS^D{}_1 – CS^D{}_0$

Cotton Industry Assumptions

P_0 = \$450 per bale

Q_0 = 2.5m bales

$Q^E{}_0/(Q^D{}_0+Q^E{}_0)$ = 94%

e^D = -1.20

e^E = -5.00

e^S = 0.80