An Evaluation of the Economic, Environmental and Social Impacts of NSW DPI Investments in IPM Research in Invertebrate Rice Pests

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Economic Research Report No. 41

August 2008

NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Abstract

Research into IPM technologies has been conducted by NSW DPI for over 20 years. Evaluating the returns from investment in specific research and development projects is an important component of the NSW DPI science and research program. An economic evaluation has been conducted of IPM in managing invertebrate pests in rice in NSW. We found that there has been widespread adoption of many IPM practices amongst NSW rice growers leading to a flow of economic benefits to the rice industry and the community. Important environmental and human health benefits were also identified. A benefit-cost ratio of 9.05 was calculated for the return to NSW DPI investment in rice invertebrate pests IPM research. The net present value of the benefits of this research to 2020 was $67.9 million. Important environmental and human health benefits were not valued nor were ‘spillover’ benefits to other States.

Keywords: benefit cost analysis, rice, IPM, invertebrate pests, evaluation

JEL code: Q160

ISSN 1442-9764

ISBN 978 0 7347 1901 0

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Citation:
Orr, L.M., Stevens, M.M., and Mullen, J.D. (2008), *An Evaluation of the Economic, Environmental and Social Impacts of NSW DPI Investments in IPM Research in Invertebrate Rice Pests*, Economic Research Report No 41, NSW Department of Primary Industries, Orange.

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Acronyms and Abbreviations Used in this Report

ABARE	Australian Bureau of Agricultural and Resource Economics
AChE	acetylcholinesterase
APVMA	Australian Pesticides and Veterinary Medicines Authority
BT	*Bacillus thuringiensis*, a bacterium used for pest insect management
DECC	Department of Environment and Climate Change
DPI	Department of Primary Industries
IPM	integrated pest management
IRR	internal rate of return
MIA	Murrumbidgee Irrigation Area
MV	Murray Valley
NPV	net present value
NPV	nuclear polyhedrosis virus, used for the control of *Heliothis* caterpillars
NSW	New South Wales
OC	organochlorine (a class of insecticide)
OP	organophosphate (a class of insecticide)
RIRDC	Rural Industries Research and Development Corporation
R&D	Research and Development
YAI	Yanco Agricultural Institute

Acknowledgements

The authors would like to acknowledge John Lacy (District Agronomist, NSW DPI, Yanco, NSW), Helen Scott-Orr (Director Health Sciences, Strategic Alliances and Evaluation, NSW DPI, Orange, NSW) and Dr David Hall (Research Leader Plant Health Sciences, NSW DPI, Gosford, NSW) for their valuable contributions to this report.

The authors would also like to thank Dr Adrian Nicholas (Entomologist, NSW DPI, Tamworth, NSW) and Robyn Hean (Economist – Farm Forestry, NSW DPI, Armidale, NSW) for their valuable comments on the final report.

Executive Summary

Evaluating the returns from investment in specific research and development projects is an important component within New South Wales Department of Primary Industries (NSW DPI) Science and Research Division. In 2006 the NSW DPI invested an estimated $5.6 million in pest management research activities related to plants. An important element has been the development and extension of Integrated Pest Management (IPM) programs. Research into IPM strategies has been carried out by NSW DPI for over 20 years. In that time, a flow of recommendations from this research for adoption by NSW primary producers have been released.

In this evaluation, we have attempted to assess some of the important benefits to industry, consumers and the wider community in NSW resulting from NSW DPI research in IPM strategies to control invertebrate pests in rice. Invertebrate pest problems impose substantial economic costs on NSW rice farmers. Pests such as bloodworms, aquatic snails and aquatic earthworms cause extensive damage to aerially sown rice crops in NSW every year. These pests result in lower plant densities at crop establishment and lower yields, and can, in severe cases, cause the loss of entire crops.

The rice industry has largely been dependant on insecticides and other costly chemicals to control these pests, which can have adverse environmental and human health effects. Since 1990, NSW DPI has committed significant resources to invertebrate pest management in rice, with research focussed on determining the most environmentally sustainable and cost-effective management practices. This evaluation looks at NSW DPI cash and in-kind expenditure (some of which is industry funded) on a suite of projects dealing with IPM research into bloodworm, aquatic earthworm and aquatic snail management in rice. The research is based at the Yanco Agricultural Institute (YAI) and has been primarily carried out by Dr Mark Stevens, Principal Research Scientist.

Approach to the evaluation

In the analysis reported here, the investments by NSW DPI in research relating to invertebrate rice pests from 1990 to 2006 have been evaluated in an economic framework. Benefits are estimated from increased profits from using IPM practices and IPM chemicals. Costs are derived from past and projected investments in research.

Two sets of results are presented in this report. The first is a comparison of industry benefits and costs of investments by NSW DPI up to 2006; the second extends the evaluation to 2020, where the benefits from research are measured from the commencement of the initial research project to 2020, to allow for the flow of benefits into the future from research already undertaken. Also included were research costs to 2020 necessary to protect the stream of benefits arising from research already completed.

The on-farm benefits of the research program are measured as the difference in the economic return from control technologies arising from the research (the ‘with’ research scenario) and those which would have resulted if the projects had not been initiated (the ‘without’ research scenario).

Funding sources

A considerable number of research projects were undertaken for this cluster of IPM research. Research costs up to 2006 were estimated to have a present value of $5.87 million and when research costs were projected to 2020 the total was $8.45 million. Of the funds invested in invertebrate rice pest research to 2006, 64% was in-kind (salaries, capital and other costs) and 36% was from industry. The main industry funding source was the Rural Industries Research and Development Corporation (RIRDC) and the Rice Cooperative Research Centre (CRC).

Economic, social and environmental effects

The benefit-cost ratio (BCR) for NSW DPI invertebrate rice pest research up to 2006 was 8.39. The net present value (NPV) of this research up to 2006 is $43.4 million. The internal rate of return (IRR) is 226% to 2006. When research benefits and costs are extended to 2020 the BCR is 9.05 the NPV is $67.98 million and the IRR is unchanged. These results indicate that research by NSW DPI into invertebrate pests in rice has generated substantial long-term economic benefits, with the projections to 2020 based on the assumption that adoption of new chemistries for bloodworm control will rise from current levels.

These economic benefits have positive social consequences, largely through their contribution to the incomes of farmers and those who provide inputs to rice production, handling and processing in NSW. Lower health risks for those in the community who are linked in some way to rice production are also of social benefit. The health risks to aerial spray operators who were once exposed to harmful chemicals while mixing seed dressings have been reduced.

In environmental terms, the invertebrate rice pest research program has had major impacts. Adoption of the recommendations from the research has led to increased use of more pest specific, efficacious and less toxic insecticides with lower rates of active ingredient used. This has resulted in outcomes such as potential for increased farm biodiversity and reduced off-farm environmental contamination. The environmental impacts of invertebrate rice pest research have not been valued in this analysis.

Funders and beneficiaries

The NSW DPI invertebrate rice pest research evaluated in this report has been partly funded by the RIRDC and the Rice CRC. Their funding is derived from industry levies and matching Commonwealth Government funds. Because Australia is largely a price taker on the world rice market, most of the benefits of the research program are likely to remain with rice producers. Benefits have flowed to consumers, transport services, processors, local towns and communities and the environment. Benefits have also flowed to chemical suppliers who have gained from research and development (R&D) of new and alternative uses for chemicals.

The strongest rationale for public funding of R&D into the control of vertebrate pests in the rice industry is based on reducing threats to environmental and human health in the community at large. We are uncertain about the size of the economic benefits from this research relative to the environmental and human health benefits but in our judgement the share of industry funding in the future for this type of research should exceed fifty percent unless the objectives of the research are specifically environmental or human health in nature.

1. Introduction

Integrated Pest Management (IPM) as part of wider pest management is an important issue for agricultural producers, consumers and government in NSW. On-farm pest management impacts on the quantity and quality of produce and the costs of production. Producers benefit from potentially reduced costs of production and reduced crop damage, whereas consumers benefit from better quality, and potentially lower priced produce. There may also be reduced risks to human and environmental health.

The distinguishing features of an IPM strategy are: the use of knowledge about the biology of pests and their interaction with their natural enemies, and about cultural and chemical control strategies, along with the monitoring of pest and beneficial populations, to allow growers to make profitable pest management decisions. The antithesis of IPM is calendar spraying without regard to the size of pest and beneficial populations. While new scientific information has enabled farmers to make more profitable pest management decisions, particularly with respect to pesticides, it has also been a valuable input into the management of externalities associated with pests and the use of pesticides, and into the public regulation of pest management. It is appropriate for a public institution such as NSW DPI to conduct research and development (R&D) activities to generate information of this nature, which has characteristics of a public good, and is to some degree, unique to the agricultural ecosystem of NSW.

Evaluating the returns from investment in R&D is an important activity within NSW DPI Science and Research Division. The findings from these evaluations are reported in DPIs' Economic Research Report series available at http://www.dpi.nsw.gov.au/research/areas/health-science/ economics-research#Economic-Research-Reports. Earlier evaluations are summarised in Mullen (2004).

NSW DPI has invested in R&D into IPM technologies for over 20 years. In 2006, NSW DPI invested an estimated $5.6 million in pest management research activities related to plants. These research activities encompassed a wide variety of pests that affect NSW plant industries – including pests, diseases and weeds – and a wide range of control strategies. Research has been carried out not only at the farm level (including chemical efficacy) but also at the post-harvest level often involving market access issues. The opportunity cost of this investment is the benefit to the people of NSW, were these resources used in other areas such as health and education. Hence, it is important that NSW DPI can demonstrate that it uses these resources in ways that enhance the welfare of the people of NSW.

The current suite of evaluations on IPM is designed to assess the economic, environmental and social impacts of three specific areas of NSW DPI IPM investment. These are:

- An assessment of R&D in IPM in rice.
- An assessment of R&D in cold disinfestation for citrus export.
- An assessment of R&D in IPM in lettuce.

We would like to be able to value all economic, environmental and social impacts and relate these to the investments made, but generally we are only successful in valuing some of these impacts because of:

- Uncertainty about the impact of the technology on farm production both now and in the future.
- Uncertainty about environmental and social impacts both now and in the future.
- Uncertainty about the value of environmental and social resources both now and in the future.
- Limited resources to undertake these evaluations.

Our approach has been to first describe qualitatively the economic, environmental and social impacts of the actual investment. We also describe the rationale for government investment from a market failure viewpoint which seeks to identify the characteristics of the investment resulting in farmers individually, or collectively, under-investing in the areas under consideration. We examine the share of public and private funding in the investment and compare this to a qualitative assessment of whether the benefits of the investment flow largely to farmers or largely to the community.

We then attempt to quantify as many impacts as practicable to arrive at the common measures of economic performance such as the benefit-cost ratio. There are insights to be gained from persevering with an empirical benefit-cost analysis even under uncertain scenarios. A key step is to identify not only the expected impact of the investment in research on an industry, the ‘with’ research scenario, but just as importantly, how the industry would continue to develop without the investment by NSW DPI, the ‘without’ research scenario. Rarely is the ‘without’ research scenario a no-change scenario because there are usually other sources of similar R&D leading to ongoing productivity growth. This quantitative approach also gives an indication of the relative importance of key parameters such as the rate and extent of adoption of IPM technology, the on-farm impacts of IPM, and the size of the investment and its time path.

In assessing the ‘with’ and ‘without’ research scenarios, key outputs from R&D activities and communication strategies are described to give credence to claims about the contribution of NSW DPI and to assumptions about the rate and extent of adoption of the IPM technology.

This report presents the results of one of these evaluations conducted in 2007, of the invertebrate rice pest IPM research cluster. The size and nature of the rice industry in NSW is described and the significant invertebrate pests affecting rice production in NSW are outlined. We summarize the nature of IPM technologies arising from this research, their rate of adoption and their economic, environmental and social impacts. Because of differences in production systems, water availability, yields, pest problems and management responses, our analysis has been conducted for two rice growing regions in NSW – the Murrumbidgee (MIA) region and the Murray Valley (MV) region. An ex-post evaluation of the flow of benefits and costs from invertebrate rice pest IPM research to 2006 is presented. In addition, we assess the likely flow of benefits and costs to 2020 in a more speculative ex-ante analysis.

2. The NSW rice industry

Rice is grown on irrigated farms in the Murray and Murrumbidgee Valleys of south-western NSW and a small amount is sometimes grown in northern Victoria and the Lachlan Valley. Data on important industry statistics are shown in Table 1 and Table 2. All dollar figures are in real terms, measured in 2006 dollars.

The area of land under rice production has averaged around 119,000 hectares over the past 17 years, peaking at around 184,000 hectares in 2001 and falling to a low of around 38,000 hectares in 2003 (SunRice, 2007), due to the impacts of the prevailing drought and associated water availability issues.

Around 2,500 farms in NSW produce around a million tonnes of paddy each year. Production peaked at 1.7 million tonnes in the 2000-01 season but fell to around 400 thousand tonnes over the period 2003-05 due to severe water shortages in the rice growing regions. Average yields per hectare in the MIA exceeded 10 tonnes in 2003 and 2006. Australian producers are the only ones worldwide to achieve this level of productivity per hectare.

Table 1: NSW rice production,

	MIA		MV		TOTAL	
Year	Area	Average yield	Area	Average yield	Area	Average yield
	(ha)	(t/ha)	(ha)	(t/ha)	(ha)	(t/ha)
1990	59,775	8.3	50,635	7.8	110,410	8.1
1991	44,465	9.0	40,238	9.0	84,703	9.0
1992	60,952	9.2	62,189	8.6	123,142	8.9
1993	60,856	8.1	62,046	7.3	122,902	7.7
1994	64,964	8.3	67,692	8.0	132,656	8.2
1995	62,660	9.0	66,576	8.6	129,235	8.8
1996	69,169	6.8	80,550	6.0	149,719	6.4
1997	73,077	8.6	92,624	8.1	165,701	8.3
1998	79,083	9.7	61,107	9.1	140,188	9.4
1999	82,031	9.4	68,795	8.9	150,826	9.2
2000	80,957	8.4	50,887	8.0	131,843	8.3
2001	97,195	9.5	86,882	9.5	184,077	9.5
2002	78,040	8.8	69,228	8.0	147,268	8.4
2003	33,621	10.4	4,735	8.3	38,356	10.2
2004	35,842	8.7	28,893	7.5	64,735	8.2
2005	21,983	7.4	23,217	6.1	45,200	6.7
2006	54,976	10.3	49,541	9.5	104,517	9.9

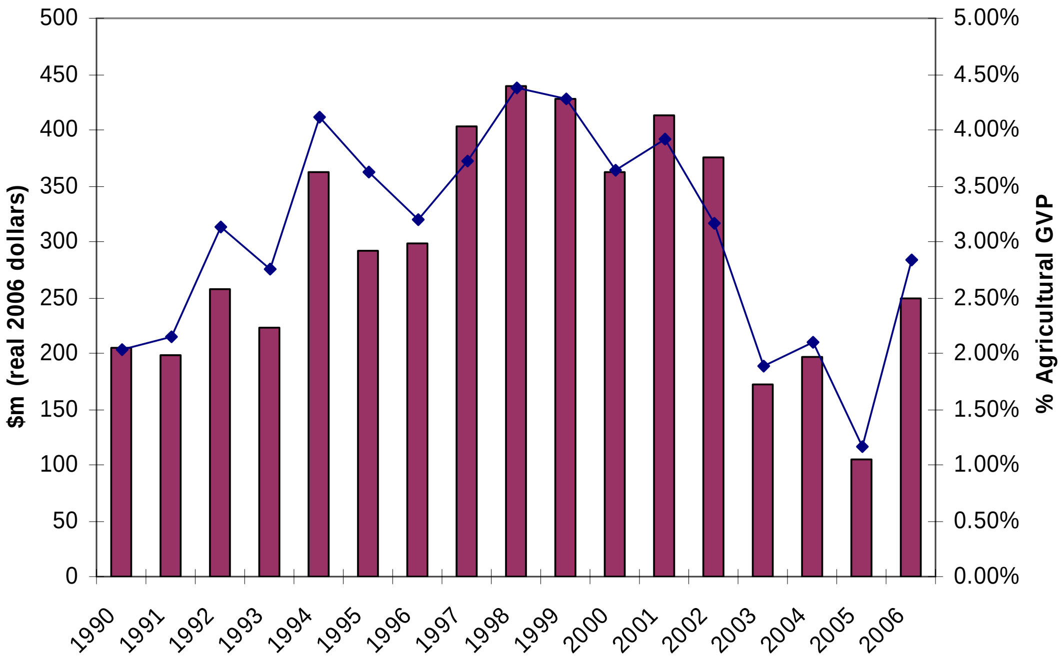
Medium grain rice prices in nominal terms were $157 per tonne in 1990 and rose to $313 per tonne in 2003, before falling to around $265 per tonne in 2006. In real terms (2006 dollars), medium grain rice prices rose from around $230 per tonne in 1990 to nearly $370 per tonne in 1994, before falling to around $265 per tonne in 2006. Annually around 75% of rice grown in NSW is medium grain varieties, with the remaining 25% being either short or long grain varieties.

Table 2: NSW medium grain rice price and value of production, 1990-2006

Year	Price	Value of Production	Price	Value of Production
	(nominal dollars)		(2006 dollars)	
	($/t)	($m)	($/t)	($m)
1990	157.1	140.1	230.3	205.4
1991	189.2	137.6	271.9	197.7
1992	163.2	181.9	230.5	256.8
1993	200.9	160.6	279.7	223.5
1994	267.1	261.4	369.9	362.0
1995	237.1	216.1	320.8	292.4
1996	244.4	225.8	322.9	298.4
1997	224.3	307.6	293.4	402.5
1998	214.2	339.3	276.8	438.6
1999	216.8	331.2	280.2	428.1
2000	232.5	289.2	290.7	361.6
2001	193.4	346.4	230.2	412.4
2002	243.7	323.1	283.5	375.8
2003	313.1	151.3	356.8	172.4
2004	279.5	179.0	306.8	196.5
2005	284.1	99.6	297.5	104.3
2006	265.0	248.7	265.0	248.7

Up to 2001, rice accounted for an increasingly large share of NSW total agricultural receipts, peaking at around 4.5% of agricultural gross value of production (GVP) in 1998-99. In real terms, rice GVP increased from just over $200 million in 1990 to over $400 million in the late 90s and early 2000s, before falling back to around $250 million in 2006. The fall in real GVP during the period 2002-05 is a direct result of the decline in production due to the impact of drought and water shortages.

Figure 1: Rice GVP and share of agricultural GVP, $m



Source: ABS 7113.0, 7121.0, 7503.0 and compiled by the authors.

All rice grown in NSW is sold to Ricegrowers Limited. It is milled and packaged locally and marketed under the SunRice brand. SunRice has been marketing rice for over 50 years and is Australia's largest exporter of value-added food and the world's fifth largest rice food exporter.

Rice is Australia's third largest cereal grain export after wheat and barley and the ninth largest agricultural export. SunRice exports 85% of Australia's rice to over 70 major international destinations including the Middle East, Japan and Hong Kong. The domestic market receives the remaining 15%.

2.1 Significant invertebrate pests in rice

Relatively few invertebrate pests impact on the NSW rice industry. Climatic factors (low winter temperatures and low summer humidity) mitigate against the survival of many rice pests that require more tropical conditions to survive, and an extensive quarantine area has contributed to the ongoing exclusion of other exotic pests (Stevens, 2000).

Armyworms, leafminers and tadpole shrimp are all relatively minor pests which can affect the rice crop sporadically, often with only small crop areas being affected. However, bloodworms, aquatic earthworms and aquatic snails can cause significant damage.

Bloodworms, the larvae of chironomid midges, attack the roots of newly-sown rice seed and are able to cause seedling losses of over 80% if not controlled. Bloodworms have historically been controlled with the cholinesterase inhibitor, maldison, as a seed treatment, which requires mixing by aerial sowing operators. Current common practice is to treat bloodworms with chlorpyrifos and/or alphacypermethrin insecticide sprays after sowing. Seed treatment with fipronil is practiced by some growers, however, this differs from the previous maldison seed treatment protocol in that much lower chemical application rates are used, and the seed is treated using purpose-built equipment that reduces the risk of workers being exposed to the chemical.

Aquatic earthworms are in effect an 'environmental' pest – they make the conditions within newly flooded rice bays unsuitable for developing rice seedlings (Stevens, 2003). Dense aquatic earthworm infestations interact with the rice crop in a number of ways, altering soil structure and water quality and prejudicing successful plant establishment. There are currently no registered insecticides or biological controls for the management of aquatic earthworms. The key management practice in controlling this pest is crop rotation.

Aquatic snails attack rice plants from early establishment through to tillering. The traditional control method for management of this pest has been heavy applications of copper sulphate to the floodwater. Crop rotation is now utilised as a key management practice.

These three pests – bloodworms, aquatic snails and aquatic earthworms – are the most significant pests affecting the NSW rice crop, and are the focus of this evaluation.

3. Integrated pest management in rice

Decisions about pest control strategies are complex because of the mobility of pests and their ability to respond to control strategies. Many control strategies, particularly those of a chemical nature, also have adverse impacts, sometimes distant in time, on non-target species and on non-target sites. These non-target impacts, sometimes referred to as externalities, come in many forms. They range from pest control issues, such as the loss of natural enemies of target species, secondary pest outbreaks and the emergence of resistant pest strains, to health risks to farm labour and the consumers of farm produce, as well as risks to environmental resources such as air and water quality.

In the decades immediately following the development of synthetic pesticides, there developed almost total reliance on these chemicals for pest control. Right from these early years there were likely ‘spillover’ impacts of consequence to human and environmental health, although not all of these were immediately recognised or thought to be significant. On the farm, however, pests began to develop resistance to the chemicals, requiring ever more applications and the search for new chemicals – a pesticide ‘treadmill’.

Much of the early research into IPM was conducted within the University of California (UC) system. The key elements of IPM programs seem to have been first brought together in a classic paper by Stern et al. (1959) who discussed the management of arthropod pests and recognized that pests had to be managed in ways profitable to farmers. Their paper began with a discussion of why arthropods had increased in significance as pests of agriculture. They identified the recent development of agriculture and the sometime indiscriminate use of pesticides as the main causes for the increased problems with arthropods. They spoke in terms of “general equilibrium” populations of pests and suggested that, in general, pesticides provided only a temporary lowering of the equilibrium population, whereas biological controls held the potential of a permanent lowering. The objective of pest management was to lower the pest population below an economic threshold, but the problem was complex because the threshold was not fixed, varying with economic, biological and physical parameters. They called for the integration of biological and chemical control strategies based on greater knowledge of the ecosystem, science-based monitoring and prediction of pest populations, the augmentation of natural enemies, and the use of selective insecticides. All of these have become important components of IPM programs. A component they did not foresee was the use of gene technology, although they did talk about traditional breeding for resistance.

From the early 1970s NSW rice producers have relied on synthetic pesticides to control bloodworms in their crops. Some key developments during the 1970s and 1980s include:

- The emergence of bloodworms as the most significant invertebrate pests of rice.
- The rapid increase in the use of synthetic pesticides, especially in the late 1980s and early 1990s when maldison and chlorpyrifos were heavily used for the control of bloodworms.
- Problems with the use of maldison, as aerial operators reported detrimental health effects such as headaches after use (Stevens et al, 1998).

- Increased knowledge of the biology of these invertebrate pests, which became the basis for development of the NSW DPI rice IPM program.

In the late 1980s, the insecticides, maldison (as a seed treatment) and chlorpyrifos (as a spray), were registered for use in controlling bloodworms in rice crops. The use of these chemicals quickly grew until over 95% of rice producers were utilising these insecticides. A common invertebrate pest control schedule at the time included maldison seed treatment at 300 grams active ingredient (ai) per hectare (ha), followed by two aerial spray applications of chlorpyrifos or diazinon at up to 75 or 120 grams ai per ha respectively, or trichlorfon at up to 425 grams ai per ha.

Maldison, chlorpyrifos, diazinon and trichlorfon are all cholinesterase inhibitors in the organophosphate chemical family. Cholinesterase inhibitors tie up acetylcholine esterase (AChE), an important enzyme of the nervous system. As insecticides, they work by causing uncontrolled firing of electrical nerve impulses, leading to seizure and death. Without proper precautions, some of these chemicals can also lead to paralysis and respiratory failure in humans and other mammals (Ware 2000, EXTOXNET 1993).

The only option for rice producers to control aquatic snails in their rice crops was to treat with copper sulphate pentahydrate (bluestone). Affected areas were often treated with two applications of bluestone which equated to up to 24 kilograms per hectare of copper sulphate (or approximately 6.1 kg of elemental copper). Virtually all of this copper entered the soil where it contributed to an increased risk of copper poisoning in livestock when rice fields were rotated into pastures.

As a result of a strong research program in the early 1990s by NSW DPI staff supported by some industry funds from RIRDC and elsewhere, initial recommendations for IPM of some invertebrate pests in rice crops had been developed by 1993. Further research led to additional recommendations in the area of chemical use and cultural management practices for the main invertebrate pests in rice. Research is continuing today.

In 1995, aerial operators placed a ban on the use of maldison seed treatments for the control of bloodworms in NSW rice crops. Their decision to do so was based on concerns about occupational health and safety, as the emulsifiable concentrate formulations of maldison were claimed to give pilots headaches (Stevens et al, 1998).

For two seasons growers had to sow untreated seed, and then spray at least two applications of chlorpyrifos, trichlorfon or diazinon for bloodworm control. Not only did this increase costs to growers (who had to pay for an extra spray pass by aircraft), and increase the risk of spray drift to non-target areas, it also increased the risk of crop damage by bloodworms prior to the first spray application, as untreated seed was sown. Seed treatments were (and continue to be) an effective way of protecting the crop from the time of sowing whilst avoiding the drift hazards associated with spray application.

By 1993, research had demonstrated that of the broad-spectrum organophosphate insecticides available, chlorpyrifos was the most effective spray treatment for bloodworm control.

Locating an alternative seed treatment that would be both effective and acceptable to aerial operators became a major priority for the NSW rice industry. Trials at Yanco Agricultural Institute (YAI) during 1995 showed that the insecticide fipronil, applied to seed at rates as low as 12.5g ai per ha provided far superior bloodworm control to maldison, and in fact had a similar level of residual activity (14-18 days) to chlorpyrifos (Stevens, 1996). The first trademark for fipronil, Cosmos®, was commercially released in 1998.

Concerns surrounding residues of chlorpyrifos in drainage water, combined with a review by the Australian Pesticides and Veterinary Medicines Authority (APVMA) into its use, placed a degree of uncertainty over its future availability. This prompted further research in the period from 1999 to 2003 into alternatives to chlorpyrifos for bloodworm control.

In 2003, the pyrethroid insecticide, alphacypermethrin (trademarked Dominex®) was identified as providing at least equivalent and possibly superior control of bloodworms in establishing rice crops. This gave rice producers an alternative to chlorpyrifos for direct spray application, allowing rotation of insecticide groups to reduce the risk of resistance developing. Chemical inputs are reduced with the use of alphacypermethrin. The risk of alphacypermethrin contaminating releases of drainage water is also reduced because alphacypermethrin rapidly partitions from surface water and bonds to sediments. Alphacypermethrin is therefore less likely to have an environmental impact off-site in drainage water releases (Stevens, 2000).

Recent research is continuing to identify alternatives to broad-spectrum insecticides for bloodworm control. The selective bacterial insecticide *Bacillus thuringiensis* var. *israelensis* (BTI), has been recognised as effectively controlling bloodworms, with little impact on beneficial predatory species (Stevens, 2007). Biochemical factors affecting oviposition site selection[1] in the major species of bloodworms damaging rice crops are also being investigated as a possible control method. No recommendations have yet been made for rice producers based on these newer areas of research.

Research focussing on IPM practices such as crop rotation for the control of aquatic earthworms was conducted during the late 1990s. Recommendations were widely promoted about IPM practices for aquatic earthworms, which involved growing winter cereals and using extended fallow periods as well as avoiding irrigated pastures immediately preceding rice crops.

Aquatic snails can also be controlled by the use of IPM practices. Research conducted during the early 1990s recognised that a single season's crop rotation could virtually eliminate the problem of snail infestation. Research conducted recently has focussed on the fungicide, chlorothalonil, and another alternative compound, niclosamide, for the control of aquatic snails. Niclosamide studies have demonstrated that this chemical may provide effective control of aquatic snail eggs, as well as immature and adult snails at low application rates (Stevens, 2007). Niclosamide does not accumulate in soils and does not pose an environmental threat, unlike copper sulphate that has been widely used until now.

[1] Research has shown that females of the main pest species will not lay eggs into rice fields already containing larvae.

However, research suggests that chlorothalonil provides erratic control of aquatic snails due to its low water solubility and high soil absorptiveness (Stevens, 2007).

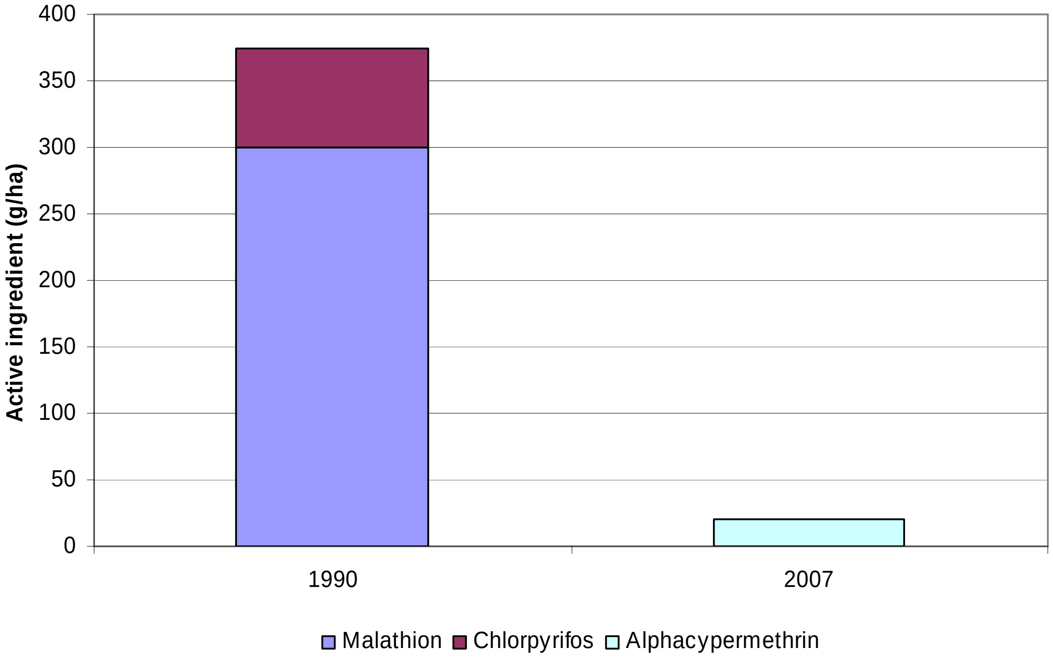
As a result of this body of research, the key elements for invertebrate pest IPM in rice include:

- The use of fipronil (Cosmos®) and alphacypermethrin (Dominex®) for effective bloodworm control at far reduced application rates and with lower downstream environmental effects than maldison and chlorpyrifos.
- The registration and use of the bacterial insecticide, BTI, which selectively controls bloodworms.
- The use of specific crop rotations to control aquatic earthworms and aquatic snails.
- Development and registration of alternatives to copper sulphate (bluestone), such as niclosamide, for the control of aquatic snails.

It is widely accepted that insecticide use in rice has declined significantly over the last 15 years. Figure 2 demonstrates this point by showing the estimated amount of active ingredient (ai) required per hectare for the minimum industry standard practice for bloodworm control falling by over 94% from around 375grams per ha ai in 1990 to only 20grams per ha ai in 2007. As different pesticides have different toxicological profiles, inference should not be drawn that the potential human and environmental impacts of pesticides are necessarily linearly related to the sum of the active ingredients.

Environmental and human health impacts from bloodworm control chemicals have the potential to be reduced by choosing chemicals such as fipronil and alphacyphermethrin. Fipronil is a disruptor of the insect nervous system and while highly toxic to fish, bees and aquatic invertebrates, is almost non-toxic to waterfowl and other species (Beyond Pesticides, 2001). Fipronil has low soil mobility and little potential for groundwater contamination. The sediment bonding nature of alphacypermethrin means its increased use has the potential to reduce the environmental impact of this chemical off-site in drainage water releases.

Figure 2: Minimum insecticide requirements for a two treatment bloodworm control program.



The actual amount of active ingredient applied in each year from 1990 is dependant on the level of adoption of IPM recommendations in the rice growing regions, and also the area of crop sown. Aggregated up to the State level, taking into account the adoption rates for IPM research (estimated by the researcher and industry), the estimated amount of active ingredient applied to control bloodworms in rice is shown in Table 3.

Table 3: Estimated amount of active ingredient applied 1990-2006.

Year	**Maldison**	**Chlorpyrifos**	**Diazinon**	**Trichlorfon**	**Fipronil**	**Alpha-cypermethrin**
	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
1990	33,123	6,625	882	6,250	-	-
1991	25,411	5,082	677	4,795	-	-
1992	36,943	7,389	984	6,971	-	-
1993	36,871	8,204	540	3,827	-	-
1994	39,797	9,850	53	375	-	-
1995	38,771	9,596	52	366	-	-
1996	-	22,233	-	-	-	-
1997	-	24,607	-	-	-	-
1998	-	20,818	-	-	-	-
1999	-	21,493	-	-	189	-
2000	-	17,799	-	-	330	-
2001	-	23,470	-	-	690	-
2002	-	18,777	-	-	552	-
2003	-	4,890	-	-	144	-
2004	-	7,768	-	-	121	324
2005	-	4,577	-	-	85	452
2006	-	10,190	-	-	131	1,254

This represents a projected decline in total active ingredient applied for bloodworm control in rice from over 52,000 kilograms in 1993 to just over 10,000 kilograms in 2006.

4. Rice IPM research in NSW DPI

Since 1990, NSW DPI has committed significant resources to IPM strategies for invertebrate pests in rice, with research focussed on determining the most environmentally sustainable and cost-effective management practices for pest control.

This evaluation looks at NSW DPI expenditure (some of which is industry funded) on a suite of projects dealing with IPM research into bloodworm, aquatic earthworm and aquatic snail management in rice. The research is based at the Yanco Agricultural Institute (YAI) and has been primarily carried out by Dr Mark Stevens, Principal Research Scientist, referred to as the researcher in the following sections of the report. The objectives of this research have been:

- To ensure that rice farmers can minimise, or preferably eliminate, crop yield and quality losses associated with invertebrate pest damage.
- To enable farmers to achieve the above objective at minimal cost, thus increasing the profitability of their farming enterprise.

- To minimise pesticide usage by developing cultural and biological control programs, in order to reduce input costs and protect both human health and the environment from adverse effects of pesticide use.
- To ensure that when pesticide use is essential, the pesticides used are specific to the target pest, applied safely, and used at the lowest effective rate.
- To develop, where necessary, newer generation pesticides that provide effective options for rice producers in the event of regulatory authorities withdrawing older compounds from the market.
- To ensure that advances in rice IPM research that lead to changes in crop management recommendations are effectively communicated to all rice producers and other relevant industry personnel.

The ex-post component of our analysis focuses on seven projects. Information about their objectives and level of investment are presented in Tables 4 and 5.

Table 4: Summary of invertebrate rice pest IPM projects evaluated, 1990-2006

Project	Summary
DAN 73A – Improved management strategies for bloodworms and aquatic snails in rice	This project, conducted between 1990 and 1993, quantified the effectiveness of existing chemical treatments and evaluated new chemical treatments for bloodworm and snail control. Suitability of IPM practices to snail control was determined and pest biology and life cycles were examined.
DAN97A – Reduced insecticide applications for rice crop protection in southern NSW	This project, conducted between 1993 and 1996, followed on from DAN73A. The project further evaluated bloodworm control treatments, focussing on seed treatments and also evaluated rice varieties for resistance to bloodworm. Further work was done on identifying alternative snail control chemicals.
DAN 120A – Resistance to bloodworm attack in rice	This project, conducted between 1996 and 1998, involved screening 28 rice varieties for resistance to bloodworm attack.
DAN 137A – Preliminary studies on biology and control of the rice worm *Eukerria saltensis*	This project, conducted between 1995 and 1996, clarified the effects of aquatic earthworms on the rice bay environment and evaluated chemical control measures for aquatic earthworms.
DAN 146A – Sustainable control of aquatic earthworms and bloodworms in rice	This project, conducted between 1996 and 1999, further evaluated chemical treatments for aquatic earthworm and quantified its impact on crop establishment failure. The project also evaluated low drainage alternatives to chlorpyrifos for bloodworm control and investigated existence of other bloodworm species.
DAN 184A – Improving bloodworm, snail and earthworm control in rice	This project, conducted between 1999 and 2002, generated new data on efficacy of bloodworm control chemicals, determined resistance of bloodworms to organophosphate chemicals and investigated the potential of oviposition deterrents for bloodworm management. The project also investigated the influence of crop rotations on earthworm populations and further screened rice varieties for bloodworm resistance.

DAN 203A – Sustainable management of invertebrate rice pests	This project, conducted between 2002 and 2006, evaluated alternatives to broad-spectrum insecticides for bloodworm control including oviposition deterrents and bacterial insecticides. Further studies on bloodworm population dynamics were also completed. Trials of chemicals for snail control were completed and evaluated. Pesticide screening for earthworms continued.

The total investment in these projects from all funding sources from 1990 to 2006 was $5.87 million in real terms (2006 dollars). The NSW DPI share of annual funding varied from 45% to 80%. On average, NSW DPI provided 64%, and industry sources provided 36%, of the research funds.

An eighth ongoing project, DAN240A ‘Management and Ecology of Key Rice Pests’, currently funded by RIRDC, aims to develop new DNA techniques to determine which species of bloodworm are associated with rice crop damage during the later part of the crop establishment period. The project also aims to further evaluate other potential seed treatments for commercial use against bloodworm, and efficacy and residue evaluations of chemicals for aquatic snail control. There have been no quantifiable benefits from this project at this stage, but the cost of this project as well as the projected level of maintenance expenditure of $223,000 each year is included in the ex-ante analysis to 2020. The actual level of funding for invertebrate rice pest research is dependant on future water availability for the rice industry, and the resulting commitment from industry and government to funding research.

Research costs into the future are included to protect the stream of benefits arising from research already completed. Maintenance expenditure is required because pest management strategies have to be adapted through time as their targets develop resistance to chemicals.

Table 6 shows the level of funding committed for project DAN240A and the estimated level of funding beyond this project to 2020. The total investment in invertebrate rice pest research for 1990-2020 is estimated at $8.45 million in real terms (2006 dollars). It is estimated that the NSW DPI share of funding for DAN240A and further maintenance investment to 2020 will average around 60% with industry providing 40% of research funds.

Table 6: Financial data for DAN240A, 2006-2009, and estimated maintenance, 2009-2020.

Year (2006 dollars)	**DAN 240A**	**Maintenance**
	($,000)	($,000)
2006	234.6	-
2007	244.5	-
2008	211.4	-
2009	30.3	165.0
2010-20	-	223.0
Present value in 2006		$8,450,164

Table 5: Financial data for projects evaluated 1990–2006

Year	**DAN 73A**	**DAN 97A**	**DAN 120A**	**DAN 137A**	**DAN 146A**	**DAN 184A**	**DAN 203A**	**NSW DPI Share of funding**	**Deflator 2006=100**	**Research costs**
				(nominal $)						(real $)
	($,000)	($,000)	($,000)	($,000)	($,000)	($,000)	($,000)	%		($,000)
1991	151.1							76	69.6	217.1
1992	165.1							79	70.8	233.1
1993	168.1							80	71.8	234.0
1994		225.7						70	72.2	312.5
1995		204.6						79	73.9	276.8
1996		211.2	67.3	11.2				68	75.7	382.8
1997			67.0		154.9			53	76.4	290.3
1998			16.7		157.9			50	77.4	225.6
1999					162.9			56	77.4	210.6
2000						315.9		65	80.0	395.0
2001						320.8		65	84.0	381.9
2002						303.6		70	86.0	353.1
2003						28.2	220.8	30	87.7	283.7
2004							219.3	37	91.1	240.7
2005							189.2	45	95.5	198.1
2006							35.0	45	100	35.0
Present value in 2006										$5,874,647

4.1 Outputs from invertebrate rice pest R&D

The key outputs of IPM research into invertebrate pests in rice have been:

- Recognition and evaluation of the most effective broad-spectrum and selective chemical treatments for bloodworms.
- Recognition and evaluation of biological controls and oviposition deterrents for bloodworms.
- Recognition and evaluation of the most effective chemical treatments for aquatic snails.
- Evaluation of 44 rice varieties for invertebrate pest resistance.
- Information on the biology, ecological/crop effects, species identification and ecology of bloodworms, aquatic snails and aquatic earthworms.
- Recommendations on the application of cultural control methods, such as avoidance of repeat cropping, to control aquatic snails.
- Recommendations on the application of cultural control methods, such as altering crop rotations, to control aquatic earthworms.

Research into many of these areas is continuing and further outputs from current research will be delivered.

These research findings have been reported in publications, at grower meetings and at field days. To assist the efforts of NSW DPI agronomists who facilitate the extension of invertebrate rice pest research recommendations in NSW, the results of this research have been incorporated into the *Rice Crop Protection Guide* published each year.

The recommendations from this research have not required a direct or formal extension program; therefore, no costs for extension have been included in the analysis. Publications such as the *Rice Crop Protection Guide* would exist without this research, as would the conduct of grower meetings and field days.

4.2 Outcomes from invertebrate rice pest R&D

Economic outcomes
NSW DPI research into IPM of invertebrate pests in rice has benefited rice producers in two significant ways. There has been a reduction in both the level of crop damage from better management and control of rice pests, and in chemical costs from adoption of alternative treatments requiring lower chemical application rates and use of IPM practices.

Environmental and social outcomes
There are a number of environmental outcomes on-farm and for the broader community. On-farm environmental outcomes include: an increase in farm biodiversity associated with the replacement of broad-spectrum chemicals with more selective chemicals, and reduced copper contamination of soil, which reduces the risk of subsequent copper poisoning in livestock and of broader environmental impacts.

Adoption of more pest specific, efficacious and less toxic insecticides has reduced the impact of insecticide use on farm biodiversity. Sensitive community analyses have shown that whilst some components of the aquatic fauna of rice crops recover rapidly from the impact of broad-spectrum chemicals, these invertebrate communities as a whole do not recover fully, even by the end of the growing season. The ecological significance of this has not been fully investigated in Australia. However, overseas studies have shown that the use of broad-spectrum chemicals during crop establishment results in reductions in aquatic biodiversity that spill over to the terrestrial invertebrate community, detrimentally affecting predators that provide natural biological control of pests later in the growing season (Stevens, 2007).

Copper applied to rice fields ultimately enters the soil, where it can accumulate over time, potentially causing pasture toxicity problems for livestock when rice fields are rotated into a pasture phase, as part of standard farm management procedures. Soil accumulated copper does not break down and can only be removed very slowly (as a necessary trace element component of harvested crops). Implementation of crop rotation practices by all rice producers affected by aquatic snails could substantially reduce the estimated 320,000 kilograms of copper sulphate being applied to rice crops annually (Stevens, 2003).

Broader community environmental outcomes of invertebrate rice pest research include: reduced spray drift as control methods move away from chemical sprays towards seed treatment and crop rotation strategies, reduced risk of chemicals moving off-site as a result of lower chemical application rates and adoption of chemicals with lower drainage residue levels, as well as an improvement in regional biodiversity associated with replacement of broad-spectrum chemicals with more selective chemicals.

An additional consideration is the Environmental Protection Limits (EPL) for insecticides in drainage systems established by the NSW Department of Environment and Climate Change (DECC). Although DECC 'action' levels are currently well above the EPL it should be anticipated that actionable residue levels will fall in the future.

The main social outcomes from the development of IPM technologies to manage invertebrate pests in rice are in the form of reduced risks to the health of farm families, farm workers, aerial applicators and the community generally. There will also be increased regional income and employment and consequently greater social amenity from a more prosperous rice industry.

In general, as a result of this research, rice growers have an enhanced understanding of insecticide use and handling and are more conscious of the impact of insecticides used in rice production systems on the on-farm and off-farm environment. They also have a greater awareness of the attitudes of the community in regard to pesticide usage. While the actual impact on human health of past practices for managing invertebrate pests is unclear, there was the potential for adverse outcomes because of the nature of the chemicals used. Health authorities routinely report incidents of pesticide poisoning, some of which may be attributed to pest management in the rice industry. Similarly, the actual impact on human health of IPM technologies is uncertain, but there is clearly the potential for improved human health outcomes because of the nature of the chemicals used, their substantially reduced application rates, and the increased adoption of alternative control technologies not based on chemical use.

The Ricegrowers' Association of Australia promotes the perception of rice as an environmentally friendly crop through the development of its Rice Environment

Policy (2000) and Biodiversity Strategy and Plan. The community attitude to rice production is positively influenced by rice grower adoption of research recommendations.

Social outcomes also arise from the improved prosperity of the rice industry as a result of improvements in yield and reductions in the cost of production associated with invertebrate rice pest research. Given the reliance on rice as a major crop in the two rice growing regions of the MIA and MV, higher incomes for rice farmers have meant increased spending in local communities, and therefore more prosperous rural communities with stronger community institutions.

Aerial operators have experienced reduced health problems as a result of cessation of use of the seed treatment, maldison, for bloodworm control in rice. Aerial operators had refused to use maldison before the recommendations regarding the alternative seed treatment, fipronil, were developed, so this outcome is therefore not attributable to the research evaluated in this report.

The switch from maldison seed treatments to the use of aerial sprays to control bloodworms in 1996, resulted in an increase in demand for aerial operators. Seed treatments are mixed with seed prior to sowing and applied when seed is aerially sown, while spray treatments such, as chlorpyrifos and alphacypermethrin, require the additional engagement of aircraft to apply these chemicals. This could have a beneficial effect on the incomes of aerial spray operators, but only at the expense of rice producers. Notably, increased adoption of fipronil seed treatment would reduce the number of aerial spray applications required.

Increased adoption of fipronil over time has important social benefits in terms of neighbour relations through the reduction of spray drift risk associated with increased use of seed treatments over spray applications.

We have not attempted to value these environmental, social or human health outcomes.

4.3 Community versus industry outcomes from rice invertebrate pests R&D

The extent to which the benefits from the invertebrate rice pest research program are shared between the rice industry and the NSW community has implications for public research support. Important economic, social and environmental outcomes were identified above.

Many of the economic benefits from invertebrate rice pest research clearly flow to the rice industry and are shared by producers, input suppliers, processors and consumers. Patent arrangements allow chemical companies to capture as economic rents some of the efficiency gains from the new chemicals they develop through an ability to charge higher prices for new chemicals than they cost to produce. An example of this flow of benefits to input suppliers is the development of fipronil (Cosmos®) as an alternative bloodworm treatment. The patent for fipronil (Cosmos®) is due to expire in early 2008, and market competition should result in a substantial price decrease. When this occurs, producers and consumers will become the major direct beneficiaries, as the cost of rice production will fall.

Overall, new technologies which arise from the invertebrate rice pest research program have generated benefits for the community and industry. The investment in research has been jointly funded by public and private sectors. On average, around 40% of funds have come from industry for this research and 60% of funds have come from public sources (NSW DPI).

The strongest rationale for public funding of R&D into the control of vertebrate pests in the rice industry is based on reducing threats to environmental and human health in the community at large. We are uncertain about the size of the economic benefits from this research relative to the environmental and human health benefits but in our judgement the share of industry funding in the future for this type of research should exceed fifty percent unless the objectives of the research are specifically environmental or human health in nature.

4.4 Adoption of recommendations

Identifying the pathways to adoption of technology, time to adoption and the level of adoption are critical components in determining impacts and the consequent benefits of research investments. The pathways to adoption of recommendations were embedded in the project planning for the invertebrate rice pest research program. The main pathway to adoption was through communication; the second, minor pathway was commercialisation through registration of new chemicals.

There is extensive literature on the factors influencing the adoption by farmers of new technologies (Hayman *et al* (2007) and Pannell *et al* (2006)). Adoption of invertebrate rice pest research recommendations is dependent on a number of factors. However, a necessary condition from a rice grower’s perspective is that the benefits from adoption must outweigh the costs of adoption.

Here, we focus the discussion more closely on the adoption of IPM technologies in rice where the broad components of the program are the use of soft chemicals or biological controls and the use of a variety of IPM practices. Farmers may not adopt these components to the same extent and, hence, it is difficult to precisely classify growers as adopters or not.

The factors influencing the use of soft chemicals or biological controls include: the cost of recommended chemicals relative to the benefits from more effective control, the willingness of aerial operators to apply seed treatments versus spray treatments, real or imagined health risks for aerial operators associated with manual handling and seed treatments and concerns regarding chemical resistance associated with repeated use of one chemical or mode of action.

Factors influencing the adoption of IPM practices for aquatic snail and earthworm control include: the cost of recommended IPM practices relative to the benefits of control using any existing treatments, the level of perceived risk posed by alternative treatments for aquatic snails, the perceived importance of pest control relative to other production issues such as water use efficiency, and the rice producers ability to alter crop rotations from a land use and water availability perspective.

4.5 The final user population

The size of the potential user population for invertebrate rice pest research varies according to the area of rice potentially susceptible to each type of invertebrate pest.

To estimate the size of the potential user population for each research output, the area sown to rice each year in the two main rice growing regions, the MV and the MIA (Table 1), are combined with estimates of the percentage of land affected by each type of invertebrate rice pest (Table 7). The estimates shown in Table 7 were made by the researcher and were supported by industry experts.

Table 7: Estimate of percentage area of each region affected by each pest

	Bloodworms (% area)	Aquatic snail (% area)	Aquatic earthworm (% area)
MV	100	8	40
MIA	100	30	20

Estimates of the area susceptible to each type of pest for the period 1990-2020 are shown in Table 8.

Table 8: Estimates of the final user population 1990-2020

	MV				MIA			
	Bloodworms (ha)	Snails (ha)	Earthworms (ha)	Snails and earthworms (ha)	Bloodworms (ha)	Snails (ha)	Earthworms (ha)	Snail and earthworms (ha)
1990	50635	2937	18633	1620	59775	14346	8369	3587
1991	40238	2334	14807	1288	44465	10672	6225	2668
1992	62189	3607	22886	1990	60952	14629	8533	3657
1993	62046	3599	22833	1985	60856	14605	8520	3651
1994	67692	3926	24911	2166	64964	15591	9095	3898
1995	66576	3861	24500	2130	62660	15038	8772	3760
1996	80550	4672	29643	2578	69169	16601	9684	4150
1997	92624	5372	34085	2964	73077	17539	10231	4385
1998	61107	3544	22487	1955	79083	18980	11072	4745
1999	68795	3990	25317	2201	82031	19687	11484	4922
2000	50887	2951	18726	1628	80957	19430	11334	4857
2001	86882	5039	31973	2780	97195	23327	13607	5832
2002	69228	4015	25476	2215	78040	18730	10926	4682
2003	4735	275	1743	152	33621	8069	4707	2017
2004	28893	1676	10633	925	35842	8602	5018	2151
2005	23217	1347	8544	743	21983	5276	3078	1319
2006	49541	2873	18231	1585	54976	13194	7697	3299
2007	2000	116	736	64	14000	3360	1960	840
2008[a]	0	0	0	0	5000	1200	700	300
2009-20 [b]	34800	2018	12806	1114	52200	12528	7308	3132

a: ABARE estimate, b: researcher estimate

Adoption profiles for chemical use have been developed from estimates made by the researcher and other industry experts. The levels of adoption shown in Figure 3 and Table 9 show adoption as a result of research as a percentage of the final user population.

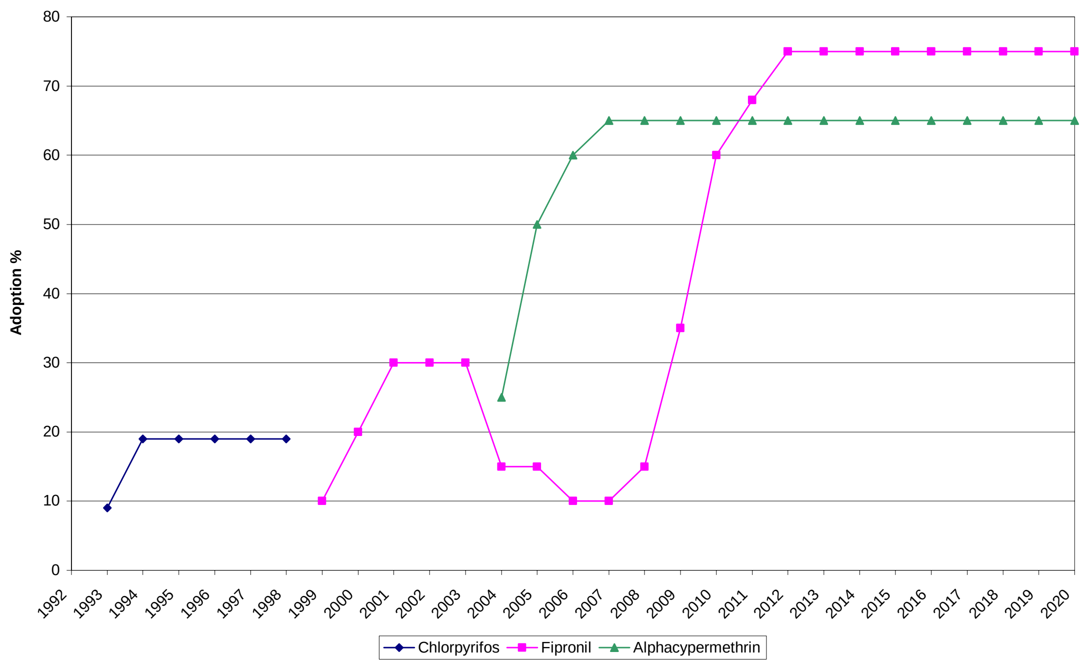
The adoption profile for bloodworm chemicals is shown in Figure 3. In 1992, 80% of the rice industry was using chlorpyrifos to control bloodworms, with 20% using alternative treatments, such as trichlorfon and diazinon. Within two years of the recommendation that chlorphyrifos was the most effective chemical available against bloodworms, an additional 19% switched to chlorpyrifos. The impact of this research runs through to 1998 when it is assessed by the researcher that rice growers would have switched to using chlorpyrifos in the absence of research. Hence, adoption as a result of the research falls to zero in 1999.

Adoption of fipronil (Cosmos®) is estimated to have peaked at 30% within two years of it being registered for use in rice. Adoption has fallen to around 10% currently, due to the cost of Cosmos® relative to other bloodworm chemical treatments, poor marketing, and variability in the willingness of aerial operators to apply seed treatments before sowing.

It is estimated by the researcher that when fipronil (Cosmos®) is released from patent in 2008 and its cost declines, pressure from growers on aerial operators for its use will increase adoption to around 75% of the industry by 2012 generating benefits to the research.

Alphacypermethrin has been adopted by around 50% of rice producers in 2006; this level is expected to stabilise at around 65% in the long term.

Figure 3: Adoption profile for chemicals from IPM research, 1992-2020



The adoption profile for those project outcomes relating to IPM practices for aquatic snail and aquatic earthworm control is shown in Table 9.

Table 9: Adoption profile IPM practices

	Aquatic snails	Aquatic earthworms
	(% of final user population)	
1994	10	-
1995	20	-
1996	30	-
1997	30	-
1998	30	-
1999	30	-
2000	30	15
2001	30	30
2002	30	50
2003	0	0
2004	15	25
2005	15	25
2006	30	50
2007	0	0
2008	0	0
2009-20	30	50

Based on estimates, IPM practices (non-repeat rice cropping) were implemented on 10% of the area for aquatic snail control in the 1994 growing season.

Adoption of IPM practices for aquatic snail control rose to 30% of the affected area by 1996. As a result of adverse growing conditions in the drought years of 2003-2005 and 2007, less rice producers chose to adopt IPM farming practices, with other factors such as water availability influencing decision making about farm practices. Zero adoption of IPM practices for aquatic snail control is forecast for 2008 as rice producers again showing a preference to repeat crop with rice to take advantage of residual soil moisture in drought years.

An adoption rate of 10% for IPM practices (no irrigated pasture prior to rice) was estimated as a result of earthworm research recommendations occurring from the 2000 rice growing season, rising to 50% in 2002 for the area affected by aquatic earthworms.

A zero level of adoption amongst rice producers affected by earthworms is estimated for 2003, 2007 and for 2008. This is due to limited water constraining production of irrigated pastures and therefore making the issue of IPM control of earthworms superfluous. It is expected that from 2009 onwards, production conditions will exist which will result in adoption of earthworm control recommendations returning to at least 50%.

5. Defining the 'with' and 'without' scenarios

In this analysis, we have attempted to value the economic outcomes of NSW DPI research into IPM of invertebrate pests in rice in terms of reduced crop damage and reduced costs of production from utilising less chemical. However, no valuation has been placed on the environmental and social impacts.

Not all of the productivity gains in the NSW rice industry since 1990 can be attributed to NSW DPIs' invertebrate rice pest research. Some productivity gains have come from better varieties, new chemicals and improved plant nutrition and irrigation techniques. We have tried to isolate those productivity gains that have arisen from the development and adoption of IPM practices and IPM chemistries, the ‘with’ research scenario from productivity gains which would have occurred in the industry anyway, the ‘without’ research scenario. If environmental and social impacts had been valued, ‘with’ and ‘without’ scenarios would similarly have needed to be developed.

As explained more fully below, the economic benefits from invertebrate rice pest IPM research are estimated by the difference in net revenue per hectare between adopters and non-adopters of research recommendations. Hence, the ex-post economic analysis requires changes in management practices for adopters and non-adopters to be tracked through time and estimates of their net revenue per hectare to be made. These differences in net revenue are aggregated to give an estimate of industry benefit by applying the adoption profiles for the IPM practices and IPM chemicals identified above.

Since 1990, two major changes in invertebrate pest management technologies for rice have occurred. Between 1992 and 2004 recommendations have been made regarding the most effective chemicals for bloodworm control, and new chemicals were registered for use against this pest which reduced the level of crop damage attributable to it. In 1994 and 2000, recommendations for IPM practices within an IPM strategy were released for the control of aquatic snails and aquatic earthworms.

5.1 IPM chemicals for bloodworm

Quantifiable benefits have arisen from the release of recommendations and results of chemical efficacy trials for bloodworm control in rice crops. This research has resulted in a reduction in the level of crop damage from better control of bloodworms.

Use of the chemical, chlorpyrifos, reduced bloodworm damage resulting in an average yield improvement of 7.5% for adopting rice producers. Additional cost savings are made for those rice producers switching from trichlorfon and diazinon to chlorpyrifos, in the order of $3 to $6.20 per hectare. Adopting fipronil (Cosmos®) further reduced crop damage, resulting in an average yield improvement of 2% over chlorpyrifos, however this benefit is reduced by the higher cost of fipronil (Cosmos®) relative to chlorpyrifos. It is estimated that there would be an increase in cost per hectare of $16 to $19 to 2008, then an extra $8 per hectare from 2009 when fipronil (Cosmos®) comes off patent.

Adoption of alphacypermethrin also reduced damage in crops suffering severe bloodworm infestation, resulting in a yield improvement of 20% over chlorpyrifos treatment. There is no cost impact from the use of aphacypermethrin over chlorpyrifos.

Without NSW DPI research into invertebrate rice pests, NSW rice growers would have had very few options for effective treatment for bloodworms and other aquatic pests. As almost all rice grown in Australia is grown in NSW, there is no investment by any other State department of agriculture in rice research. Without NSW DPI research into invertebrate rice pests, it is highly unlikely that there would have been any other public or private body undertaking research in this field.

From the time of the release of the early research in 1994 identifying chlorpyrifos as the most effective spray treatment for controlling bloodworms in rice, a picture of what the ‘without’ research scenario would be like emerges. Without the research rice producers would have continued to utilise the existing regime, including one maldison seed treatment and one spray treatment of chlorpyrifos (80% of area), trichlorfon or diazinon (20% of area).

From the time aerial operators refused to apply maldison seed treatment for the 1996 season, rice producers were left with no choice but to control bloodworms using two spray treatments of either chlorpyrifos (estimated 80% of area), trichlorfon or diazinon (estimated 20% of area).

Given that the chemicals available for use to control bloodworms are relatively cheap and aerial spray operators are happy to apply them, there would have been little incentive for others to seek out or research alternative chemicals such as seed or spray treatments. Without the NSW DPI research program, it is unlikely that fipronil or alphacypermethrin would have been developed or registered for use in controlling bloodworms in rice crops.

Table 10: Impact of IPM chemicals research for bloodworms

With Research	Cost Impact	Yield Impact	Without Research
Up to 1996 1 x maldison *plus* spray: 1 x chlorpyrifos treatment	Cost saving for those switching from trichlorfon and diazinon to chlorpyrifos	Yield improvement of 5-10% from chlorpyrifos treatment over trichlorfon and diazinon, average 7.5%	***Up to 1996*** 1 x maldison *plus* spray: 1 x chlorpyrifos treatment on 80% area 1 x trichlorfon on 13% area or 1 x diazinon on 7% area
From 1996 – 1998 2 x chlorpyrifos spray treatment			***From 1996 – 1998*** 2 x each spray treatment
From 1998 1 x fipronil seed treatment *plus* spray 1 x chlorpyrifos	Extra cost of fipronil over chlorpyrifos, $16 to $19/ha to 2008, then $8 to 2016	Yield improvement of 1-3% from fipronil treatment over chlorpyrifos, average 2%	***From 1998*** 2 x chlorpyrifos treatment on 100% area
From 2004 2 x alphacypermethrin spray treatments	Same cost as alternative chlorpyrifos, therefore no cost impact	Yield improvement, 20% from alphacypermethrin treatment over chlorpyrifos for those suffering significant damage (0.5% of area)	***From 2004*** 2 x chlorpyrifos treatment on 100% area with yield losses of 20% for those suffering significant bloodworm damage (0.5% area)

Without the development and registration of these new chemicals for use in controlling bloodworms in rice, the industry would have been exposed to significant risk by relying primarily on one chemical (chlorpyrifos). In the event that regulatory authorities such as the APVMA and the DECC revoke or restrict the use of chlorpyrifos, rice growers would be left with no viable strategies for bloodworm control.

An additional likely feature of the 'without' scenario is that a small percentage of rice growers would be unable to control bloodworm successfully with chlorpyrifos. It is estimated that 0.5% of rice area in the absence of an alternative chemical, would have experienced yield losses of 20% due to bloodworm control failure. The main reason for this failure is the apparent ineffectiveness of chlorpyrifos against some species of bloodworm, which may exist in the cropping environment under certain growing conditions (Stevens, 2000).

5.2 IPM practices for aquatic snail and earthworm control

Recommendations were released in 1994 identifying the effectiveness of a single season‘s rotation (i.e., no repeat cropping) for controlling aquatic snails. Adoption of this practice among rice growers resulted in reduced crop damage leading to a yield improvement of 2 to 3%, worth $44 per hectare in the MV and $70 per hectare in the MIA in real terms. In addition, cost savings are made from adoption of crop rotations replacing the need for copper sulphate applications to control aquatic snails; this cost saving was equal to $33 per hectare in 2006.

Recommendations were released in 2000 identifying the effectiveness of altering crop rotations (i.e., avoidance of irrigated pasture immediately prior to rice in rotations) and other management factors in controlling aquatic earthworms. Adoption of these IPM practices amongst rice growers resulted in reduced crop damage leading to a yield improvement of 5 to 7%, worth $146 per hectare in the MV and $115 per hectare in the MIA at in real terms. The impacts of these IPM practices for aquatic snail and earthworm control are outlined in Table 11.

The 'without' research scenario for IPM practices is described by identifying the nature of change in rice grower crop management practices which would have occurred in the absence of invertebrate rice pest research. It is estimated by the researcher that 70% of the rice area affected by earthworms would have implemented appropriate crop management practices; in particular, the avoidance of irrigated pastures immediately prior to rice, in response to other factors such as water availability. In contrast, growers affected by snails would have been unlikely to alter the management practices that promote damaging infestations other than in response to the results of the research.

Table 11: Impact of IPM practices for aquatic snail and earthworm control

With Research	Cost Impact	Yield Impact	Without Research
A percentage of growers affected by aquatic snails adopt suitable crop rotation practices reducing area affected and crop damage and cease using copper sulphate.	Save cost of copper sulphate and application, $12 per ha in 1994 up to $33 per ha in 2006.	Reduced crop damage from aquatic snail infestation, resulting in yield improvement of 3% in MIA and 2% in MV for area adopting practices.	Rice area affected by snails suffers crop damage due to repeat cropping.
Up to 50% of remaining area affected by aquatic earthworms adopt suitable crop rotation practices in response to research recommendations	No cost impact as no chemical options available.	Reduced crop damage from aquatic earthworm infestation, resulting in yield improvement of 7% in MV and 5% in MIA for area adopting practices.	70% of rice area affected by earthworms implement suitable crop rotation practices due to restricted water availability

5.3 Benefits to 2006 from NSW DPI invertebrate rice pest IPM R&D

Table 12 shows the yield benefit (in terms of additional returns per hectare) for rice growers from reduced crop damage due to the use of IPM chemicals for bloodworm control, and the related change in the cost of chemicals per hectare. Table 13 shows the corresponding results for adoption of IPM practices for aquatic snail and earthworm control.

Table 12: Annual yield benefit and cost saving per hectare from IPM chemicals research for bloodworms, 1993-2006

	MV Yield Benefit			**MIA** Yield Benefit			Cost Saving	
	Chlorpyrifos ($/ha)	Fipronil ($/ha)	Alpha-cyphermethrin ($/ha)	Chlorpyrifos ($/ha)	Fipronil ($/ha)	Alpha-cyphermethrin ($/ha)	Chlorpyrifos ($/ha)	Fipronil ($/ha)
1993	82.6	-	-	91.6	-	-	3.0	-
1994	124.6	-	-	129.3	-	-	2.8	-
1995	117.1	-	-	122.5	-	-	3.0	-
1996	84.5	-	-	95.8	-	-	6.2	-
1997	103.5	-	-	109.9	-	-	6.0	-
1998	110.2	-	-	117.5	-	-	6.1	-
1999	-	33.0	-	-	34.9	-	-	-16.7
2000	-	31.6	-	-	33.2	-	-	-16.9
2001	-	30.3	-	-	30.3	-	-	-16.7
2002	-	33.4	-	-	36.7	-	-	-17.9
2003	-	45.9	-	-	57.5	-	-	-18.3
2004	-	36.5	349.4	-	42.4	405.3	-	-18.8
2005	-	29.9	288.9	-	36.3	350.4	-	-19.3
2006	-	43.7	419.6	-	47.4	454.9	-	-19.8

Table 13: Annual yield benefit and cost saving per hectare from IPM practices for aquatic snails and earthworms, 1994 - 2006

	MV Yield Benefit		**MIA** Yield Benefit		Cost Saving
	Snail Rotation ($/ha)	Earthworm Rotation ($/ha)	Snail Rotation ($/ha)	Earthworm Rotation ($/ha)	Snail Rotation ($/ha)
1994	37.4	-	57.6	-	12.0
1995	35.1	-	54.6	-	13.1
1996	25.3	-	42.7	-	14.3
1997	31.0	-	48.9	-	15.5
1998	33.0	-	52.3	-	16.9
1999	33.0	-	51.8	-	18.5
2000	31.6	105.5	49.3	80.6	20.1
2001	30.3	100.9	44.9	73.5	21.9
2002	33.4	111.3	54.5	89.1	23.9
2003	45.9	153.2	85.5	139.7	24.0
2004	36.5	121.9	63.0	103.0	26.9
2005	29.9	99.8	53.9	88.1	29.8
2006	43.7	145.7	70.4	115.0	32.6

5.4 Benefits to 2020 from NSW DPI invertebrate rice pest IPM R&D

The drawback of conducting only an ex-post evaluation of IPM R&D to 2006 is that the benefits from previous research continue well past 2006 in the form of long lasting productivity gains through reduced crop damage and changes to chemical costs.

While the productivity gains from reduced crop damage are long lasting, the nature of IPM is such that there is an ongoing process of adaptation by pests to measures implemented to control them. Hence, an IPM program needs ongoing maintenance R&D to preserve efficiency gains.

We have extended our analysis of the benefits and costs from DPI IPM R&D to 2020, in part to be consistent with the series of evaluations of investments in agricultural R&D being undertaken by research economists in NSW DPI.

We have assumed that the flow of annual expenditure associated with project DAN 240A will continue to 2009. Beyond this, a level of maintenance R&D of around $223,000 per annum will likely be used to respond to the emergence of new pests, the development of new chemicals and/or the ongoing development of resistance within pest populations. Adoption rates used beyond 2006 for each technology are given in Figure 3 and Table 9.

The Australian Bureau of Agricultural and Resource Economics (ABARE) estimated that in 2007 only 16,000 hectares of land was used for rice production due to a lack of irrigation water at the beginning of the season and further cuts to water allocations during the growing season (ABARE, 2007). This total area was split between the MV and the MIA based on figures for rice area in 2003, when drought conditions and water availability were similar. The projected area of rice production for 2008 is based on ABARE forecasts (ABARE, 2007) and is supported by the researcher.

Projections beyond 2008 for the area of production are based on researcher estimates of the 'steady state' area of rice production given current water availability and water legislation. The researcher has estimated the annual area of production in the MV beyond 2008 at 37,000 hectares and in the MIA at 50,000 hectares. The areas to benefit from rice invertebrate pest IPM research to 2006, and then to 2020, are shown in Table 14.

Yield estimates beyond 2006 for the MV are 9 t/ha and for the MIA are 9.5 t/ha (NSW DPI, 2007).

Beyond 2006 the medium grain rice price of $265/t is used. Table 15 shows the estimated benefit per hectare for rice growers from reduced crop damage due to use of IPM chemicals for bloodworm control and changes to chemical costs for the period 2007-2020.

Table 14: Areas to benefit from rice invertebrate pest IPM research, 1993-2020

Year	IPM Chemicals Research						IPM Practices			
	MV			MIA			MV		MIA	
	Chlorpyrifos (ha)	Fipronil (ha)	Alpha-cyphermethrin (ha)	Chlorpyrifos (ha)	Fipronil (ha)	Alpha-cyphermethrin (ha)	Snail (ha)	Earthworm (ha)	Snail (ha)	Earthworm (ha)
1993	5,584	-	-	5,477	-	-		-		-
1994	12,862	-	-	12,343	-	-	542	-	1,949	-
1995	12,649	-	-	11,905	-	-	1,065	-	3,760	-
1996	15,305	-	-	13,142	-	-	1,933	-	6,225	-
1997	17,599	-	-	13,885	-	-	2,223	-	6,577	-
1998	11,610	-	-	15,026	-	-	1,467	-	7,117	-
1999	-	6,880	-	-	8,203	-	1,651	-	7,383	-
2000	-	10,177	-	-	16,191	-	1,221	916	7,286	729
2001	-	26,065	-	-	29,159	-	2,085	3,128	8,748	1,750
2002	-	20,768	-	-	23,412	-	1,661	4,154	7,024	2,341
2003	-	1,421	-	-	10,086	-	0	0	0	0
2004	-	4,334	36	-	5,376	45	347	867	1,613	538
2005	-	3,483	58	-	3,298	55	279	697	989	330
2006	-	4,954	149	-	5,498	165	1,189	2,972	4,948	1,649
2007	-	200	7	-	1,400	46	0	0	0	0
2008	-	0	0	-	750	16	0	0	0	0
2009	-	12,180	113	-	18,270	170	835	2,088	4,698	1,566
2010	-	20,880	113	-	31,320	170	835	2,088	4,698	1,566
2011	-	23,664	113	-	35,496	170	835	2,088	4,698	1,566
2012-20	-	26,100	113	-	39,150	170	835	2,088	4,698	1,566

Table 15: Annual yield benefit and cost saving per hectare from IPM chemical research for bloodworms, 2007-2020

	MV Yield Benefit		**MIA** Yield Benefit		Cost Saving
	Fipronil ($/ha)	Alpha-cyphermethrin ($/ha)	Fipronil ($/ha)	Alpha-cyphermethrin ($/ha)	Fipronil ($/ha)
2007	41.4	397.5	43.7	419.6	-19.8
2008	41.4	397.5	43.7	419.6	-19.8
2009	41.4	397.5	43.7	419.6	-14.4
2010	41.4	397.5	43.7	419.6	-11.2
2011-20	41.4	397.5	43.7	419.6	-8.0

Table 16 shows the corresponding results for adoption of IPM practices for aquatic snail and earthworm control.

Table 16: Annual yield benefit and cost saving per hectare from IPM practices for aquatic snails and earthworms, 2007 - 2020

	MV Yield Benefit		**MIA** Yield Benefit		Cost Saving
	Snail Rotation ($/ha)	Earthworm Rotation ($/ha)	Snail Rotation ($/ha)	Earthworm Rotation ($/ha)	Snail Rotation ($/ha)
2007	0.0	0.0	0.0	0.0	32.6
2008	0.0	0.0	0.0	0.0	32.6
2009-20	41.4	138.1	64.9	106.1	32.6

6. Benefit-cost analysis

The economic surplus framework for modeling research-induced innovations as shifts in supply curves is well established (e.g., Alston *et al.* 1995). In that approach, *k*, the reduction in the marginal cost of supplying a product such as rice is estimated, applied as an exogenous shift in farm supply, and changes in consumer and producer surplus at the new market equilibrium are estimated.

This economic surplus modeling approach is more difficult to apply when there are several supply shifts (new technologies) over time and when adoption of the technologies also occurs over time. Here, we have used the incremental profit approach (GRDC, 1992) to estimate the change in profit per hectare as new technologies come on stream and as adoption rates change. This approach is equivalent to assuming that the demand curve is perfectly elastic and the supply curve is perfectly inelastic. Hence, it underestimates the total gain in economic surplus, although the error is generally not large. Despite the implications of these assumptions about demand and supply, the estimated change in profit or economic surplus should be interpreted as an estimate of gains to be shared by the industry – producers, processors and consumers – not just producers, although when demand is elastic, most of the benefits accrue to producers.

Benefit-cost analysis has been used to compare the value of benefits arising from the research with the costs of the R&D. The investment criteria used are the net present value (NPV) of the research and the benefit-cost ratio (BCR). The NPV of research is the difference between the discounted benefits and the discounted costs and should be positive. The BCR, the ratio of the net present value of benefits to the present value of costs of the research should be greater than one.

6.1 Benefit-cost results to 2006

We used data from historical NSW DPI gross margin budgets for medium grain rice in the MV and MIA regions and the views of researchers and industry experts to estimate the change in net revenue (profit) from the introduction of new technologies to manage invertebrate pests in rice. Production and price information from the NSW Ricegrowers Association, the ABS, ABARE and SunRice for the MV and MIA regions, and estimates of the adoption of technologies are then applied to the per hectare changes in net revenue to derive an estimate of the annual change in net profit for the rice industry for the period 1993-2020.

Nominal revenue flows from 1993 to 2006 were adjusted to real dollars using the Gross Domestic Product (GDP) deflator with the base year being 2006. Benefits and costs from 1990 until 2006 were compounded forward to 2006 at a real discount rate of 4% to convert benefit flows to a present value in 2006.

The net benefits from research for the MV and MIA regions were aggregated to give an annual benefit for NSW as a whole. The aggregated benefits for the ex-post analysis from 1993-2006 are shown in Table 17.

Table 17: Benefits of invertebrate rice pest IPM research by region, 1993-2006

Year	**IPM chemicals research**		**IPM practices**	
	MV *($'000)*	MIA *($'000)*	MV *($'000)*	MIA *($'000)*
1993	478	518	0	0
1994	1,639	1,631	27	136
1995	1,519	1,494	51	254
1996	1,389	1,341	77	354
1997	1,927	1,609	103	424
1998	1,350	1,857	73	493
1999	113	150	85	519
2000	150	264	160	565
2001	353	395	425	714
2002	320	439	558	759
2003	39	396	0	0
2004	88	143	128	200
2005	52	73	86	112
2006	173	218	524	699

The benefits of research from Table 17 are matched with the costs of research from Table 5 and are shown in Table 18.

Table 18: Benefits and costs of invertebrate rice pest IPM research, 1991-2006

Year	Real		Discounted	
	Benefits *($'000)*	Costs *($'000)*	Benefits *($'000)*	Costs *($'000)*
1991	0	217	0	391
1992	0	233	0	404
1993	1,387	234	2,310	390
1994	4,753	313	7,610	500
1995	4,490	277	6,913	426
1996	4,177	383	6,183	567
1997	5,317	290	7,568	413
1998	4,877	226	6,675	309
1999	1,119	211	1,473	277
2000	1,423	395	1,801	500
2001	2,246	382	2,733	465
2002	2,415	353	2,826	413
2003	496	284	558	319
2004	614	241	664	260
2005	338	198	351	206
2006	1,614	35	1,614	35

The flows of costs and benefits from 1991 to 2006 are used to calculate investment criteria, presented in Table 19. The present value of the cost of research is $5.87 million and the present value of the benefits of research is $49.3 million. The NPV is $43.4 million; BCR is 8.39; and the IRR is 226%.

Table 19: Results of benefit-cost analysis, 1991-2006

Investment Criteria	**Units**	**Value**
Present Value of Costs	$'000	5,875
Present Value of Benefits	$'000	49,277
Net Present Value (NPV)	$'000	43,402
Benefit-Cost Ratio (BCR)		8.39
Internal Rate of Return (IRR)	%	226

These results indicate that the funds invested by NSW DPI and RIRDC in the joint research projects in invertebrate rice pests IPM research between 1990 and 2006 has returned $8.39 for every dollar invested in the research.

6.2 Benefit-cost results to 2020

In the analysis of costs and benefits of invertebrate rice pests IPM research to 2020, industry projections are used from 2007 to 2020 for the 'with' research baseline. For this evaluation, the costs and benefits flow from 1991 to 2020. The aggregated benefits for the MV and MIA regions for the period 2007 to 2020 are shown in Table 20.

Table 20: Benefits of invertebrate rice pest IPM research, 2007-2020

Year	IPM chemicals research		IPM practices	
	MV *$'000*	MIA *$'000*	MV *$'000*	MIA *$'000*
2007	7	50	0	0
2008	0	24	0	0
2009	368	597	350	624
2010	670	1,080	350	624
2011	830	1,330	350	624
2012-2020	911	1,460	350	624

Table 21: Benefits and costs of invertebrate rice pest IPM research, 1991-2020

Year	Real		Discounted	
	Benefits *($'000)*	Costs *($'000)*	Benefits *($'000)*	Costs *($'000)*
1991	0	217	0	391
1992	0	233	0	404
1993	1,387	234	2,310	390
1994	4,753	313	7,610	500
1995	4,490	277	6,913	426
1996	4,177	383	6,183	567
1997	5,317	290	7,568	413
1998	4,877	226	6,675	309
1999	1,119	211	1,473	277
2000	1,423	395	1,801	500
2001	2,246	382	2,733	465
2002	2,415	353	2,826	413
2003	496	284	558	319
2004	614	241	664	260
2005	338	198	351	206
2006	1,614	270	1,614	270
2007	57	245	55	235
2008	24	211	22	195
2009	1,940	195	1,724	174
2010	2,724	223	2,329	191
2011	3,134	223	2,576	183
2012	3,346	223	2,645	176
2013	3,346	223	2,543	169
2014	3,346	223	2,445	163
2015	3,346	223	2,351	157
2016	3,346	223	2,261	151
2017	3,346	223	2,174	145
2018	3,346	223	2,090	139
2019	3,346	223	2,010	134
2020	3,346	223	1,932	129

The benefits of research from Table 17 and Table 20 are matched with the costs of research from Table 5 and Table 6 and are shown in Table 21.

The flows of costs and benefits from 1991 to 2020 are used to calculate investment criteria, presented in Table 22. The present value of the cost of research is $8.45 million and the present value of the benefits of research is $76.4 million. The NPV is $67.98 million; BCR is 9.05; and the IRR is 226%.

Table 22: Results of benefit-cost analysis, 1991-2020

Investment Criteria	Units	Value
Present Value of Costs	$'000	8,450
Present Value of Benefits	$'000	76,433
Net Present Value (NPV)	$'000	67,982
Benefit-Cost Ratio (BCR)		9.05
Internal Rate of Return (IRR)	%	226

These results indicate that the funds invested by NSW DPI and the former NSW Agriculture in the joint RIRDC research program into invertebrate pests in rice over the past fifteen years and to 2020 will have returned $9.05 for every dollar invested in the research.

6.3 Low yield and adoption scenario

The key parameters influencing the size of the benefits are the yield improvements estimated as a result of adoption of the research recommendations, as well as the estimated level of adoption of the research recommendations. They are investigated in this section

Researcher and industry estimates of the predicted adoption rate of the seed treatment fipronil (Cosmos®) differ significantly. Extension staff and chemical resellers predict that adoption will not increase any higher than current levels (as predicted by the researcher) due to inherent problems with usage of seed treatments. Issues such as difficulty with seed treatment mixing equipment, and pilot dissatisfaction with the additional time required for mixing seed treatments were cited as significant deterrents to the adoption of fipronil for control of bloodworms in rice.

Given this discrepancy, an estimate of benefits from using unchanged adoption of fipronil use from current levels (i.e., adoption constant at 15% out to 2020) and the lower of the researchers' estimates of adoption of snail and earthworm rotation recommendations (i.e., maximum adoption of 20% out to 2020) was undertaken. In addition to the altered adoption rates, estimated yield increases from adoption were also set at the lower level of estimates made by the researcher. They are shown in Table 23.

Table 23: Yield impacts used for sensitivity analysis

IPM recommendation	Region	Yield Impact
		(%)
Bloodworm control - chlorpyrifos	Both	5
Bloodworm control - fipronil	Both	1
Snail recommendations	MV	1
	MIA	2
Earthworm recommendations	MV	5
	MIA	3

The aggregated benefits from the two sources; IPM chemicals for bloodworm control and IPM practices for aquatic snails and earthworms for the MV and the MIA calculated using the revised figures are shown in Table 24.

Table 24: Revised benefits of invertebrate rice pest IPM research, 1993-2020

	IPM chemicals research		**IPM practices**	
	MV *($'000)*	MIA *($'000)*	MV *($'000)*	MIA *($'000)*
1993	353	382	0	0
1994	1,203	1,197	17	99
1995	1,116	1,097	33	187
1996	1,037	998	35	178
1997	1,432	1,194	46	213
1998	1,002	1,376	33	247
1999	0	8	39	263
2000	-9	-2	76	283
2001	-37	-41	205	357
2002	-23	14	180	335
2003	7	108	0	0
2004	10	30	62	132
2005	0	14	43	76
2006	66	89	169	310
2007	3	20	0	0
2008	0	8	0	0
2009	73	123	114	280
2010	90	148	114	280
2011-2020	107	173	114	280

The results of this sensitivity analysis are shown in Table 25. Even with the most conservative estimates of rates of adoption and yield improvements, research into invertebrate rice pests provides a significant return from investment, with a NPV of $27.8 million and a BCR of 4.29.

Table 25: Revised benefit-cost analysis, 1991-2020

Investment Criteria	Units	Value
Present Value of Costs	$'000	8,450
Present Value of Benefits	$'000	36,254
Net Present Value (NPV)	$'000	27,804
Benefit-Cost Ratio (BCR)		4.29
Internal Rate of Return (IRR)	%	186

7. Conclusions

Since 1990, NSW DPI has been involved with RIRDC in conducting research into IPM strategies for control of invertebrate pests in rice crops. In that time, it has released a flow of recommendations concerning IPM practices to control aquatic snails and earthworms and facilitated the registration of new chemicals for bloodworm control. Adoption of these recommendations and the use of the new chemistries have led to a reduction in the level of crop damage experienced by the rice producer from these pests, as well as changes to the on-farm cost of invertebrate pest control.

There have been two components to this analysis. An ex-post component has focussed on estimating the actual flow of benefits and costs to 2006. The benefit-cost ratio found in the analysis was 8.39:1, with an internal rate of return of 226%. The net present value of invertebrate rice pest IPM research over the period from 1999 to the completion of project DAN203A in 2006 was estimated at $43.4 million.

The second component was ex-ante in nature speculating about the flow of benefits arising from both investment in R&D to 2006 and a level of maintenance R&D through to 2020. In the second analysis, known investments in the invertebrate rice pest IPM program from 1990 to 2006 have been extended to include the investment in a further project DAN240A to 2009. Beyond this point, a level of maintenance expenditure is included at around $223,000 per year to 2020. Benefits beyond 2006 are calculated by extending the current flow of benefits arising from adoption of IPM practices and increased use of new bloodworm controls through to 2020.

The benefit-cost ratio found in the ex-ante analysis was 9.05, with an internal rate of return of 226%. The net present value of invertebrate rice pests IPM research over the period from 1990 to 2020 was estimated at $67.98 million. These results show a strong return to the rice industry of $9 for every dollar invested in the research, a return which is likely to have been higher than many alternative uses for those funds. These results indicate that research by NSW DPI into invertebrate pests in rice has the potential to generate substantial long-term economic benefits.

An additional analysis was undertaken to demonstrate the effects on returns of changes to the estimated levels of crop damage and the extent of adoption of IPM practices and IPM chemical control for bloodworms. The results of this analysis show a benefit-cost ratio of 4.29 would have been obtained if the assumptions of crop damage and adoption at the lower end of the researcher and industry estimates were made.

Because Australia is largely a price taker on the world rice market, most of the economic benefits of the research program are likely to remain with rice producers.

However, benefits have also flowed to chemical suppliers who have gained from research and development of new and alternative uses for chemicals particularly during the period of patent protection. Due to the nature of the Australian rice industry, there are relatively few spillovers from invertebrate rice pests IPM research to other states. The Australian rice industry is located within a relatively limited geographical area within NSW with only a small amount of production (averaging less than 1% of production over the last 7 years) occurring in Victoria so a very small economic benefit from this research will flow to Victorian rice producers. The production technologies associated with producing rice are very crop specific, hence the benefits from the existence of chemical efficacy data and chemical trial results as well as recommendations for IPM practices are not relevant and do not spill over to other crop situations.

This study has also identified some on and off-farm social and environmental benefits in the form of reduced risks to human and environmental health from invertebrate rice pests IPM research, which we have not quantified but which justify continued support from the public sector to ensure a level of investment closer to community expectations.

On-farm environmental and human health outcomes of invertebrate rice pests IPM research include: reduced usage of types of broad spectrum insecticides which can lead to an increase in farm biodiversity, and reduced exposure of farm owners and workers to harmful effects of these insecticides. On the whole, the more selective insecticides have fewer harmful effects on mammals. The newer chemistries generally require less active ingredient to be applied, hence the total quantity of insecticide applied is greatly reduced when newer rather than older chemistry is used. On-farm environmental outcomes also include reduced copper contamination of the soil from replacement of chemical control measures with IPM practices.

Environmental and human health outcomes which spill over to the community include: reduced spray drift as pest control methods move away from chemical sprays to seed treatment and crop rotation strategies, and reduced risk of chemicals moving off-site as a result of lower chemical application rates and the use of chemicals with lower drainage residues.

We focussed on quantifying the industry benefits from a program in R&D investment funded jointly by RIRDC and the NSW DPI. In 1990-2006, about 36% of the funding came from RIRDC and the remaining 64% came from public funding. For 2006-2020, it is expected that this funding split will continue with around 40% of funding coming from industry.

The strongest rationale for public funding of R&D into the control of invertebrate pests in the rice industry is based on reducing threats to environmental and human health in the community at large. We are uncertain about the size of the economic benefits from this research relative to the environmental and human health benefits but in our judgement the share of industry funding in the future for this type of research should exceed fifty percent unless the objectives of the research are specifically environmental or human health in nature.

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