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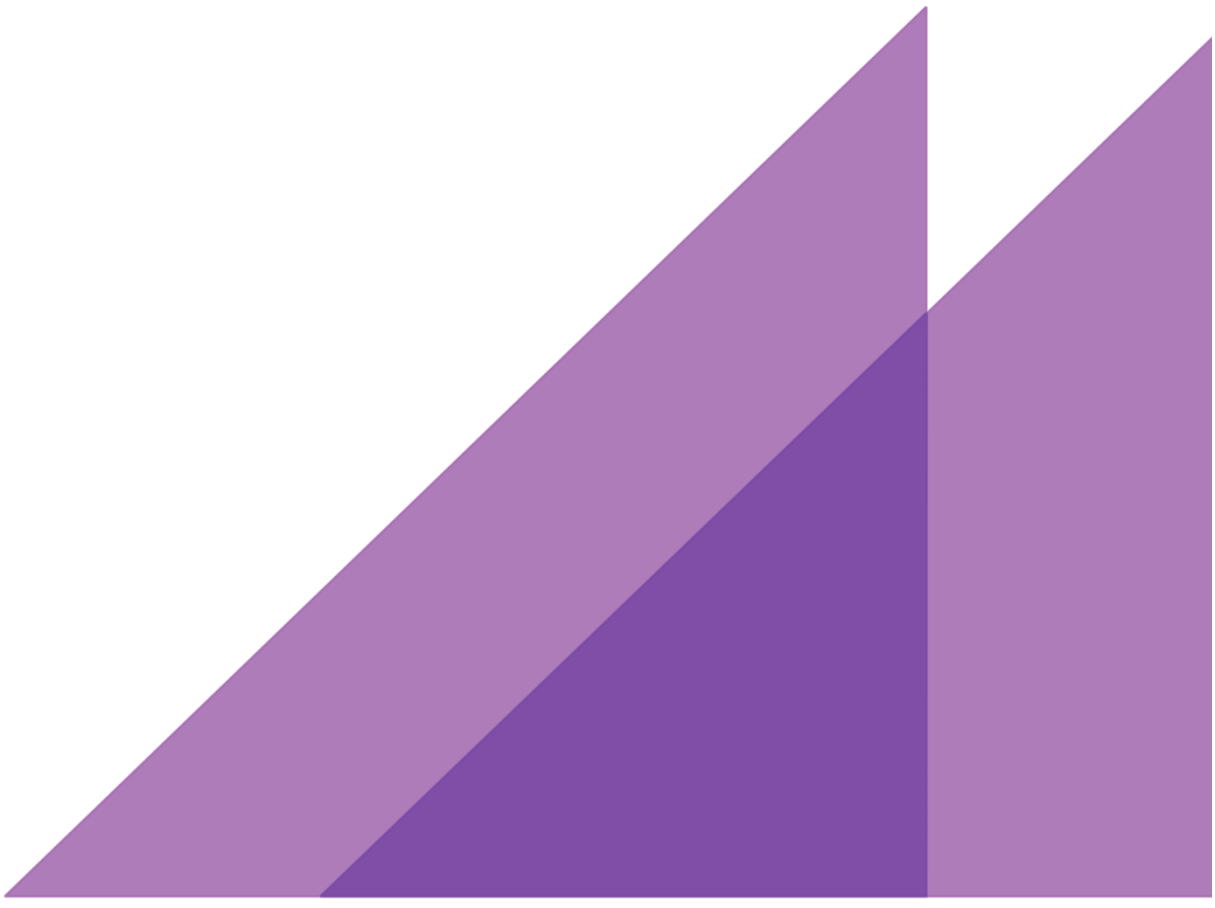
REPORT TO
CSIRO

DECEMBER 2014

CSIRO's IMPACT AND VALUE

AN INDEPENDENT EVALUATION



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Appendix A Process used to select the case studies

Case studies were chosen, through a purposive sampling approach, to provide coverage of major classes of CSIRO activity, when viewed in conjunction with recent reviews, and to demonstrate some strong value propositions.

It is undoubtedly true that the selection process favoured the inclusion of some projects and programs where it was generally believed that some form of uptake and adoption, or impact had been realised. However, it also led to the inclusion of some case studies where the subsequent cost-benefit assessment, while favourable, was not overly strong. It also excluded some potentially very high impact case studies. The case studies selected spanned a fairly wide range when viewed in terms of the benefit-cost assessments undertaken.

CSIRO specified various criteria to be used in selecting the case studies, namely:

- Research must represent the likely **themes** dominant in the next CSIRO (2015-25) Strategy
- Research must be relatively **mature** (able to show outcomes) and have achieved a key milestone on its path to impact in the last 4 years' funding.
- At least 3 case studies that show Impact Scale 4[3], to provide upper bound for benefit-cost ratio.
- Evidence of inputs (i.e. **costs)**, outputs, outcomes must be available so that a CBA can be conducted and cost-benefit ratio generated.
- **Resources** (Science Leader) must be available from within the Group to assist with access to data & information.
- The case studies should be broadly representative of the **domains** and pathways to impact in which CSIRO works.
- The case studies should demonstrate a range of **impact pathways.**

The selection process began with a 'long list' of 38 candidates for case study consideration and then, through application of the criteria, moved towards a 'short list' of 16, out of which the final decision to do deep case study assessment of seven of these was taken. All activities included in the 'long list' had already been identified as having significant benefit, and the shortlisting process, followed by the selection of only half of those on the shortlist, certainly removed from the case study set a wide range of activities that had already demonstrated significant value and where, in most cases, there was also good prospects for substantial additional future value.

Included amongst the activities that were on the shortlist, but which ultimately were not selected as case studies were the following:

- CSIRO's Reverse Addition-Fragmentation chain Transfer (RAFT) technology that offers a revolutionary new approach to the development of sophisticated multi-function polymers, with potential application across a very wide range of areas.
  - The diverse range of potential applications, the dramatically greater control offered by RAFT, down to the molecular level, and the innate flexibility of the technology, strongly suggest the technology could revolutionise many areas of polymer design

[3] Impact Scale 4 refers to impact that is global in nature.

and application in ways that could deliver very high value, as a commercialised technology and as an opportunity for Australian industry.

  - RAFT is already licensed globally, but the expertise and IP remain in CSIRO.

- CSIRO's Wireless Ad hoc System for Positioning (WASP), a portable, low cost system for tracking people and objects even in areas where traditional methodologies do not work.
  - The technology offers diverse applications, but CSIRO has been pursuing applications mainly in the areas of mining, security (including medical monitoring and emergency responses, such as to fires where GPS is not viable) and sport
  - Again, the technology has global relevance and appears to support a wide range of commercially and socially attractive applications.
- Coastal Property Adaptation, dealing with flood risks and threats from climate change and sea level rise.
  - For example ACIL Tasman's 2010 study suggested benefits of the order of $200 million for coastal communities through better planning and zoning
- Teleophthalmology – a service being delivered out of work done by CSIRO's Digital Productivity and Services Flagship, targeting blindness with diabetic retinopathy, with the service being delivered to remote areas of Australia via an ophthalmologist using a satellite solution.
  - The service is delivering direct value while demonstrating the opportunities for digital technologies to deliver high value services to remote Australia.
- CSIRO's Continuous Titanium Powder Manufacture Process (TIRO™) which delivers the capability for the production of pure titanium and titanium alloy, and the production of manufactured titanium products at dramatically lower cost than traditional methods.
  - This opens up opportunities for competitive titanium manufacture in Australia, and for the development of new products using titanium.

Even beyond the shortlist, the original selection of potential case studies included a number of areas with strong value propositions – including in relation to management of the Great Barrier Reef, the now commercialised UltraBattery, and the Zebedee hand-held laser 3D scanning and mapping technology.

The case studies that emerged from the selection process account for approximately 7 per cent of CSIRO's operating expenditure and 8 per cent of its expenditure on Flagship, program and project activities. This reinforces the extent to which major investment is being made beyond the case studies selected for analysis.

Appendix B Case study: Australian Animal Health Laboratory (AAHL)

SUMMARY OF KEY FINDINGS

- AAHL provides Australia with important disease mitigation and outbreak response mechanisms for animal and zoonotic (human pathogens of animal origin) diseases that could devastate industries such as beef production (worth $7.1 billion in 2012-13), aquaculture (worth $1.1 billion in 2011-12), horse racing (worth $6.2 billion per annum) and livestock breeding. AAHL also has an important role to play in protecting human health, which delivers benefits across the economy as a whole.
- AAHL is actively involved in providing protection from threats of
  - Foot and mouth disease (FMD)
  - Transmissible Spongiform Encephalopathy
  - Hendra virus
  - Middle Eastern respiratory syndrome
  - Avian influenza
  - Insect-borne diseases
  - Aquatic animal (finfish, molluscs and crustaceans) diseases
- The insurance value in relation to foot and mouth disease (FMD) alone is some $431 million per annum, which exceeds AAHL's annual operation costs by more than seven times (see Table A2).
- Insurance values in relation to AAHL's work on other Biosecurity threats add considerably to the insurance value benefits delivered in relation to FMD. For example, there are several studies that suggest that an avian influenza pandemic would reduce Australian GDP in the first year alone by up to 10 per cent of GDP.

B.1.1 Purpose and audience

This independent case study has been undertaken to assess the economic, social and environmental impact of CSIRO's Australian Animal Health Laboratory (AAHL). The case study has been prepared so it can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of CSIRO's activities.

The report is provided for accountability, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, CSIRO and the general public.

B.1.2 Background

AAHL was officially opened in 1985 (although research work began in 1984). It plays a vital role in protecting the health of Australia's livestock, aquaculture species and wildlife from the impact of infectious diseases. This in turn helps to ensure the ongoing competitiveness of Australian agriculture and trade.

AAHL can respond rapidly to disease outbreaks that could have serious national impact

Importantly, AAHL has the capability to respond rapidly to disease outbreaks that could have serious national impact. AAHL also helps to protect the general public from the threat of zoonotic diseases (viruses that pass from animals to humans).

Before AAHL opened, most samples that needed to be tested for exotic animal disease were sent overseas for analysis. This took considerable time and resulted in a loss of control over important trade-related information for Australia. The establishment of AAHL meant exotic diseases could be diagnosed within Australia, providing protection and support for Australia's trade in the export of animal products and live animals. Since opening, AAHL has

supported Australian state veterinary laboratories by testing hundreds of thousands of samples and has helped to detect and characterise many new viral diseases.

The AAHL facility would cost $1.4 billion to build now

The AAHL building alone would cost in the order of $1.4 billion to replace.[4] This excludes the cost of the land and the costs and time in replacing the massive staff capability that has been assembled. Its annual operating budget is approximately $60 million, with approximately two-thirds met from the CSIRO and the remainder from the Commonwealth Department of Agriculture, industry, international agencies and other smaller sources of funding.

AAHL received NCRIS funding for the recent construction of the Physical Containment level 4 (PC4) Zoonosis Suite as well as a PC3 laboratory to study arboviruses. In addition, some funding was provided for the work on Hendra virus through the Intergovernmental Hendra Virus Taskforce. Details of AAHL's revenue are shown in Table B1.

Table B1 **AAHL resourcing ('000)**

	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014
Income						
CSIRO operational funding	5404	7003	8441	9735	9595	8152
Department of Agriculture Operational Funding	7138	7159	7252	7391	7545	7665
External revenue	10850	13334	11137	12640	9762	11128
Support services						
CSIRO Support services	12511	12815	12332	10922	13408	14928
Depreciation						
CSIRO Funded Depreciation	2233	2906	3206	4953	4541	5563
CSIRO Government Funded Depreciation	12997	12997	12997	12997	12997	12997
TOTAL	**51133**	**56214**	**55365**	**58638**	**57848**	**60433**

Source: CSIRO

Table B2 **AAHL expenditure ('000)**

	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014
Salaries	16032	18972	20459	21453	19017	18745
Travel	1479	1440	946	1000	975	907
Operating	5881	7084	5425	7313	6910	7293
CSIRO support services	12511	12815	12332	10922	13408	14928
Depreciation						
Depreciation AAHL P&E	697	1139	1270	1271	1635	1508
Depreciation AAHL Building	14533	14764	14933	16679	15903	17052
	51133	**56214**	**55365**	**58638**	**57848**	**60433**

Source: CSIRO

B.1.3 Approach

The approach taken in this case study is based on CSIRO's impact framework and generally aligns with the nine-step process described in the CSIRO's impact evaluation guide, namely:

1. Initial framing of the purpose and audience of the impact evaluation.

[4] CSIRO 2014 estimate of building replacement cost, excluding demolition and land costs.

2. Identify nature of impacts (*what is the impact pathway, what are the costs and benefits*)
3. Define a realistic counterfactual (*what would have occurred in the absence of CSIRO*)
4. Attribution of research (*CSIRO vs. others' contribution*)
5. Adoption (*to date and in future*)
6. Impact (*timing, valuation, distributional effects among users, effects on non-users*)
7. Aggregation of research impacts (*within program of work*)
8. Aggregation of impacts (*across program of work*)
9. Sensitivity analysis and reporting.

This case study examines potential impacts from a small subset of AAHL's research activities.

B.1.4 Project origins and inputs

AAHL's mission is:

> To protect a healthy, productive and prosperous future for Australia's animals and people by delivering world renowned science that will further our understanding and management of infectious diseases

AAHL's research aligns with the goal of the Biosecurity Flagship

AAHL's work also aligns well with the goal of the Biosecurity Flagship by reducing risks from disease and improving the effectiveness of mitigation and eradication responses. The diagnostic skills and knowledge of scientists at AAHL form an important component of Australia's preparedness to deal with an emergency animal disease outbreak. Despite Australia's strict quarantine procedures, there is still a risk that an exotic (foreign) animal disease could be introduced into Australia. The potential impacts, dependent on the disease, include illness in humans, domestic animals and wildlife and cost to the economy of billions of dollars through loss of trade, tourism and other costs associated with recovery from a disease outbreak.

AAHL plays an integral role in investigating exotic and emergency disease outbreaks …

AAHL plays an integral role in investigating exotic and emergency disease incidents, allowing such diseases to be ruled out or to ensure rapid implementation of control strategies. It also provides diagnostic testing services for surveillance programs such as the National Arbovirus Monitoring Program, the Northern Australia Quarantine Strategy and the National Transmissible Spongiform Encephalopathy Surveillance Program.

… and identifying and characterising new diseases

AAHL has also been crucial in identifying and characterising new diseases including Hendra Virus, Australian Bat Lyssavirus, Pilchard Herpes Virus and Abalone Herpes Virus.

Quality assured diagnostic tests are critical to the success of surveillance programs and to the accurate diagnosis and control of disease outbreaks. A state-of-the-art high throughput testing laboratory, the Diagnostic Emergency Response Laboratory was opened in 2008 and can be operated in two different modes – routine or outbreak – dependent on the circumstances.

There is an increased incidence of emerging human infectious diseases of animal origin around the world. Zoonotic diseases have caused fatalities in humans including viruses borne by bats that can be transmitted either directly or indirectly to humans such as:

- Hendra and Nipah viruses,
- Australian bat Lyssavirus,
- Sudden Acute Respiratory Syndrome (SARS)
- Middle Eastern Respiratory Syndrome (MERS)
- Zaire Ebola virus.

AAHL's expertise is internationally recognised

AAHL has developed world-leading methodologies to isolate bat viruses and is now internationally recognised for this work. AAHL research has led to the characterisation of new viruses and development of a vaccine as in the case of Hendra virus; and the successful isolation of the SARS virus from the Chinese horseshoe bat.

B.2 Program activities and outputs

In the current strategy period there has been important work undertaken in relation to:

- Foot and mouth disease (FMD)
- Transmissible Spongiform Encephalopathy
- Hendra virus vaccine
- Middle Eastern respiratory syndrome (where the work is now gearing up)
- Avian influenza
- Insect-borne diseases
- Aquatic animal (finfish, molluscs and crustaceans) diseases
- Testing

B.2.1 Foot and mouth disease preparedness

FMD is a serious biosecurity threat to Australia …

… an FMD outbreak could cost the Australian economy $50 billion over 10 years

Activity

Fo*ot and mouth* disease (FMD) is the most serious biosecurity threat facing Australian agriculture and an FMD outbreak could cost the Australian economy up to $50 billion over 10 years (Buetre B. *et al*., 2013). Australia has been free of the disease since 1872 (AHA, 2014) but many of our neighbours in Asia are not as fortunate. In many Asian countries, the livelihoods of the people are dependent on their livestock and as FMD affects both milk production and reproduction, the disease can have a severe and relatively quick impact on many people.

Australia remains very much at risk of a FMD outbreak

While Australia is classified as free from FMD, the disease is endemic in much of the Asian region and the ease and rapidity of international travel by large numbers of people means that Australia remains very much at risk of an outbreak.

The AAHL facility has both the infrastructure and scientific capability to manage testing and research requirements during an FMD outbreak. However, all 'peace time' research on the virus is performed in partner laboratories overseas.

As vaccination is a key control measure that will be used in the face of an outbreak, CSIRO is working with these partner laboratories to study the effectiveness of FMD vaccines in target animal species to verify that the currently available vaccine strains in the Australian vaccine bank will protect against newly emerging strains of the virus.

Outputs

In the current CSIRO strategy period (2011-15) AAHL scientists are helping several countries in the region to improve their diagnostic capabilities and research into FMD, which in turn helps AAHL better understand the FMD virus strains circulating in the region.

As vaccination is a key control measure that will be used in the face of an outbreak, CSIRO continues to work with various other laboratories to study the effectiveness of FMD vaccines in target animal species to verify that the currently available vaccine strains in the Australian vaccine bank will protect against newly emerging strains of the virus

B.2.2 Transmissible Spongiform Encephalopathy

Activities

AAHL is the reference laboratory for the National Transmissible Spongiform Encephalopathy (TSE) Surveillance Program. TSE includes bovine spongiform encephalopathy (BSE, referred to in the media as mad cow disease) and scrapie in sheep. Australia is free of these diseases and has been designated a "negligible risk" status (the lowest risk) by the World Organisation for Animal Health (OIE).

AAHL's role supports trade by helping to maintain a surveillance system for TSEs that is consistent with the OIE Terrestrial Animal Health Code. This assures all countries which import cattle and sheep commodities that Australia remains free of these diseases. It is important that Australia meets this requirement to assure continued access to export markets.

Outputs

The principal Transmissible Spongiform Encephalopathies (TSEs) of concern to Australia are BSE and scrapie. Australia has never had a case of BSE and had only an isolated case of scrapie in 1952. Diagnosis of any TSE in Australian livestock would have major impact on both domestic and international markets.

AAHL tests an average of 400 samples each year from diseased animals to rule out TSEs. AAHL also plays a major role in the national TSE freedom assurance program (TSEFAP), testing an average of 300 samples collected at abattoirs each year as part of the national surveillance program to assure our international trading partners that Australia's status as free of these diseases is being monitored and maintained.

These programs have resulted in the diagnosis of several cases of atypical (spontaneous) TSE in recent years and AAHL has played a central role in assuring Australian regulators and international partners that these cases are of no public health or trade significance, but rather indicate that the surveillance system is effective.

B.2.3 Hendra virus vaccine

Activities

The Hendra virus that was first identified by AAHL scientists in horses in 1994 is a Biosafety Level-4 disease agent, which is the most dangerous level of pathogen in the world. CSIRO isolated and identified the virus within two weeks of it being reported. A horse vaccine was identified as a crucial element of the strategy for breaking the cycle of Hendra virus transmission from animals to people, as it prevents the horse developing and passing on the disease.

Developing a vaccine was crucial to breaking the cycle of Hendra virus transmission

While Hendra virus has relatively limited transmission, it has fatal outcomes. The 1994, 2005 and 2011-14 Hendra virus outbreaks in Queensland and New South Wales highlight the risk such serious pathogens pose to the Australian community. AAHL's work on the Hendra virus has involved innovative science and international collaboration.

In 2008 an international research team including AAHL scientists evaluated a recombinant subunit vaccine formulation to protect a small animal model against the lethal Nipah virus. This research provided significant input to the development of a prototype Hendra virus vaccine for horses.

Outputs

In May 2011 CSIRO announced a prototype vaccine, and along with its collaborators, launched the Equivac® HeV vaccine in November 2012. It breaks the only known Hendra virus transmission pathway from horses to humans. To date, the infection pathway of humans with Hendra virus has been from bats to horses, then from horses to humans. There is no evidence of human to human transmission or of direct bat to human transmission.

AAHL is the only laboratory in the world capable of studying horses at PC4

The development of the vaccine was the result of a close collaboration between CSIRO and the Uniformed Services University of the Health Sciences (the US federal Health Sciences University) supported by the US National Institutes of Health and Pfizer Animal Health Australia (now Zoetis Australia). The high containment facility at AAHL was essential for evaluating its beneficial effects as AAHL is the only laboratory in the world with a large animal facility capable of studying horses at PC4. This work could therefore not have been undertaken anywhere else.

Following a surge in Hendra virus cases in 2011, regulatory authorities agreed to assess the Hendra virus horse vaccine with high priority during its registration process. The Intergovernmental Hendra Virus Taskforce was formed, and the National Hendra Virus Research Program allocated funding to ensure critical timelines for vaccine development were maintained.

In 2012, the Australian Pesticides and Veterinary Medicines Authority granted the Hendra virus horse vaccine (Equivac® HeV) a Minor Use Permit after the vaccine met all essential safety, quality and efficacy requirements. Later that year, Pfizer Animal Health (now Zoetis Australia) made the Equivac® HeV vaccine available, under permit, for accredited veterinarians to administer to horses. It is recommended that horses receive three doses of vaccine and then subsequent boosters. More than 200,000 doses have now been administered in Australia.

Equivac® HeV is the world's first commercial vaccine for a Bio-Safety Level-4 disease

By March 2013 CSIRO scientists confirmed that horses were immune to a lethal exposure of the Hendra virus six months post vaccination. The Australian Veterinary Association now recommends that all horses in Australia are vaccinated against the Hendra virus. Equivac® HeV is a world-first commercial vaccine for a Bio-Safety Level-4 disease agent.

This vaccine enables commercial and private equine activities to continue with minimal negative impact by increasing personal safety for horse owners, vets and others who regularly interact with horses. The vaccine has reduced costs attributed to future disease response and containment and also minimised the chances of the Hendra virus mutating and spreading more readily between horses, or from human to human.

B.2.4 Middle Eastern respiratory syndrome

Activities

Middle East Respiratory Syndrome (MERS) is a viral respiratory illness first reported in Saudi Arabia in 2012. It is caused by a coronavirus called MERS-CoV. The disease reservoir host for the virus is the bat and the virus has spread from bats to camels and to people. Most people who have been confirmed to have MERS-CoV developed severe acute respiratory illness following close contact with an infected person. They had fever, cough, and shortness of breath. About 30 per cent of people confirmed to have MERS-CoV infection have died (CDC, 2014) and so far, all the cases have been linked to countries in and near the Arabian Peninsula. There is potential for MERS-CoV to spread further and cause more cases globally. The first imported cases of MERS in the USA were confirmed in travellers from Saudi Arabia in May 2014.

Given AAHL's capability to develop animal models for the study of infectious diseases, AAHL has been researching MERS in mice and ferrets as potential models for human disease.

AAHL's expertise is recognised in its international partnerships

CSIRO and Duke-NUS (an alliance between Duke University in North Carolina, USA and the National University of Singapore) have recently signed a relationship agreement with a view to forming the International Collaborative Centre for One Health to assist in taking a new approach to tackling deadly viruses such as MERS. This partnership approach integrates the disciplines of medical, veterinary, ecological and environmental research to develop new tests for early and rapid detection of emerging infectious diseases.

Outputs

In the current CSIRO strategy period AAHL has ensured that Australia has the ability to diagnose this disease, for public health preparedness and has also commenced some surveillance work in Australian camels.

CSIRO scientists at AAHL have also investigated the suitability of housing alpacas in AAHL's Large Animal Facility as a potential animal model for disease in camels. By understanding the impact of the virus on the immune system of alpacas it is hoped this may lead to understanding why camels are susceptible to infection and how they transmit the disease to people.

B.2.5 Avian influenza

Activities

Avian Influenza is the most likely potential pandemic threat. AAHL is the national reference laboratory for Avian Influenza. When the H5N1 strain spread through China and then Southeast Asia, with increasing numbers of deaths in people, AAHL was contacted by AusAID to work first in Indonesia and Vietnam, and then most of ASEAN countries. AAHL is now recognized for its work on dangerous emerging zoonoses in the region.

AAHL is recognized for its work on dangerous emerging zoonoses in the region

AAHL is coordinating animal health (OFFLU) inputs to the WHO vaccine strain selection meetings that choose the antigens for human influenza vaccines, both for seasonal influenza and identified pandemic threats of animal origin. AAHL is also involved in other advisory activities in relation to avian influenza. AAHL is part of the global preparedness effort for a possible pandemic. It also plays an important national preparedness role by ensuring Australia has the capacity to respond quickly to an outbreak of avian influenza in Australia poultry.

AAHL's work on influenza is crucial to Australia's pandemic preparedness

The capability of AAHL to work with influenza viruses that have pandemic potential allowed Australia to have a human vaccine approved by the Therapeutic Goods Administration ready for an H1N5 epidemic and a stockpile of vaccine is available (Department of Health and Ageing, 2009).

Outputs

In early-2013 a new avian influenza threat, the H7N9 strain, emerged in China which threatens Southeast Asia and beyond. In response to the outbreak, AAHL has developed diagnostic test kits for the H7N9 strains and through its international connections assisted FAO to make these available among regional countries. The kits were exported to laboratories in 13 countries across the region to enable rapid diagnosis and facilitate effective disease control strategies.

AAHL's H7N9 test kits were exported to laboratories across the region

AAHL has become a trusted adviser in the region and AAHL's contacts with SE Asian Avian Influenza laboratories and knowledge of the disease in the region is recognised globally.

During the late-2013 outbreak of avian influenza around Young in NSW, AAHL undertook research to rapidly characterise the virus, proving that it was a local H7N2 strain and not the highly pathogenic strain circulating in Asia. If it had been found to be H7N9 it would have been the first case outside China. Because H7N9 is known to infect humans, the profile of the response would have had to be quite different. Even so, the outbreak led to the destruction of 450,000 chickens with a resulting shortage of eggs in NSW in the lead-up to Christmas (DPI (NSW), 2014).

B.2.6 Insect-borne diseases

Activities

Mosquitoes, midges and ticks, transmit many disease-causing viruses. These can affect livestock, wildlife and human health. With the impact of climate change, urbanisation and global travel, this mode of disease transmission is likely to become the most significant in the spread of new and emerging diseases across the world.

Insect borne diseases are an emerging challenge

Some of the most serious of these viruses (arboviruses) include yellow fever, West Nile virus, Japanese Encephalitis and Rift Valley fever. Although these viruses are not endemic in Australia, they are studied by AAHL's scientists from a surveillance and research perspective.

Other arboviruses such as bovine ephemeral fever (BEF), bluetongue, epizootic haemorrhagic disease, Dengue fever, Kunjin and Ross River virus are already in Australia and are closely managed in order to reduce the spread and impact of these diseases to livestock and people. AAHL is the national reference laboratory for the arbovirus surveillance program.

By studying the factors that influence arboviruses, immune response and the distribution of these carrier insects (vectors), AAHL has been able to develop intervention strategies and provide Australia with early warnings of new or exotic diseases.

The PC4 Insectary was built under NCRIS and houses colonies of exotic and endemic insects

AAHL's arthropod research program is underpinned by insectaries within both the Physical Containment levels 3 and 4 areas of AAHL. The PC4 Insectary was built under the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS) and houses colonies of exotic and endemic insects. PC4, being the highest level of biocontainment, will allow testing of Australian biting arthropods for their ability to transmit some of the most dangerous exotic viruses known. The insectary is available for use by Australian and international researchers for collaborative studies of arthropod‑borne diseases.

Outputs

AAHL programmes in the current CSIRO strategy period (2011-15) include work on bluetongue virus. Bluetongue virus is carried between animals through the bite of the culicoides biting midge. This viral disease is clinically unapparent in cattle and yet seriously affects sheep. Though endemic in northern Australia with little impact, any spread to the sheep populations of southern-Australia would cause a severe impact and significant trade losses to our sheep industry.

AAHL monitors culicoides midge population movements across southern Australia

AAHL's work on the culicoides midge involves surveillance studies on their occurrence in southern Australia, monitoring of midge population movements across the Timor Sea, and studying their genetics and investigating the ability of local southern species to transmit the

virus. Projects on the bluetongue virus involve researching how the virus evolves and changes and understanding the pathogenesis of transmission of the virus by midges.

By researching the immune mechanism that protects insects from the diseases they carry, it may be possible in the future to create poor virus transmitters thereby breaking the transmission cycle.

Current research programs are also delivering results in the study of Bovine Ephemeral Fever (BEF), commonly known as three day sickness. BEF is a disease of cattle and occasionally buffaloes, marked by short fever, shivering, lameness and muscular stiffness. Transmitted by mosquitoes, the disease is widespread in northern Australia.

BEF is of concern to the livestock industry as it causes serious economic losses through deaths, loss of condition, decreased milk production, lowered fertility of bulls, mismothering of calves, delays in marketing and restrictions on the export of live cattle.

CSIRO's arbovirus research team at AAHL are working to improve the BEF vaccine, understand the factors controlling the occurrence of BEF in animals, the evolution of the virus in Australia, as well as contributing to surveillance programs by characterising new and emerging virus strains.

B.2.7 Aquatic animal diseases

Activities

AAHL maintains a significant diagnostic and research capability for aquatic animal diseases, particularly those caused by exotic, and new and emerging, infectious agents. This work supports capture fisheries, aquaculture, and natural resources. AAHL projects in the current CSIRO strategy period (2011-15) include work on Ostreid herpesvirus (affecting edible oysters), Abalone herpesvirus (affecting farmed and wild abalone), Megalocytivirus (affecting a range of finfish species) and Yellowhead virus (affecting a range of prawn species).

AAHL's work supports Australia's aquaculture industry

Most recently, work has been focussed on viral agents causing diseases currently affecting Australia's largest aquaculture industry, Tasmanian salmonid farming. Using whole genome sequencing technology, AAHL is characterising viral isolates from diseased salmon. This research has demonstrated that an Orthomyxovirus initially isolated from salmon in 2006, and more recently in 2012, is in fact closely related, if not identical, to an Othomyxovirus isolated from healthy pilchards in 1998 and again in 2007 from South Australian waters, and in 2013 from pilchards in Tasmanian waters. This research clearly demonstrates that there are unique viruses present in wild fish species in Australian waters that can cross over to aquaculture species with serious consequences.

This research is part of a larger project on virus characterisation, contracted by the Tasmanian salmonid industry, and is vital to this industry's overall health strategy to develop viral vaccines. Salmonid farming delivered an annual value of some $516 million to fishermen in 2011-12 (RIRDC, 2014). The gross value of Australia's aquaculture production was $1.05 billion in 2011-12 (ABARES, 2013b).

Outputs

AAHL scientists have undertaken the painstaking research required to validate a number of molecular diagnostic tests for Abalone herpesvirus, Ostreid herpesvirus, Megalocytivirus and white spot virus (of prawns) so that diagnostic laboratories within the Australian network, state veterinary authorities and the Australian Chief Veterinary Officer are confident in the performance of these tests when used for surveillance, diagnosis and import and

export testing. Moreover, research on the yellow head complex of viruses has demonstrated the emergence of novel genetic variants necessitating further research on their pathogenicity and on development and validation of further diagnostic tests for this virus complex.

AAHL has continued its long association with the Tasmanian Department of Primary Industry, Parks, Water and Environment and the Tasmanian Salmonid Growers Association. AAHL is a partner in an overall strategy to provide high quality health services to the salmonid industry. The results of research on the characterisation of the three significant viral pathogens, the Orthomyxovirus, the Aquabirnavirus and the Aquareovirus, are forming the groundwork on which the salmonid vaccine development program is being based.

B.2.8 Testing capability

Activities

Testing is, arguably, the most important work done by AAHL. It underpins Australia's multimillion dollar animal exports

AAHL maintains a significant diagnostic capability for animal diseases. The maintenance and continuous upgrading of this capability to cover new diseases or to incorporate new laboratory technologies is the most significant scientific activity at AAHL. AAHL works with State veterinary laboratories by testing samples for disease exclusion in the following categories:

- Category 1 – testing of animals being imported and exported to and from Australia
- Category 2 – testing of diagnostic samples provided by State veterinarians showing signs of clinical disease for serious problems such as avian influenza
- Category 3 – required when veterinary officers suspect an outbreak of exotic disease due to evidence such as a mass bird die-off in the case of influenza. FMD and zoonotic diseases fall in this category.

AAHL performs a large number of diagnostic tests every year

Some 797 tests are currently available and ready for immediate use. Of these, 371 tests are accredited within AAHL's Quality Assurance system, covering 55 terrestrial and 40 aquatic animal diseases. In the past year, AAHL received and responded to 592 cases that were either Category 2 or 3 (i.e. dealt with potential reportable emergency animal disease and/or had history of human exposure and required urgent results to determine response and/ or treatment regime). AAHL has performed between 85,000 and 68,000 diagnostic tests annually over the past 5 years.

Outputs

AAHL's diagnostic testing services for surveillance programs validate the nation's reputation as a safe and reliable trading partner and maintain the nation's competitive position in the global trade of animal products and live animals.

These services also enhance pre-border security by providing diagnostic support to our Asian neighbours.

Some 797 tests are currently available and ready for immediate use. Of these, 371 tests are accredited within AAHL's Quality Assurance system, covering 55 terrestrial and 40 aquatic animal diseases. This is, arguably, the most important work carried out at AAHL, as it constitutes the essential elements of the diagnosis, surveillance and response activities that facilitate the animal health certification required by Australia's multimillion dollar export trade in animals and animal products. The total value of Australia's meat exports (including live sheep and cattle) was $7.89 billion in 2012-2013 (ABARES, 2013a).

In the past year, AAHL received and responded to 592 cases that were either Category 2 or 3 (i.e. dealt with potential reportable emergency animal disease and/or had history of human exposure and required urgent results to determine response and/ or treatment regime). AAHL has performed between 85,000 and 68,000 diagnostic tests annually over the past 5 years.

CSIRO has led the development of the LEADDR network

CSIRO has also led the development of the Laboratories for Emergency Animal Disease Diagnosis and Response (LEADDR) network. The LEADDR network ensures harmonisation between diagnostic testing at AAHL and state laboratories. This has increased the efficiency of Australia's testing network and its capacity to meet surges in demand that arise during disease outbreaks.

B.2.9 Awards and public recognition

Research at AAHL has been awarded

The Hendra vaccine program has been recognised internationally as an outstanding example of bringing together the veterinary and medical professions to control a major public health threat.

The efforts of the research team at AAHL to inform and help the veterinary profession and horse industry understand the mechanisms of transmission and infection control have been recognised through an Equine Veterinarians Australia Award for Service to the Horse Industry, and an Australian Veterinary Association Meritorious Service Award in 2013.

The Hendra Virus Research Team won a prestigious Eureka Award in 2014

The work on the Hendra virus was also recognised with the CSIRO Chairman's Medal 2013 and the ultimate accolade in 2014 with the team winning a prestigious Eureka Award (the Australian Infectious Diseases Research Centre Eureka Prize for Infectious Diseases Research) (AM, 2014).

The Abalone herpesvirus project team, comprising of scientists from DPI Victoria and AAHL were awarded the Daniel McAlpine DPI Science Award in 2010 in recognition of the rapid development and deployment of diagnostic tests for this previously unknown virus.

B.3 Status of Outcomes and Impacts

B.3.1 Nature of Outcomes and Impacts

There are a variety of existing and potential beneficiaries from the work of AAHL. Using CSIRO's triple bottom line benefit classification approach, Table B3 summarises the nature of the outcomes and impacts to date.

Table B3 **Impacts and Outcomes of AAHL research**

Outcome Impact	Description
Environmental impact category	
Improved biodiversity *Impact: Ecosystems and Biodiversity* *Reach: State industry*	Access to Hendra vaccine means a reduction in the number of infected horses and less need to dispose of diseased animals. Lower incidence of disease and increased awareness about disease transmission means reduced pressure from the community to kill bats. Benefits to ecosystems/biodiversity through reduction in threats to species. Environmental benefits delivered by healthy bat populations include seed distribution and pollination.
Social impact category	
Improved health outcomes *Impact: Life & health* *Reach: National, global*	Access to an influenza vaccine that best protects against the current influenza virus(es) will reduce illness incidence rates, minimise the risk of a pandemic and save lives. Early warning of emerging health threats will help to develop intervention strategies and reduce the severity of any disease outbreak. The Hendra vaccine is saving lives of those who work with horses (especially veterinarians).
More reliable farm income streams *Impact: Standard of living, resilience* *Reach: National, global*	Reduced incidence of disease among farm animals and less loss of stock is a benefit to the standard of living of farming communities (in Australia and overseas). Development of the Hendra virus vaccine has reduced the risks of disruption to events involving horses (pony club meetings, race meetings, dressage, etc.).
Greater confidence in agricultural industry *Impact: Social licence to operate and community confidence* *Reach: National*	The reduction in disease incidence and the need to cull infected animals provides a higher level of confidence in the sector among the general population. AAHL's work underpins the security of rural employment for farmers and for other businesses in the supply chain. The development of the Hendra vaccine has halted the movement of equine veterinarians away from horse treatment.
Economic impact category	
More reliable livestock trade *Impact: International trade, the macro economy.* *Reach: National*	An outbreak of an animal disease such as FMD would be extremely damaging to Australia's international livestock trade. Outbreaks of FMD in Taiwan and Korea led to the loss of billions of dollars of meat exports. The work done by AAHL provides the buyers of our meat with the confidence that those exports are from disease free herds.
Improved diagnostic testing *Impact: New products or services* *Reach: National, global*	CSIRO can test for a large number of different animal diseases. It conducts many tens of thousands of tests each year.
New vaccines created *Impact: New products or services* *Reach: National, global*	CSIRO developed the Hendra vaccine that is currently being marketed by Zoetis Australia. CSIRO research also helps to ensure the efficacy of the annual influenza vaccine sold by firms such as CSL.

Source: ACIL Allen Consulting

The beneficiaries (and potential beneficiaries) of AAHLs work include:

- Farmers raising animals
- The meat and fish processing industry
- Animal and animal product customers in countries that import from Australia
- Pony clubs and other people involved in equestrian activities
- The Australian community

As shown in Table B3 many of the outcomes and impacts from AAHL's research will have global reach. The benefits of that research will also accrue to our international partners and neighbours both across the region and globally.

B.3.2 Counterfactual

The work undertaken at AAHL could not have been done elsewhere in Australia

Given the unique nature of the AAHL with its high level containment facility, the work described in this case study could not have been undertaken elsewhere in Australia. There are just a few other facilities of this type around the world and the delays in accessing these facilities in a time of an emergency would add significantly to the cost of managing an outbreak of foot and mouth disease. In the absence of AAHL, no other country would have developed a vaccine for Hendra virus.

B.3.3 Attribution

ACIL Allen has assigned 50 per cent of the benefits of FMD preparedness to CSIRO

Outcomes from the work of AAHL can to a significant extent be attributed to CSIRO. ACIL Allen has assigned 50 per cent of the benefits of foot and mouth disease preparedness to CSIRO/AAHL. There are of course other participants in the foot and mouth preparedness strategy who undoubtedly add substantial value to the strategy, but they are not as pivotal to the outcomes as AAHL. The reason for the 50 per cent attribution is that AAHL was the critical contributor and the source of the value. In the event AAHL did not exist there would undoubtedly be other alternative approaches adopted – however these would have been at similar or more likely greater cost. The fact is that AAHL does exist. An alternative facility that played a comparable key role in FMD preparedness, were there one, would be assigned the same percentage of benefits.

Pfizer Australia provided an adjuvant for the Hendra vaccine and took the product to market. ACIL Allen has therefore conservatively assigned 30 per cent of the Hendra vaccine outcome to Pfizer and 70 per cent to AAHL.

AAHL liaises closely with the WHO and the UN FAO on its influenza work

In relation to the work on influenza, AAHL has worked closely with the World Health Organisation and the UN Food and Agriculture Organisation. These international organisations have an important coordinating role. ACIL Allen has attributed 70 per cent of the impact to CSIRO.

B.3.4 Adoption

Adoption rates are likely to be very high

In the event of a serious animal disease outbreak, the adoption rate of AAHL's work is likely to be high. For example, in the event of an outbreak of foot and mouth disease the seriousness of such an event would ensure that adoption rate of AAHL's work would be expected to be 100 per cent.

ACIL Allen understands from its discussions with CSIRO that the take-up rate for the Hendra virus vaccine is currently around 15 per cent nationally, although this figure increases to more than 50 per cent in high risk areas.

B.4 Assessment of impacts

B.4.1 Impacts to date

The impacts to date from AAHL's research lie primarily in costs avoided from outbreaks of animal diseases, or reduced costs due to earlier containment of outbreaks. The direct beneficiaries of this work are owners of animals, but indirect benefits flow to suppliers of goods and services to the agricultural sector and to the general public though animal diseases impacting on availability or price of agricultural products and through the reduction of animal diseases being passed through to the human population.

Losses from a FMD outbreak would be very large

Experience from FMD outbreaks in other countries provide an indication of the scale of the risks that Australia faces:

- In Taiwan, following the 1997 FMD outbreak, pork exports valued at $US 1.6 billion fell by over US$1.3 billion to $US 234 million with the loss of the Japanese market (Chang *et al.*, Griffith 2005). Other countries stepped in to take over Taiwan's market share. With the loss of export markets, 27 million tons of pork was diverted to the domestic market with disastrous consequences for producers.
- An outbreak of FMD in the Republic of Korea in 2000 had similar consequences.
- In 2000 Argentina's exports of beef fell 52 per cent (Rich, 2004). Outbreaks of FMD in Uruguay and Brazil in the same year resulted in loss of export markets, prices falling

below the cost of production and serious damage to the livestock industries of these countries (FAO 2006).

Given that the value of Australia's cattle and calve, sheep, lamb and pig slaughterings in 2012-13 were worth over $10 billion (including slaughter of dairy cattle and skin value for sheep and lambs), the potential losses from a significant FMD outbreak are large (ABARES, 2013a).

B.4.2 Potential future impacts

As international trade and travel increase, so does the risk of animal diseases reaching Australia from overseas sources. The benefits of AAHL's work in relation to foot and mouth disease preparedness can be determined from the estimated cost of an outbreak of this disease.

B.4.3 Cost Benefit Analysis

ACIL Allen believes that the best way to illustrate the value delivered by AAHL is to undertake a detailed analysis of the insurance value it delivers as this is the key benefit it delivers. In effect the protection that AAHL's work provides for the Australian people and industry against serious health and economic risks.

As noted in Section B.2, AAHL works on a wide range of diseases, including:

- Foot and mouth disease (FMD)
- Transmissible Spongiform Encephalopathy
- Hendra virus vaccine
- Middle Eastern respiratory syndrome
- Avian influenza
- Insect-borne diseases
- Testing capability

In examining which of these to analyse for the purposes of this case study we sought to identify for which of the above we could obtain information that was:

- *Reliable* – i.e. information collected and analysed by reputable groups or organisations
- *Recent* – i.e. work that had been done in the relatively recent past
- *Relevant* - information that was applicable to Australia's circumstances.

In ACIL Allen's view the information available for FMD best met the above criteria. That is not to say that information was not available on the other research topics listed that enables us to say with confidence that the insurance value delivered by the FMD work is very much just a lower bound.

Foot and Mouth disease

ACIL Allen has estimated the potential benefits of AAHL's disease surveillance and vaccine R&D activities in attenuating the adverse economic impacts of a potential foot-and-mouth disease (FMD) outbreak in Australia, drawing on the findings of a 2005 ABARE report and a 2013 ABARES report.

Economic impact of FMD outbreaks

ABARES has modelled FMD disease control strategies

In 2013 ABARES modelled FMD disease control strategies for three scenarios (ABARES, 2013):

- a *small outbreak in North Queensland*, where most cattle are raised on extensive rangelands
- a *small outbreak in Victoria's Goulburn Valley*, which has a high density of livestock and intensive dairy farms
- a *large multi-state outbreak* that, by the time of detection, has spread from Victoria to all eastern states (New South Wales, Queensland, South Australia, Victoria and Tasmania).

The following disease control strategies were examined:

- for the small and large outbreaks
- **stamping out**, which involves destruction and disposal of animals in infected and dangerous contact premises
- **stamping out with extensive vaccination**, which requires vaccination of all FMD-susceptible animals within a designated ring surrounding infected and dangerous contact premises; and removal of vaccinated animals once the disease is contained
- for the large multi-state outbreak (in addition to the above)
- **stamping out with targeted vaccination**, which includes the vaccination of all cattle and sheep on mixed cattle and sheep farms within a designated ring surrounding infected and dangerous contact premises. In outbreak areas outside the high-risk ring, stamping out (without vaccination) is undertaken.

A national livestock standstill is a key element of any response

All strategies would be preceded by a national livestock standstill which would have a significant economic impact on day 1, before the implementation of any of the above strategies.

Historically, stamping out has been used to manage FMD outbreaks. It ensures disease eradication and a swift return to disease-free status and access to international markets. However, it involves the rapid destruction and disposal of large numbers of stock. This can be highly resource intensive and can also lead to criticism within the community.

More recently, several countries have combined vaccination with stamping out to achieve effective control of FMD. Removal of vaccinated animals can delay the time to regain market access after eradication is achieved. However, early vaccination may assist with or be essential for effective disease control.

ABARES also examined targeted vaccination to explore the effectiveness of control in a situation where resources to undertake widespread extensive vaccination might not be available.

A FMD outbreak would have large direct and indirect economic impacts. Producers of FMD-susceptible livestock would bear most of the revenue losses as a result of countries placing restrictions on imports from Australia. Loss of exports and depressed domestic prices would significantly reduce the revenues of producers.

ABARES' estimates of the present value of direct costs of an FMD outbreak over 10 years in each scenario and under each disease control strategy is shown in Table B4. The direct cost of an outbreak is calculated by adding the estimated revenue losses to livestock producers to the costs associated with the chosen control strategy. The control costs are estimated to be $0.32-0.37 billion (depending on the control strategy) for the large multi-state outbreak, $0.09-0.10 billion for the small outbreak in Victoria and $0.06 billion for the small outbreak in North Queensland.

Table B4 **Present value of total direct costs of an FMD outbreak over 10 years by type of outbreak and control strategy ($billion)**

Type of outbreak and control strategy	Total direct costs ($billion)
Large multi-state outbreak	
Stamping out	$52.21
Stamping out with extensive vaccination	$49.89
Stamping out with targeted vaccination	$49.62
Small outbreak in Victoria	
Stamping out	$6.00
Stamping out with extensive vaccination	$6.26
Small outbreak in Queensland	
Stamping out	$5.64
Stamping out with extensive vaccination	$5.96

Source: ABARES (2013), *Potential socio-economic impacts of an outbreak of foot-and-mouth disease in Australia*

ABARES' modelling showed that the lowest cost disease eradication strategy depends on the initial conditions of the outbreak and the type of production system in the outbreak area. In the smaller outbreaks, the additional time required to remove vaccinated animals from the population (and the consequent increase in delay in regaining FMD-free status and market access) was greater than the reduction in eradication time due to vaccination (at least in the case of the small Victorian outbreak – vaccination actually had no effect on the eradication time in the small North Queensland outbreak).

Based on ABARES' modelling results, ACIL Allen has summarised the total direct costs of an FMD outbreak over 10 years with and without the vaccination option (see Table B5). The composite small outbreak is a combination of the small Victorian outbreak and the small Queensland outbreak (with equal weighting for both).

Table B5 **Present value of total direct costs of an FMD outbreak over 10 years by type of outbreak and availability of vaccination option ($billion)**

Type of outbreak and control strategy	Total direct cost ($billion)
Large multi-state outbreak	
With vaccination option	$49.62
Without vaccination option	$52.21
Small outbreak in Victoria	
With vaccination option	$6.00
Without vaccination option	$6.00
Small outbreak in Queensland	
With vaccination option	$5.64
Without vaccination option	$5.64
Composite small outbreak	
With vaccination option	$5.82
Without vaccination option	$5.82

Source: ACIL Allen Consulting analysis based on ABARES (2013)

Relative probability of FMD outbreaks by severity

In a 2005 study by ABARE[5], early detection of FMD was found to be highly significant in influencing the probability of containing the spread of the disease when vaccination is not available.

In the reference case of the 2005 ABARE study, the probability of a severe FMD outbreak under a stamping out disease control strategy was only 0.19 while the probability of a small outbreak was 0.81. Under a stamping out with vaccination strategy, the probability of a large outbreak was zero while the probability of a small outbreak was one.

However, should detection be delayed by two weeks, the probability of a severe outbreak under a stamping out only strategy rises to 0.93 (with a concomitant reduction in the probability of a small outbreak from 0.81 to 0.07). According to ABARE, the probability of a severe outbreak under a stamping out and ring vaccination strategy remains at zero even with delayed detection, as the resulting outbreaks under all scenarios would invariably be small.

In the ABARE study, a large outbreak results in over 90 per cent of the livestock in the affected region being slaughtered, compared with fewer than six per cent if the outbreak were small.

Estimation of AAHL benefits

AAHL's activities in relation to FMD are expected to assist in the control of a FMD outbreak in Australia in three ways:

- AAHL's disease surveillance activities, in conjunction with those of other relevant State/Territory and Commonwealth government agencies, ensures that the possibility of delayed detection of a FMD outbreak is reduced and that the response to an outbreak is optimised (thereby preventing a small outbreak from becoming a severe one).
- Australia maintains a vaccine bank with a private company in Europe and AAHL is involved in testing these vaccines and developing knowledge on how effectively these work for the strains of FMD that are currently circulating in South East Asia and internationally.
- AAHL works closely with the World Organisation for Animal Health (OIE) and the UN Food and Agriculture Organisation (FAO) to improve FMD surveillance and response capacity across SE Asia to decrease the potential likelihood of FMD spreading from Asia into Australia.

The impact of AAHL's activities (both surveillance-related and vaccine-related) on the economic impact of a FMD outbreak is summarised in Table B6. The expected direct economic costs for each type of outbreak is equal to the product of its relative probability and its direct economic costs.

[5] Abdalla, A. et al. (2005), *Foot and Mouth Disease: Evaluating alternatives for controlling a possible outbreak in Australia*, ABARE eReport 05.6, April.

Table B6 **Expected cost of a FMD outbreak in Australia with and without AAHL (in present value terms over 10 years)**

Type of outbreak	Relative probability	Direct economic costs	Expected direct economic costs
With AAHL (vaccine and timely disease detection)			
Severe outbreak	0.00	$49.62	$0.00 billion
Composite small outbreak	1.00	$5.82	$5.82 billion
Aggregate			**$5.82 billion**
Without AAHL			
Severe outbreak	0.93	$52.21	$48.56 billion
Composite small outbreak	0.07	$5.82	$0.41 billion
Aggregate			**$48.96 billion**

Source: ACIL Allen Consulting

AAHL helps reduce the expected costs of a FMD outbreak in Australia by $43.14 billion

ACIL Allen's analysis suggests that the presence of AAHL helps reduce the expected total direct economic costs of a FMD outbreak in Australia by $43.14 billion in present value terms over 10 years, from $48.96 billion without the AAHL to $5.82 billion with AAHL. It does so by preventing a small outbreak from becoming a severe one.

It is difficult to estimate the probability of an FMD outbreak occurring in Australia – minor outbreaks are believed to have occurred in 1801, 1804, 1871 and 1872. CSIRO estimates that likelihood of an outbreak in any given year is currently in the order of 1 in 50 years (that is, a probability of 2 per cent), due to an increase in international travel, selective (rather than 100 per cent) testing of luggage at custom checkpoints and the threat of bioterrorism.

While AAHL is an important link in the Australia-wide FMD surveillance system, it also plays a critical role in ensuring an effective national response once an outbreak has occurred. Assuming a 2 per cent annual probability of a FMD outbreak and that AAHL contributes 50 per cent to the effectiveness of the FMD surveillance system once an outbreak has occurred, ACIL Allen estimates that AAHL's benefits (its "insurance value") in relation to FMD is approximately $431 million a year.

Sensitivity analysis

As there is considerable uncertainty about the probability of a FMD outbreak in Australia in any given year and about the magnitude of AAHL's contribution to the national disease surveillance system, sensitivity analysis has been undertaken to assess the impact of these uncertainties on the estimate of AAHL's benefits in relation to FMD. The results of this analysis are shown in Table B7.

Table B7 **Estimate of AAHL's annual benefits in relation to FMD under alternative assumptions**

Contribution of AAHL to effectiveness of national animal disease surveillance system	FMD outbreak probability = 0.01	FMB Outbreak probability = 0.04	FMB Outbreak probability = 0.04
AAHL contribution = 25%	$108 million	$216 million	$431 million
AAHL contribution = 50%	$216 million	$431 million	$863 million
AAHL contribution = 75%	$324 million	$647 million	$1,294 million

Source: ACIL Allen Consulting

It could be argued that an effective FMD vaccine would be made available in Australia even in the absence of AAHL. Table B8 shows the impact of AAHL's disease surveillance activities (but not its vaccine-related activities) on the economic impact of a FMD outbreak in Australia.

Table B8 **Expected cost of a FMD outbreak in Australia with and without AAHL – no vaccine (in present value terms over 10 years)**

Type of outbreak	Relative probability	Direct economic costs	Expected direct economic costs
With AAHL (timely disease detection)			
Severe outbreak	0.19	$52.21	$9.92 billion
Composite small outbreak	0.81	$5.82	$4.71 billion
Aggregate			**$14.63 billion**
Without AAHL			
Severe outbreak	0.93	$52.21	$48.56 billion
Composite small outbreak	0.07	$5.82	$0.41 billion
Aggregate			**$48.96 billion**

Source: ACIL Allen Consulting

ACIL Allen's analysis shows that AAHL's contribution to the national disease surveillance system helps reduce the expected direct economic costs of a FMD outbreak in Australia by $34.33 billion in present value terms over 10 years, from $48.96 billion without AAHL to $14.63 billion with AAHL.

The annual insurance value of FMD surveillance alone is very large.

If the probability of an outbreak in any given year is again assumed to be 0.02 and that AAHL contributes 50 per cent to the effectiveness of the Australia-wide FMD response system in the event of an outbreak, then AAHL's benefits (its "insurance value") in relation to FMD due to its role in animal disease surveillance alone is estimated to be approximately $343 million per annum.

These results suggest that AAHL's disease surveillance and response activities accounts for approximately 80 per cent of its "insurance value" against FMD, with its vaccine-related activities accounting for the remaining 20 per cent.

The insurance value of AAHL's non-FMD work is likely to also be considerable

We were also able to obtain some information about the financial implications of some of the other diseases being studied at AAHL. While the information was not of the same quality as for FMD it does provide a good indication that the insurance values associated with other work at AAHL may be considerable. That information is discussed below.

Hendra virus

Since the discovery of the Hendra virus in 1994, there have been 50 outbreaks with 4 human fatalities (out of 7 infected). More than 80 horses have succumbed to the disease or were put down as a result of it.

Over 200,000 doses of Equivac® vaccine have been used to date

The Equivac® vaccine against the Hendra virus is a world first – it is the first commercial vaccine for a Biosafety Level 4 disease agent. Since the launch of the vaccine, more than 200,000 doses of vaccine have been administered to horses. Decreasing the incidence of Hendra virus outbreaks reduces the opportunity for variant strains or mutations that could be more transmissible or lethal to emerge. AAHL is contributing to reduce the likelihood of an outbreak and to ensuring that, should one occur, its spread would be limited by the presence of vaccinated animals.

An outbreak of Hendra could have severe consequences for the horse racing industry

A major outbreak of Hendra virus could have severe consequences for the horse racing industry in Australia, making it unlikely that Australian horses could participate in events overseas, severely damaging the horse breeding industry and adversely impact on equestrian activities.

The estimated value of the racing industry was more than $6.2 billion per annum (Gordon, 2001) or more than $8 billion if volunteer labour was included.[6] A report by consulting firm IER for Racing Victoria estimated that the 2011 Melbourne Spring Racing Carnival drew a total of 78,400 out-of-state visitors to Victoria and contributed $210.37 million to Victoria's Gross State Product.

Another example of potential costs to the horse industry from disease can be found from the equine influenza outbreak in 2007. Modelling carried out by the Australian Bureau of Agricultural and Resource Economics estimated that the costs resulting from the equine influenza outbreak during the period of the initial response, involving containment and eradication through restricted movement, reached $560,000 a day for disease control and $3.35 million a day in forgone income in equine businesses, including racing, farming and recreational enterprises (Callinan, 2009).

Avian influenza

Brahmbhatt (2005) has examined the socio-economic impacts and costs of avian flu and of a potential human influenza pandemic. He has identified two distinct but closely linked levels of potential impacts and costs: animal-to-animal, and limited animal-to-human transmission of the H5N1 avian flu virus which, he predicted would increases the probability of a second stage, with human-to-human transmission and a global influenza pandemic, with enormously greater costs. Animal and human health considerations are closely linked.

Two types of economic costs arising from this were identified: the cost of increased illness and death among humans and animals, and the cost of the preventive, control and coping strategies adopted by the public and private sectors to avoid or reduce illness and death.

Brahmbhatt considered that the priority should be curbing the disease "at source", in the agricultural sector, thereby reducing the probability of a human epidemic. He noted that there are great uncertainties about the timing, virulence, and general scope of a future pandemic. The Spanish flu of 1918-19 killed 50 million, which today would translate to 150 million deaths, which, while an extreme scenario, gives an indication of the huge potential costs in a worst case scenario.

Brahmbhatt drew on experience during SARS, when people tried to avoid infection by minimizing face-to-face interactions, resulting in a severe demand shock for services sectors such as tourism, mass transportation, retail sales, hotels and restaurants, as well as a supply shock due to workplace absenteeism, disruption of production processes and shifts to more costly procedures. This led to an immediate economic loss estimated at 2 per cent of East Asian regional GDP in the second quarter of 2003, even though only about 800 people ultimately died from SARS. A two per cent loss of global GDP during a global influenza pandemic would represent around $200 billion in just one quarter (or $800 billion over a whole year), and it was considered likely that the immediate shock during a flu epidemic would be even larger than in SARS.

A 1999 study of the United States calculated that, based on past patterns, a flu pandemic could lead to between 100,000 and 200,000 deaths in the USA, together with 700,000 or more hospitalizations, up to 40 million outpatient visits and 50 million additional illnesses. The 2004 value of the economic losses associated with this level of death and sickness was estimated at between $100 and $200 billion for the USA alone. Extrapolating from the USA to all high income countries, there could be a loss of $550 billion (in 2004 dollars).

[6] $6.2 billion (2004) is equivalent to $8.15 billion in 2014.

Economic costs that need to be considered include direct costs such as losses of poultry due to the disease and to culling, with impacts extending not only to farmers but also to upstream and downstream sectors such as poultry traders, feed mills, breeding farms etc. For an economy like Indonesia these direct costs would have been about $500 million (2004 dollars). Secondary or indirect economic costs could also arise, for example, from a fall in international tourism. In addition, the costs of prevention and control also need to be taken into account, including costs to the government of purchase of poultry vaccines, medications and other inputs, hiring workers for culling and clean-up, surveillance and diagnosis, hire of transportation etc. Governments may also face the need to pay compensation to poultry owners.

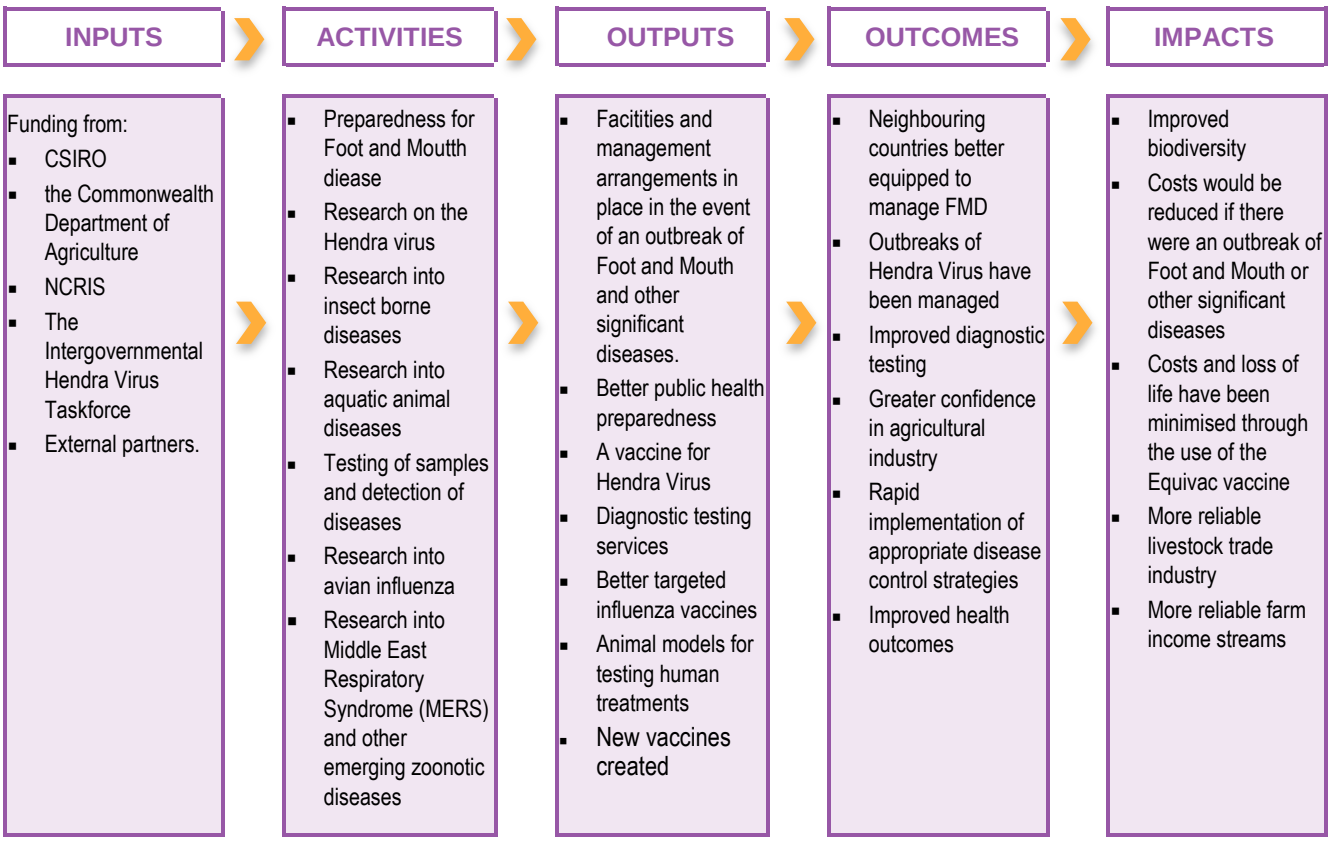
A medium level pandemic could reduce Australia's GDP by over $115 billion

Two studies from 2006 estimated that a severe global influenza pandemic would reduce Australia's GDP by approximately 10 per cent for a year (McKibbin and Sidorenko, 2006 and Kennedy *et al*., 2006). An ABARE study from the same year estimated that a medium level pandemic in Australia and globally would reduce Australia's GDP by 6.8 per cent for a year (ABARE, 2006). This means that were an influenza pandemic to occur in the near future, Australia's GDP would be reduced by $115.6-170 billion from current GDP of approximately $1.7 trillion.

B.4.4 Impact pathway diagram

Figure B1 presents the impact evaluation framework diagram for CSIRO/AAHL's work on animal health.

Figure B1 **AAHL – impact**



Source: ACIL Allen Consulting

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Appendix C Case study: Cotton Varieties

SUMMARY OF KEY FINDINGS

- CSIRO's cotton breeding research project has delivered net benefits to Australia of approximately $149.3 million in 2014 dollar terms between 2006/7 and 2013/14, representing an internal rate of return of 93 per cent over original input costs.
- ACIL Allen anticipates future benefits of over $379.5 million over the next decade under a 5 per cent discount rate as a result of cotton yield productivity increases due to CSIRO's research project.
- CSIRO's cotton research project has increased the productivity of Australia's cotton yield due to the breeding of cotton varieties that are more resistant to common diseases, are more water efficient, and are better adapted to Australian weather and soil conditions.
- There are a number of important benefits have not been included in our cost-benefit calculations, but which have nonetheless delivered benefits to Australia over the lifespan of CSIRO's cotton varieties research project. These include:
  - improved ecological health and lower exposure of farmers and farming communities to pesticides as a result of reduced pesticide use,
  - increased water efficiency – Australian cotton farming is now the most water-efficient in the world – and;
  - increased sustainability of local farming communities, due to the increased resilience of the cotton industry to risks such as disease and drought.

C.1 Introduction

C.1.1 Purpose and audience

This independent case study evaluation has been undertaken to assess the economic, social and environmental impact of CSIRO research on cotton varieties. This case study has been prepared so it can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of CSIRO's activities.

The report is provided for accountability, reporting, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, CSIRO and the general public.

C.1.2 Background

The cotton industry is very important to Australia

The cotton industry is one of Australia's major agricultural industries. Cotton exports in 2012-13 were valued at $2.7 billion. Wheat was the only crop with exports ($6.8 billion) that exceeded this value, while wool exports were valued at $2.9 billion and canola exports at $2.1 billion in that same year (ABARES, 2013). Australia is one of the world's top four cotton exporters (Cotton Australia, 2014b), although there is considerable variability in annual cotton production in Australia, largely determined by availability of irrigation water (Figure C1).

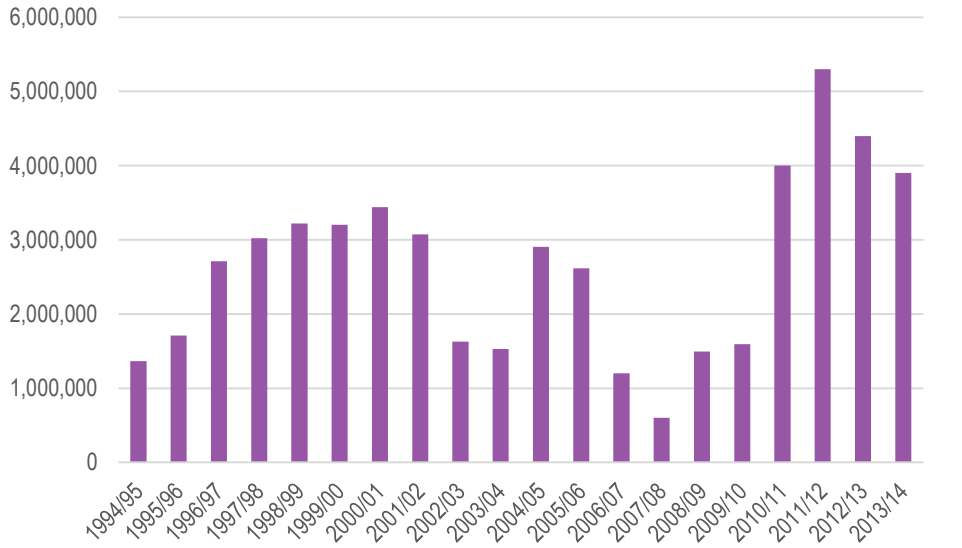
Prior to the early 1960s, cotton growing in Australia was undertaken on a relatively small scale. However, the nature of the industry transformed with the introduction of high-input irrigation cotton growing in NSW, Queensland and WA, enabled in part by new dam construction. While cotton production ceased in WA in 1974 following the emergence of insecticide-resistant pests, production in NSW and Queensland has increased considerably over time (Constable *et al.*, 2001). During the 1960s and 1970s, all cotton varieties grown in

Australia were sourced exclusively from the USA. In this period, separate breeding programs emerged that were mainly funded by state agriculture Departments or through the CSIRO.

CSIRO's Cotton Research unit consolidated all of Australia's cotton R&D

In the early 1970s it was recognised that the various cotton breeding programs were disparate and uncoordinated and that they were located away from the main cotton production centre in northern-western NSW (Narrabri). The various cotton breeding programs were eventually closed and responsibility for Australia's cotton breeding research was taken up by CSIRO, with the establishment of the CSIRO Cotton Research unit at Narrabri in 1972. Thereafter, CSIRO commenced a breeding program that sought to develop full-season varieties for Australia's primary cotton growing regions (Constable *et al.*, 2001).

Figure C1 **Cotton production in Australia - Bales**



Note: The 2013/14 crop is a forecast.
Source: Cotton Australia 2014c

Since 1972, CSIRO's Cotton breeding group has sought to develop cotton varieties that are capable of maximising productivity and quality under Australia's unique conditions, with major breeding goals including:

CSIRO is developing cotton varieties that suit Australia's unique conditions

- increased yield and regional adaptation
- resistance to diseases
- pest resistance
- increased fibre quality to compete in premium export markets.

The aim is to improve productivity and quality

CSIRO has developed four major cotton variety types – 'Siokra', 'Sicala', 'Sicot' and 'CS' – from which a number of varieties have been developed. CSIRO's first breakthrough in cotton varieties development was Siokra 1-1, released in the early 1980s, which features a slender, okra-shaped leaf (versus the larger, rounder leaf of normal cotton strains). Smaller, thinner leaves make Siokra cotton more water efficient that round leaf varieties. Siokra is also resistant to bacterial blight and partially resistant to Helicoverpa and mites. Using the original Siokra strain, eleven other cultivars have been developed, from which two varieties are transgenic. Subsequently, another major cotton variety, Sicala 3-1, was released by CSIRO in 1987, followed by the release of Sicala V-1 in 1991 and Sicala V-2 in 1994. Sicala varieties have a high degree of resistance to Verticillium wilt, a feature that reduces the

spread of the disease in the soil of cotton growing regions. Since 1996, many of these varieties have incorporated a combination of genetically modified features developed by crop breeding companies and used under licence by CSIRO. By 2013/14, approximately 99 per cent of Australia's cotton was transgenic, combining CSIRO's elite germplasm with traits from Monsanto or Bayer. The major variety in 2013/14 was Sicot 74BRF.

Australia: a unique and challenging environment for cotton growing

Australia poses unique challenges to cotton growing

Although Australia is one of the top four global cotton exporters, its cotton crops are regularly at risk due to a unique mixture of factors that influence cotton production, breeding and management. These factors include:

- climate
- soil
- pests
- disease.

These factors all endanger the future profitability of the Australian cotton industry. Australia's cotton growing region encompass an area from central Queensland extending south to the NSW-Victorian border. The broad geographic spread of cotton growing areas inevitably leads to cotton being grown in areas with different and distinct climates, from generally higher temperatures in the north, to cooler temperatures in the south, generally drier conditions in the west, to wetter conditions in the east (Constable *et al.*, 2001). This wide array often highly variable climatic conditions poses challenges for Australian cotton growers seeking to better adapt cotton seed strains and growing practices to local conditions.

The majority of Australian cotton is grown on alkaline heavy clay soil. This soil is regarded as 'sodic' (or containing high levels of exchangeable sodium), especially in the western and drier locations. This soil has a high water holding capacity and its cracking nature allows for swift refill during irrigation. However, it is prone to soil compaction and waterlogging, which can lead to sharp decreases in crop yield (Constable *et al.*, 2001).

The most damaging pest to Australian cotton production is the Helicoverpa bollworm. It has two species, *H. punctigera* and *H. armigera*, with the latter being particularly renowned for its ability to develop resistance to synthetic pesticides. Helicoverpa is a major challenge for entire seasons in the majority of production areas. In 1974, *H. armigera* developed resistance to pesticides and was responsible for the failure of the entire cotton industry in northern WA. Spider mites are also capable of causing considerable damage to cotton production every season. In addition to these major pests, other pests, such as mirids, aphids, thrips and tip borer, emerge sporadically between seasons and different cotton growing sites (Constable *et al.*, 2001).

Some diseases are widespread in Australia, including bacterial blight and Verticillium wilt, and can cause serious damage to cotton crops. Other notable diseases include Black Root Rot, Alternaria leaf spot and Fusarium wilt. These all pose growing challenges across a range of cotton production regions every season (Constable *et al* 2001).

C.1.3 Approach

This approach taken in this case study is based on CSIRO's impact framework and aligns with the nine-step process described in the CSIRO's impact evaluation guide, namely:

1. Initial framing of the purpose and audience of the impact evaluation.
2. Identify nature of impacts (*what is the impact pathway, what are the costs and benefits*)
3. Define a realistic counterfactual (*what would have occurred in the absence of CSIRO*)

4. Attribution of research (*CSIRO vs. others' contribution*)
5. Adoption (*to date and in future*)
6.. Impact (*timing, valuation, distributional effects among users, effects on non-users*)
7. Aggregation of research impacts (*within program of work*)
8. Aggregation of impacts (*across program of work*)
9. Sensitivity analysis and reporting.

In quantifying the costs and benefits of CSIRO's cotton research project, this case study examines a limited time period or 2006 to the present. However, it is important to note that CSIRO's cotton varieties research project has delivered substantial benefits over the entire life time of the research project. Our cost-benefit analysis builds upon impressive net benefits delivered between 1973 and 2001 – $5 billion according to a 2002 CIE study – and between 2002 and 2005 – $65 million per annum, according to a 2006 ACIL Tasman study.

The impacts identified in this case study will be aggregated with those from other aspects of CSIRO's work to provide an insight into the overall benefits arising from the Organisation's work.

C.1.4 Project origins and inputs

CSIRO's work on cotton has been undertaken with the goal to:

> Develop Australian cotton varieties with increased yield; with fibre quality preferred by international spinners; resistance to all important diseases; widely adapted; and with genetically modified traits of interest.
>
> Focus on better breeding and associated research outcomes for Australian cotton.

CSIRO's cotton research contributes to the Agriculture Flagship goal

Since the July 2014 restructure of CSIRO, work on cotton now resides within CSIRO's Agriculture Flagship, the goals of which is:

> To deliver transformational positive impact on the productivity, profitability and agro-ecosystem health for Australia's agri-food- and agri-fibre industries and to partner globally towards food security in a resource and climate challenged world. Together with our private and public sector partners we aspire to develop technologies, management and knowledge systems that will, by 2030, raise yield ceilings, close yield gaps and increase production efficiencies to underpin a 30 per cent increase in targeted primary food and fibre productivity and/or eco-efficiency.

The outcomes and impact from CSIRO's work on cotton varieties will make an important contribution to this Flagship goal through increased productivity due to the development of new cotton varieties that provide higher yields while requiring fewer inputs.

Inputs to CSIRO's work on cotton varieties since 2003-04 have been estimated from staff numbers at the Cotton breeding group, Narrabri and some segments of the cotton biotechnology group at the Black Mountain laboratories in Canberra (see Table C1).

Table C1 **CSIRO staff working on cotton varieties project**

Year	Full time equivalents Narrabri	Full time equivalents Black Mountain
2003-04	13.0	6.6
2004-05	13.0	6.6
2005-06	13.0	6.6
2006-07	16.0	6.6
2007-08	15.5	6.6
2008-09	19.5	6.6
2009-10	20.5	6.6
2010-11	22.3	6.6
2011-12	23.3	6.6
2012-13	24.3	6.6
2013-14	24.3	6.6

Source: CSIRO

CSIRO works closely with the cotton industry

Other inputs have come from Cotton Seed Distributors (CSD), a grower-owned and controlled organisation, which markets CSIRO-bred cotton seed and provides specialised support to Australian cotton growers through an in-field team of experienced agronomic staff. CSD has a long term partnership with CSIRO. The Australian government's Cotton Research and Development Corporation (CRDC) also provided funding. CSIRO, CSD and CRDC funding inputs dedicated to the core breeding, core biotechnology and quality assurance programs, as well as the development and use of Fusarium nurseries, are listed in Table C2.

Table C2 **Cotton varieties research project inputs ($ million)**

Year	CSIRO	CSD	CRDC	Total
2006/07	3.004	1.202	0.367	**4.573**
2007/08	2.996	1.493	0.390	**4.878**
2008/09	3.32	1.691	0.000	**5.010**
2009/10	3.842	1.471	0.000	**5.313**
2010/11	4.238	1.542	0.000	**5.780**
2011/12	4.577	1.430	0.000	**6.006**
2012/13	4.750	1.469	0.000	**6.218**
2013/14	5.472	1.579	0.000	**7.051**
2014/15	5.642	1.611	0.000	**7.252**
Total	**37.841**	**13.488**	**0.757**	**52.081**

Source: CSIRO

In the current CSIRO strategy period (2011-15), CSD support to CSIRO's cotton breeding and biotechnology research has been through the Cotton Breeding Australia Joint Venture.

C.2 Project activities

CSIRO's cotton R&D is long term and ongoing

There are a number of notable features of CSIRO's cotton breeding methodology, which have underpinned the success of the project. As noted above, CSIRO work on cotton varieties extends over a number of decades. This long experience in developing varieties to meet the challenges of various pests and diseases has been the essential underpinning of the successful work undertaken more recently. The lead time on developing new cotton varieties is around ten years and each new variety lasts about five years before it is replaced.

CSIRO also establishes strategic targets for its work on cotton and reviews these on a regular basis. Fibre quality targets are based on future spinning industry requirements and CSIRO has instrumentation to accurately measure and screen for all fibre properties of interest. Disease resistance is sought for existing and possible diseases; disease nurseries and bioassays are used to screen for resistance.

Conventional breeding techniques are used with strong emphasis on large population sizes and extensive regional testing of elite lines which are selected in experiments that are designed to ensure confidence in results. A total of 30,000 plots are sown and harvested each season. Breeder seed of candidate commercial varieties is handed over to Cotton Seed Distributors for commercial sale in Australia and worldwide.

In keeping with CSIRO tradition, there is a multidisciplinary cotton team covering plant breeding, biotechnology, agronomy, physiology, pest management and post-harvest processing.

During the current CSIRO strategy period (2011-15) CSIRO has continued to develop new varieties of cotton and undertake related activities. Research activities in this period include work on disease and pest resistance, fibre quality, regional adaptation and application of gene technology.

C.2.1 Gene technology

CSIRO's breeding project targets several issues

Breeding of new varieties relies on genetic diversity. A core activity of CSIRO's cotton varieties project is to source or create diversity of genetic features that influence yield, fibre quality, disease resistance and plant growth patterns that optimise plant size and harvest maturity to match each climate and crop management system. CSIRO is constantly importing novel germplasm through quarantine to evaluate it for use in crossing.

Continued usage of gene technology is expected to accelerate the screening and development of new conventional and transgenic cotton varieties. Research at CSIRO has grown in this area in order to develop and use molecular tools and characteristics to meet production and sustainability goals (CSIRO, 2014).

Disease and pest resistance

CSIRO has bred genetically modified (GM) cotton varieties that include insect and herbicide resistance. This has been done by introducing Bollgard® II and Roundup Ready Flex® traits from Monsanto into CSIRO germplasm (CSIRO, 2014). Box C1 outlines the benefits of Bollgard® II.

Box C1 **GM cotton and benefits of Bollgard® II**

Bollgard® II, was developed by Monsanto by introducing two genes from the soil bacterium Bacillus thuringiensis (Bt) into cotton. The effect of these genes is to produce two proteins that are toxic to the primary insect pest of cotton (Helicoverpa caterpillars) which die upon consumption of the Bollgard® II cotton. The adoption of Bollgard® II technology has led to a decrease in insecticide applications by approximately 80 per cent for the entire cotton growing industry.

The Helicoverpa caterpillars are renowned for their ability to destroy entire cotton crops if not managed appropriately. In the past, pesticides were frequently deployed to combat these pests. However, the pesticides were found to be killing beneficial insects in the process. Bollgard® II cotton varieties are advantageous as they only target Helicoverpa caterpillars. In addition, the Bt genes have been tested to confirm that they do not harm human or any other animals. These traits are approved by Australian Regulatory Authorities such as OGTR and APVMA.

Bollgard® II crops have been found to grow at an accelerated rate due to their immunity from insect attacks. Field tests have revealed Bollgard® II varieties have similar or higher cotton yield and fibre quality relative to conventional non-GM cotton varieties. Further trials have indicated that Bollgard® II varieties can be more water efficient.

Sources: CSIRO 2010, and Constable *et al* 2011.

One such issue is disease and pest resistance …

CSIRO research on disease and pest resistance has included progress on the development of cotton varieties that are resistant to Bacterial Blight and Verticillium Wilt (CSIRO 2014). Fusarium Wilt is a particularly destructive, and relatively new, disease to affect cotton in Australia. CSIRO is therefore focusing on ensuring that any new cotton varieties contain resistance to the disease. CSIRO is also developing cotton varieties for resistance to the Cotton Bunchy Top disease, a virus which is transmitted by aphids and causes reduced yields.

Fibre quality

… the need for improved yields and fibre quality are others …

CSIRO has used conventional breeding to significantly enhance cotton yield and fibre quality. It intends to develop premium fibre varieties that will enable growers to command higher sale prices through production and sale of a premium product. CSIRO is also using gene technology to assist in the identification of genes that are responsible for fibre development (CSIRO, 2014).

Regional adaptation

… varieties tailored to regional conditions is another

In Australia, cotton is grown in a variety of environments under both dry land and irrigated conditions. CSIRO-bred cotton varieties are tailored to the conditions of each region in order to augment performance. The characteristics to suit the 'central', 'hot' and 'cool' regions of Australia's cotton growing areas include:

- high yield and water use efficiency
- heat and stress resilience
- disease resistance
- maturity to match the length of the season (CSIRO, 2014).

C.2.2 Research through the value chain

CSIRO conducts research relevant to the entire cotton value chain

In addition to the genetic breeding of cotton varieties for seed supply, CSIRO is researching improved cotton crop management techniques, water management, pest management techniques, and post-harvest handling and management. CSIRO also collaborates with the Australian Cotton Shippers Association and the International Textile Manufacturers Federation on initiatives to improve post-harvest transportation and handling with the aim of ensuring that damage to, or contamination of, high quality cotton fibre is minimised (CSIRO 2008, 2009). CSIRO maintains post-harvest researchers at Geelong and Narrabri. As a result of these additional activities, CSIRO has a research presence through the cotton

growing and production value chain, enhancing the benefits gained from its core cotton varieties breeding project.

The necessary skills and expertise are drawn from across CSIRO

Work on this project utilised a wide range of CSIRO's skills and expertise. Table C3, below, lists the key capabilities and summarises the activities undertaken for each of those capabilities.

Table C3 **Key CSIRO capabilities used in cotton varieties project**

CSIRO capability	Activity
Quantitative genetics	Review literature and develop local genetic populations with diversity in characteristics of interest, especially yield and disease resistance. Continually import germplasm from overseas and exchange germplasm where possible to maximise genetic diversity in our own collection.
Cotton breeding methods	Understand history and literature on different breeding methods. Constantly review and assess alternatives to optimise the breeding timeline while achieving continual genetic improvement in yield, disease resistance, fibre quality and regional adaptation.
Molecular screening	Research and develop screening tools to use during introgression (a process by which the genes of one variety are integrated into the genes of another) of new traits into elite CSIRO germplasm. Collaborate with trait provider when required.
Regulatory requirements for GM crops	Liaison with the Office of the Gene Technology Regulator (OGTR) in field practices with GM crops. Research on appropriate pollen traps for preventing gene flow from research plots into commercial crops.
Variety development – disease resistance	Research in sources of resistance and methods of screening breeding populations for all diseases (present and future). Identification of field sites to use as field nurseries and development of screening measures for Fusarium wilt and Verticillium wilt in particular. When possible, liaise with Canberra molecular group to develop molecular markers to use in screening disease resistance.
Variety development – fibre quality	Identify present and future requirements for fibre properties and screen breeding populations for compliance with those properties. Research strategies to overcome negative associations between yield and fibre quality.
Statistical design and analysis	Research and develop field testing procedures across a number of different seasons, sites and replicates to ensure most accurate results are obtained for data on new breeding lines. Understand interaction between different seasons and sites so that specific or broad regional adaptation can be identified.
Project management	Management of individual components and coordination of Narrabri and Canberra teams to maximise synergy. Liaison with commercial partner, CSD, to match breeding and commercial strategies and to provide breeder seed of elite lines for seed increase and marketing.

Note: Only the key CSIRO capabilities are listed in the above.
Source: CSIRO

C.3 Project outputs

C.3.1 Key outputs of the project

CSIRO bred cotton varieties now dominate the market

The research project outputs consist of new cotton varieties that provide increased yield, enhanced pest resistance and are adapted to the regions in which they are grown, while using less water. Over the past 30 years, CSIRO has released a total of 102 cotton varieties (see Table C4). Since 2000, some of CSIRO's top selling transgenic cotton varieties have been Sicot 71BR (which accounted for 50 per cent of transgenic cotton market share between 2005 and 2007, measured as percentage of the total area sown with transgenic cotton seeds), Sicot 71BRF, which peaked between 2008 and 2010 at above 80 per cent

market share, and Sicot 74BRF, which rose to over 70 per cent of market share in 2013 and remains the dominant selling variety.

Table C4 **CSIRO cotton varieties, 1983 - present**

Conventional			Transgenic			
Sicot 1	CS 7S	Sicot 70	Siokra V-15i	Sicala 40RRi	Sicala 40BR	Sicot 43BRF
Sicot 3	CS 50	Sicot 72	Siokra L-23i	Sicot 289RRi	Sicot 289B	Sicot 80RRF
Siokra 1-1	Siokra L23	Sicot 80	Sicala V-2i	Siokra V-16RRi	Sicot 80B	Sicot 43RRF
Siokra 1-2	CS 189+	Siokra S-102	Sicot 50i	Siokra V-17i	Siokra V-18B	Sicot 70BRF
Sicala 3-1	Siokra V-15	Sicala 43	Sicot S-8i	Sicot 11B	Sicala 40B	Sicot F-1B
Siokra 1-4	Sicala V-2	Sicot 71	Sicot 189i	Sicot 12B	Siokra V-16B	Sicala 45B
Sicala 3-2	CS 8S	Sicala 45	Sicot 289i	Sicot 13B	Sicot 71B	Sicot 80L
Sicala 33	Siokra S-101	Siokra V-18	Siokra V-16i	Sicot 14B	Sicot 71RR	Sicot 43L
Siokra S324	Sicot 189	Sicot F-1	Sicot 189RR	Sicot 289RR	Sicot 43BR	Sicot 71BRF
Siokra L22	Siokra V-16	Sicot 73	Sicala V-2RR	Sicot 60RR	Sicot 43B	Sicot 71RRF
CS 6S	Sicala 40	Siokra 24	Sicala V-3i	Sicot 289BR	Sicot 43RR	Sicot 74BRF
CS 189	Sicot 53	Sipima 280	Sicala V-3RRi	Sicot 71BR	Sicot 80RR	Sicot 70BL
Sicala V-1	Siokra V-17	Sicot 75	Siokra 201i	Sicala 60BR	Sicala 350B	Sicala 340BRF
Sicala 34		Sicot 730	Sicot 42i	Sicala V-3BR	Sicala 60BRF	Sicot 75BRF
			Sicala 40i	Siokra V-16BR	Sicot 80BRF	Siokra V-18BL
						Sicot 75RRF

Source: CSIRO

C.3.2 Key Publications

Over the past 14 years CSIRO has published in excess of 40 scientific journal articles and a number of refereed conference papers of relevance to cotton variety development. Examples of some of the papers with the greatest impact in the field are provided below:

- Constable, G.A., Thomson, N.J. and Reid, P.E. (2001). Approaches utilized in breeding and development of cotton cultivars in Australia. In: Genetic Improvement of Cotton: Emerging Technologies. JN Jenkins and S Saha (Eds.). Science Publishers, Enfield. pp 1-15
- Stiller, WN, Reid, PE and Constable, GA (2006). Lessons learnt in developing transgenic cotton (*Gossypium hirsutum*) varieties. In: C.F. Mercer (ed.). Breeding for Success: Diversity in Action. Proceedings of the 13th Australasian Plant Breeding Conference, Christchurch, New Zealand 18-21 April 2006. pp. 56-61
- Constable, G., Llewellyn, D., Wilson, L. and Stiller, W. (2011). An industry transformed: the impact of GM technology on Australian cotton production. Farm Policy J. 8, 23-41
- Stiller, W.N., Constable, G.A. and Reid, P.E. (2009) Resistance to the new Australian strain of fusarium wilt among non-cultivated *Gossypium*. *SABRAO Journal of Breeding and Genetics* VOL. 41 Special Supplement August 2009
- Constable, GA. (2009). Breeding as a business - return on R&D investment in crop improvement. 14th Australasian Plant Breeding Conference and 11th SABRAO Congress, Cairns, 2009. Invited plenary speaker
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C.3.3 Awards and public recognition

The CSIRO cotton breeding project and team have received a range of honours for their contribution to Australia. These awards and recognition are outlined in Table C5.

Table C5 **Awards**

Award	Year	Team members
CSIRO Chairman's Medal	2003 and 2011	▪ Greg Constable and Danny Llewellyn (2003) ▪ Greg Constable, Danny Llewellyn, Warwick Stiller, Shiming Liu, Peter Reid and technical staff (2011)
Clunies Ross Award	2006	▪ Greg Constable ▪ Danny Llewellyn ▪ Gary Fitt
Sir Ian McLennan Achievement for Industry Award	1989 and 2004	▪ Norm Thomson (1989) ▪ Peter Reid (2004)
Centenary Medal	2001	▪ Greg Constable ▪ Danny Llewellyn

Source: CSIRO

C.4 Status of Outcomes and Impacts

C.4.1 Nature of Outcomes and Impacts

Outcomes

The primary outcome of CSIRO's cotton varieties project is the development new products – cotton seed varieties – through a process of genetic breeding. This process has yielded five key outcomes:

CSIRO's primary outputs have been improved cotton varieties

— *Increased cotton yield through application of genetic breeding*. Uptake of CSIRO-bred cotton varieties has led to significant increases in cotton yield per hectare as a result of both reduced crop losses due to disease and pests and greater adaptation of cotton varieties to specific local conditions.

— *Disease and pest resistance*. CSIRO has developed cotton varieties with enhanced disease resistance in order to fight serious diseases. Notable progress has been attained in developing cotton varieties that are resistant to Bacterial Blight and Verticillium Wilt in particular (CSIRO, 2014). Pesticide use has decreased by up to 80 percent amongst insect resistant Bollgard® II varieties (CSIRO, 2014).

— *High fibre quality*. CSIRO's cotton breeding project has resulted in improvements in fibre length and micronaire, which has improved Australia's reputation amongst international spinners as a source of high-quality cotton. Data from the Australian Cotton Shippers Association demonstrates significant increases in the uniformity of exported Australian cotton quality and average staple length (with a longer staple indicating longer fibres and greater spinning value) (Australian Cotton Shippers Association, n.d.).

— *Regional adaptability*. CSIRO has successfully bred a range of cotton varieties that are adapted to Australia's diverse soil and climatic conditions, including the effects of heat stress. As a result, the area over which cotton growing takes place in Australia has spread into the Darling Downs in south-east Queensland and north into central Queensland. Without CSIRO's cotton varieties bred to heat stress tolerance and Australian pests and diseases, cotton growing in these areas would have not been commercially viable.

— *Water efficiency*. Australian cotton crops use on average 40 per cent less water in producing a bale of cotton than they did 10 years ago (Roth *et al*. 2013). This overall increase in water efficiency has arisen out of a combination of new cotton varieties developed by CSIRO as well as improvements in water and crop management.

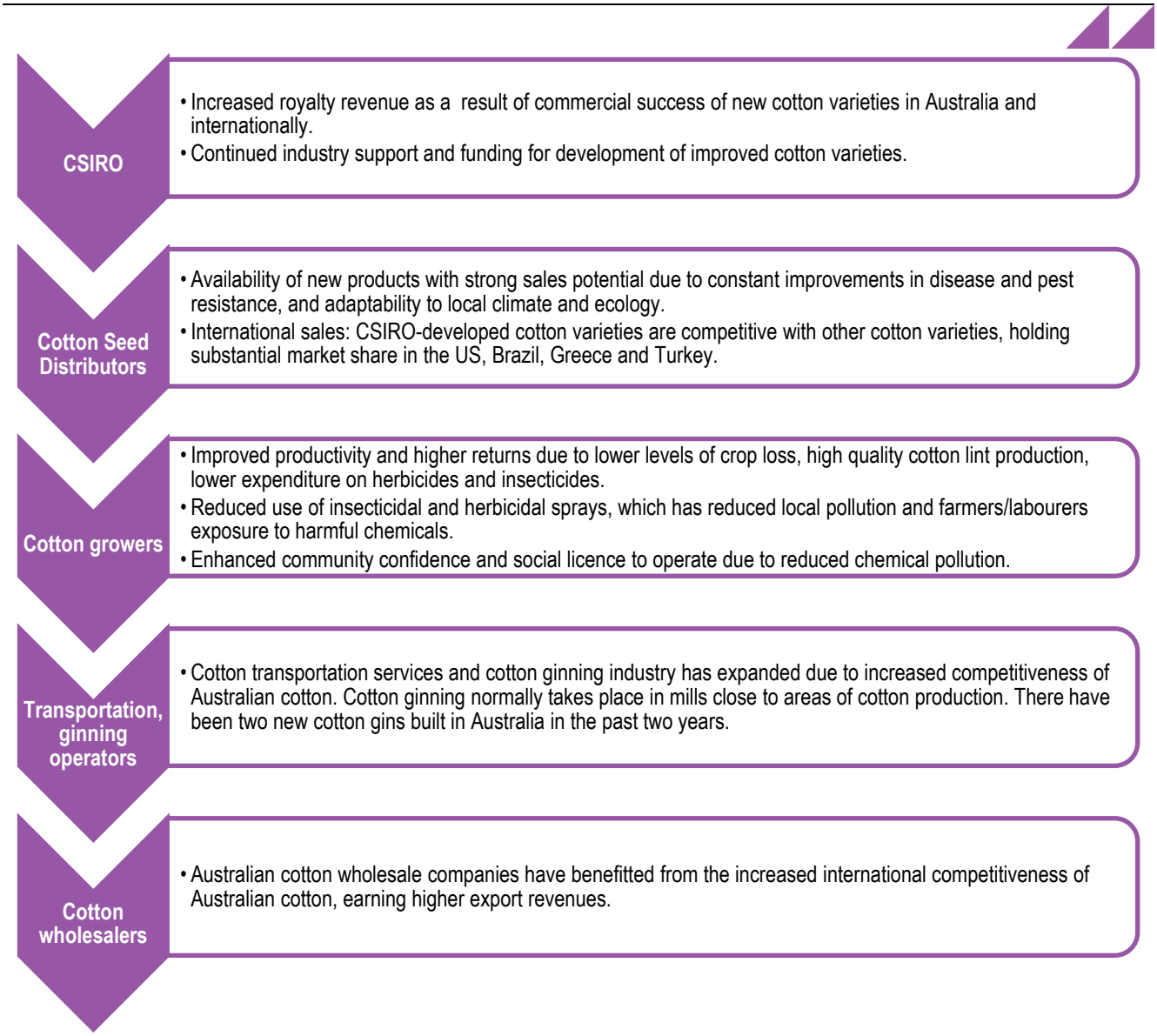
The benefits of the new varieties have driven rapid uptake

CSIRO's success in achieving these research outcomes has been borne out by the strong market uptake of CSIRO-bred cotton varieties: CSIRO cotton varieties now account for 100 per cent of cotton seeds sold in Australia, and export sales to countries such as the United States, Turkey, Brazil and Greece have been strong.

Currently CSIRO is trialling an update to Bollgard® II to assure no resistance develops to Bt. This new trait is being introduced into elite CSIRO varieties for possible commercial release in 2016.

Aside from the development of new cotton varieties, CSIRO's research has also yielded outcomes through the cotton production value chain from seed distributors to downstream processors, as outlined in Figure C2.

Figure C2 **Outcomes and impacts of new cotton varieties through the cotton production value chain**



Source: ACIL Allen Consulting; CSIRO

Impacts

Table C6 summarises the outcomes and impacts to date of CSIRO's cotton varieties research project.

Table C6 **Market and non-market impacts from CSIRO's cotton research**

Impact	Detail
Environmental impact category	
Reduced chemical contamination from insecticidal sprays Category: sustainable industry development Reach: industry	Cotton varieties utilising Bollgard® II had led to a roughly 80 per cent decrease in pesticide use across Australia. Varieties utilising Roundup Ready Flex® have led to a 52 per cent decrease in residual herbicide use (CSIRO, 2014). This has resulted in improved water, soil and air quality in cotton growing regions and lower levels of environmental pollution (Knox *et al.*, 2006).
Increased water use efficiency Category: water quality and management Reach: industry	CSIRO varieties have significantly increased water use efficiency of cotton growing in Australia. Over the past decade water use efficiency in cotton farming has improved by 40 per cent due to a combination of changed water management and CSIRO's new, water-efficient cotton varieties (Roth *et al.* 2013).
Social impact category	
Improved quality of life & health Category: life and health Reach: industry	A reduced dependency on aerial spraying of pesticides has led to reduced interaction with harmful chemicals for farmers, labourers and local communities (Knox *et al.*, 2006).
Social licence to operate and community confidence Category: social license to operate community confidence Reach: industry	Farmers who grow CSIRO cotton varieties can lessen public concerns over environmental damage or health impacts from aerial pesticide spraying near towns by generally avoiding this practice.
Increased sustainability of rural communities Category: resilience Reach: industry	Cotton underpins the economy of rural areas in which it is grown, providing income for farmers, labourers, cotton transportation workers and cotton ginning workers. The cotton industry also support local economic activity by supporting secondary industries and services.
Economic impact category	
Increased productivity of cotton growing Category: management and productivity Reach: industry	▪ Reduced crop loss as a result of disease and pest attacks means higher yield of usable cotton and lower expenditure on pesticides and herbicides. ▪ Reduced crop damage due to pest and disease attacks yields higher quality cotton, which commands a price premium on the market. ▪ Expanded area over which cotton farming is viable: from 2005 to 2013, an average 24 per cent of the area of cotton grown in Australia annually was due to CSIRO's new cotton varieties, according to data supplied by CSIRO. ▪ Average 15 per cent increase in productivity (measured as cotton produced/hectare) from 2006/7 to 20013/14, after adjustments for year-to-year production volatility.
Increased international trade Category: international trade Reach: industry	▪ Increased competitiveness of cotton exports due to increased productivity of Australian cotton farming and production of higher quality lint. Total export value of $2.7 billion in 2012-13. ▪ Increased export of CSIRO-developed cotton cultivars due to suitability for use in countries such as Brazil, the US, Greece and Turkey and the competitiveness of Australian cotton varieties against major international seed suppliers.
Employment, contribution to GDP Category: the macro economy Reach: industry	Increased economic activity and employment as a result of expansion of cotton growing areas and greater productivity. In the 2011 national census, 1,740 people self-identified as being employed in the cotton growing industry, a figure that would not include additional employment in downstream cotton transportation and processing industries as a result of increased productivity further upstream.

Source: ACIL Allen Consulting

C.4.2 Counterfactual

Australia's cotton growing industry would have suffered losses in productivity from 2006 to the present (the time period of the following cost-benefit analysis), had CSIRO's work on cotton varieties not continued.

CSIRO impact and counterfactual prior to 2006

Prior to 2006, CSIRO had already delivered significant benefits to the Australian cotton industry. These benefits formed the foundation for continued improvement post-2006 (the analysis period of this case study and cost-benefit analysis). The fragmented nature of cotton breeding programs across Australia in the 1960s and 1970s prevented the development of a strategic approach to research and breeding. CSIRO was instrumental in uniting disparate breeding programs and for establishing a cohesive approach to cotton research and breeding in Australia.

Without CSIRO's R&D the cotton industry in Australia would be less significant

In the absence of CSIRO work on cotton over the past several decades, Australia would have seen:

- *Continued reliance on US cotton varieties.* These varieties are mainly tailored to US conditions and do not provide resistance to cotton diseases found in Australia such as bacterial blight and Verticillium wilt.
- *Continued reliance on pesticides.* By adapting Monsanto technology focused on Helicoverpa resistance to Australian growing conditions, CSIRO enabled Monsanto technology to be applied more widely and effectively in Australia, reducing the need for chemical pesticide spraying. While Bollgard® was available from other seed suppliers, CSIRO's superior overall germplasm strengthened the uptake of this new gene technology. By reducing the frequency of pesticide sprays, CSIRO cotton varieties have also reduced the prospect that common pests will develop resistance to insecticides (CIE 2002).
- *Reduced yields*. Yields from CSIRO cultivars have shown an average increase of 23 kilograms of lint per hectare annually. In comparison, yields from US cultivars (which were available in Australia until 1998) show that although they showed an average increase of only 13 kilograms of lint per hectare annually, or approximately 45 per cent less relative to CSIRO's breeding activities (CIE, 2002). Moreover, the expansion of cotton growing into new regions in Australia, such as Darling Downs (in Queensland), and the Upper Namoi, Hillston and MIA regions (in NSW), would have been unlikely, had Australia continued to rely on US cotton varieties (CIE, 2002). Estimates suggest that approximately 30 per cent of the expansion in the area of cotton planted between 1983 and 2001 was largely due to the CSIRO breeding project (CIE, 2002).
- *A likely decline of the cotton industry relative to its present strength and size*.

CSIRO impact and counterfactual post-2006

In the period 2006 to the present, CSIRO's cotton varieties have continued to deliver significant yield increases. From 2006/7 to 20013/14, average productivity of Australian cotton production increased by approximately 15 per cent according to CSIRO data, after adjustments for year-to-year production volatility due to climatic factors (see Figure C6). Given that CSIRO cotton varieties accounted for over 90 per cent of cotton seeds sold in Australia by 2005 and 100 per cent of seeds sold by 2009, these increases in yields would likely not have taken place absent CSIRO.

CSIRO's cotton research continues to deliver benefits

Increased productivity of cotton farming has also generated income for growers and additional employment in related industries such as retail, service, ginning and transporting. These additional economic gains would have been foregone in the absence of ongoing CSIRO research into cotton varieties post-2006.

Advancements in Australian cotton varieties have led to high demand for CSIRO varieties on the global spinning market. A recent Deakin University and CSIRO study (SG Gordon and D Mallick, unpublished) has identified that international demand for Australian cotton is relatively inelastic, meaning that the price drops little when the volume marketed increases,

because there is large pent up demand from international spinners for higher quality cotton. Without CSIRO's research into enhancing cotton yield and fibre quality, Australian growers would have faced reduced access to these premium markets and would have foregone international market share to major competitors such as the US, Pakistan, India and Brazil.

The unique characteristics of CSIRO cotton varieties such as its regional adaptation capabilities have led to strong demand for CSIRO cotton varieties seeds in international markets. In association with Cotton Seed International and Bayer, CSIRO developed varieties are marketed as FiberMax cotton in overseas markets (CIE, 2002). This has resulted in a flow of licensing fees to CSIRO from the international sale of seed which would otherwise not have occurred.

However, it is notable that two of the largest benefits of CSIRO's cotton varieties research, reduction in pesticide use and increased water efficiency, took place largely prior to 2006. By 2006, pesticide use in cotton growing was greatly reduced, currently sitting at around 0.2g per kg of cotton lint produced. While CSIRO continues to make progress in breeding new cotton varieties for disease and pest resistance (which brings the benefit of increased lint yield), the largest reductions in pesticide use took place largely prior to our cost-benefit analysis period of 2006-the present. Similarly, data from Cotton Australia indicates that water use efficiency has largely flattened out at 2.5 ML per tonne of cotton produced since 2008, after large decreases in water usage per tonne of cotton produced in the preceding years.

Other international cotton research programs

CSIRO's cotton research is unique in the world

No other organisation in the world has been able to replicate CSIRO's level of cotton research coordination, particularly in terms of the degree to which CSIRO has been able to use its unique research structure to create nationally beneficial research outcomes. Australian cotton industry benefits from a highly integrated system of research into cotton breeding and management. Other countries have been unable to replicate this system due to the absence of Australia's strategic approach. In the USA, for example, numerous universities and private companies employ unique breeding projects for their local environments. However, these breeding projects are not connected to a larger strategic program; therefore they are not effective for a broader range of environments across the USA.

C.4.3 Attribution

100% of the outcomes of research into new cotton varieties since 2006 can be attributed to CSIRO

CSIRO was the primary source of research, breeding expertise and resources that underpinned the development of new cotton varieties. Other contributors to the successful implementation of CSIRO research include Cotton Seed Distributors Ltd, the Cotton Research and Development Corporation, and Australia's cotton growers. Cotton Research and Development Corporation provided important co-financing for CSIRO's cotton varieties project from 1990 to 2008 and the Cotton Seed Distributors provided important co-financing from 2006 to the present. Cotton growers have also played an important role in CSIRO's development of new cotton varieties by providing sites for testing of breeding material. However, these organisations and growers have not actively taken part in the research and development of these new varieties.

Monsanto has provided some of the base technology for resistance to pesticides, which has aided management of Helicoverpa pests and facilitated easier crop management for new growers, particularly in Southern regions. Some of the impact of reduced pesticide use can therefore be attributed to Monsanto. However, increases in yields have been primarily due to the development of CSIRO cotton varieties. As 100 per cent of Australian cotton is

currently grown from CSIRO cotton varieties, 100 per cent of the impact of breeding on yield productivity can be attributed to CSIRO.

60 per cent of Australia's increased cotton productivity can be attributed to CSIRO.

In their survey of 15 irrigated farm trials, Liu *et al* (2013) found that yield gain from CSIRO's cotton work can be attributed to genetics (48 per cent), management (28 per cent) and the interaction between genetics and management (24 per cent). Given that 100 per cent of cotton seeds sold in Australia have been CSIRO-bred varieties from 2009 (see Section C.4.4), and given that 100 per cent of the post-2006 research outcomes of the cotton varieties project are attributable to CSIRO, roughly 60 per cent of increased cotton productivity in Australia can be attributed to breeding of new cotton varieties by CSIRO.

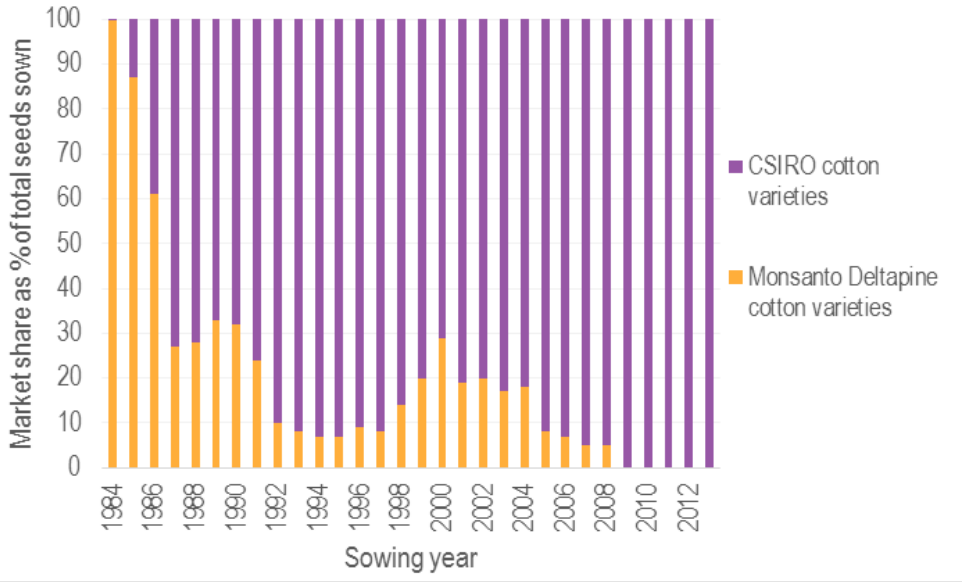
C.4.4 Adoption

Adoption rates

The adoption rate of CSIRO varieties in Australia is 100%

Australia's entire cotton crop is now grown from CSIRO-bred varieties (see Figure C3). CSIRO-bred varieties are also highly sought after in global markets. CSIRO-bred cotton varieties currently represent approximately 25 per cent of varieties sold in the USA and 30-40 per cent of cotton varieties sold in Greece, Turkey and Brazil. The adoption of CSIRO-bred varieties in global markets is expected to continue to increase.

Figure C3 **Adoption of CSIRO cotton varieties versus US varieties in Australia – percent of cotton seeds sown**



Source: ACIL Allen Consulting; CSIRO

Barriers to uptake

The share of CSIRO-bred cotton varieties in the Australian market is expected to continue to remain at or close to 100 per cent of market share going forward. While the use of GM seeds and the water intensity of the cotton industry have been a source of public concern in the past, these two issues are unlikely to affect continued uptake of CSIRO cotton varieties.

The merits and potential dangers of genetically modified food and agriculture has been regularly debated, particularly in the mid-1990s. However cotton has been largely omitted from this debate as it is not a food crop. As a result, the usage of genetically modified cotton seeds has not faced the resistance that it has in other food cropping industries.

In the past, the high levels of water consumption involved in cotton growing has been a major source of public criticism of the cotton industry, particularly given that many areas of cotton production are prone to drought. However, given that CSIRO's cotton varieties have already delivered significant increases in water efficiency, the use of these varieties has had the effect of mitigating this important barrier to uptake of cotton farming, making cotton farming less water-intensive and more sustainable.

C.5 Assessment of impacts

C.5.1 Impacts to date

CSIRO's cotton breeding project has delivered benefits, including:

The CSIRO cotton breeding project led to a range of impacts across Australia's cotton-production value chain. These impacts have taken place gradually over the several decades-long lifespan of CSIRO's cotton research. Some of the impacts described below, while very important to highlight, nonetheless took place prior to the assessment period of 2006 to the present. Other impacts of CSIRO's cotton research project have continued to deliver strong gains into the current period.

Environmental impacts

reduced chemical contamination of the natural environment

Reduced chemical contamination from insecticidal sprays

Uptake of CSIRO cotton varieties has resulted in lower use of aerial insecticidal sprays, reducing chemical contamination of local air, soil and water. A study by Knox *et al*. published in 2006 indicated that use of cotton varieties incorporating Bollgard® II technology reduced the environmental impact value of pesticide spraying by an average of 77 per cent compared to conventional cotton varieties over the first two seasons of its use (Knox *et al.*, 2006). Pesticide detections in rivers in the northern Murray Darling Basin have dropped significantly since monitoring began in 1991, particularly those pesticides most commonly used in cotton growing, such as endosulfan, fluometuron and prometryn (Mawhinney, 2012). For example, detections of endosulfan have dropped from appearing in an average of 58 per cent of water samples taken in rivers of the northern Murray-Darling by the NSW Office of Water in the years 1991-2000, to appearing in an average 6.1 per cent of water samples in the years 2000-2007. By contrast other pesticides commonly used in broadacre cropping, but not used in cotton cropping, such as atrazine and simazine, have not displayed such a large drop in detection frequency in the Office of Water's northern Murray-Darling water quality testing, suggesting that pesticides associated with cotton farming have dropped more rapidly compared to other farming activities (Mawhinney 2012).

However, while this is an important impact of CSIRO's project overall, most of the gains in pesticide use reductions took place prior to the analysis period (2006-present) that is the focus of this case study and the cost-benefit analysis.

Increased water efficiency

Increased water use efficiency

CSIRO varieties have significantly increased water use efficiency of cotton growing in Australia. Over the past decade water use efficiency in cotton farming has improved by 40 per cent due to a combination of changed water management and CSIRO's new, water-efficient cotton varieties (Roth *et al.*, 2013). One study that compared Bollgard® II cultivars and non-BT cultivars with the same genetic background showed an 8 per cent increase in overall water efficiency (Yeates *et al.* cited in Roth *et al.*, 2013). Increased water efficiency has important environmental benefits because it enables increased cotton production while minimising the harm that increased production causes in terms of reduced environmental flows for natural ecosystems. Increases in water efficiency also has positive economic impacts: the International Cotton Advisory Committee has found that Australian irrigation

costs are amongst the highest in the world. In 2010, irrigation costs represented an average 8 per cent of the total cost of production in Australia, compared with the USA at 3 per cent (Roth *et al.*, 2013).

However, as with pesticide use, most of the gains in water use efficiency took place prior to the analysis period of this case study and cost-benefit analysis.

Social impacts

Social licence to operate

– **Reduced community concerns and greater acceptance of cotton farming**

Historically, the cotton industry has drawn considerable criticism within Australia for high levels of pesticide use and high water intensity of cotton growing. Advances in water efficiency and reduction in pesticide use as a result of CSIRO's GM cotton varieties had substantially mitigated wider community concerns over the negative environmental and health impacts of pesticide and water use, strengthening cotton farmers' social licence to operate (ACIL Tasman, 2006).

Increased sustainability of rural communities

Interviews with cotton breeding project members identified a number of other spill over benefits occurring in Australian townships where cotton is grown, particularly in terms of increased employment of farm labourers and local economic activity, as a result of the increased financial sustainability of cotton farms using new cotton varieties.

Improved quality of life & health

Lower use of strong pesticides has reduced the exposure of farmers and local communities in cotton-growing areas to chemicals from aerial spraying. It has also reduced chemical contamination of local air, water and soil. Repeated and regular exposure to some pesticides has been associated with the onset of disease. For example, regular exposure to organophosphates has been linked to with chronic neurological diseases such as Parkinson's disease (National Centre for Farmer Health, 2014).

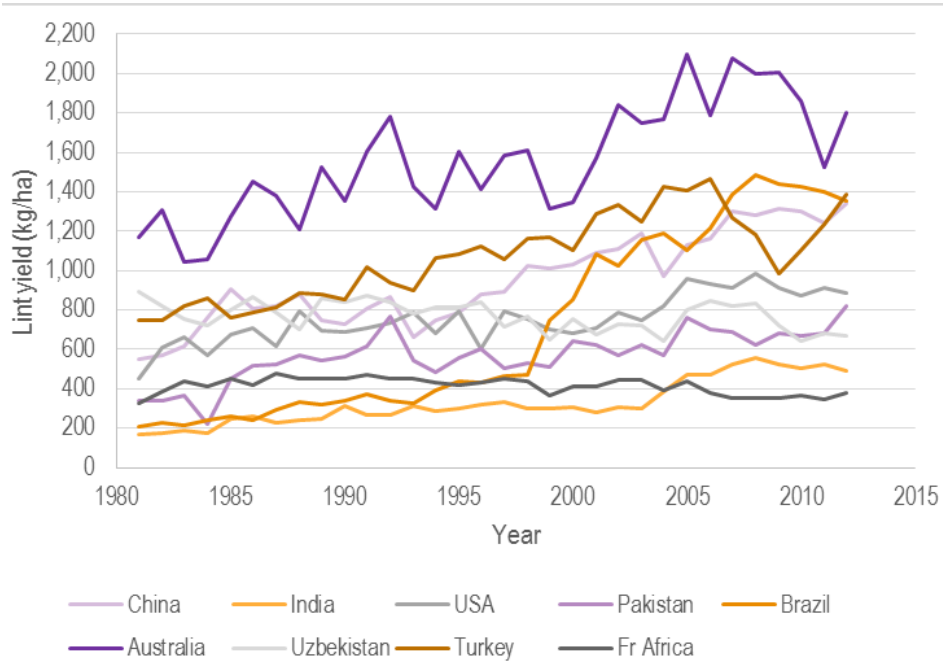
Economic impacts

Increased cotton growing productivity

Increased productivity of Australian cotton growing

CSIRO-bred cotton varieties have increased Australian cotton farmers' productivity by increasing yield, reducing crop loss due to disease and expanding the area over which cotton can be profitably grown in Australia. Between 1967/68 and 1983/84, average annual cotton yields stood at 1.052 tonnes of lint per hectare. Between 1984/85, when CSIRO released its first Siokra cotton strain, and 2012/13, average annual yields have been 1.725 tonnes of lint per hectare. Between 2003/2004, when CSIRO released cotton strains incorporating Bollgard® II technology, and 2012/13 productivity increased to average annual yields of 2.051 tonnes lint/hectare, almost double the productivity rates during the 1960s, 70s and early 80s (ABARES, 2013). Australia's cotton growing productivity measured in terms of kg of lint yield per hectare, is the highest in the world (see Figure C4).

Figure C4 **Cotton growing productivity – Australia and international competitors**



Source: CSIRO

Improvements in lint yield per hectare are due to a combination of both the commercialisation of CSIRO's cotton varieties and changes in farm management. A recent study by Liu *et al*. based on 15 irrigated farm trials per year over the period 1980 to 2009 suggested that 48 per cent of the increased average yield in the trial plots was due to breeding of new cotton varieties, 28 per cent of increased average yield was due to new farming and crop management practices, and 24 per cent of the increased average yield was due to the combination of new cotton cultivars and farm management (Liu *et al.*, 2013). Given that CSIRO cotton varieties accounted by 100 per cent of cotton seeds sold in Australia by 2009, this suggests that roughly 60 per cent of recent gains in cotton growing productivity in Australia can be attributed to CSIRO's cotton varieties breeding project.

New varieties have enabled the expansion of area under cotton cultivation

These productivity benefits have been magnified by the expansion of the cotton industry into areas that would otherwise have been unsuitable for cotton growing (due to extremes of hot or cold and/or increased presence of diseases and pests), as a result of CSIRO's climate-adapted cotton varieties. From 2005 to 2013, an average 24 per cent of the area of cotton grown in Australia annually has been due to CSIRO's new cotton varieties and the extra regional adaptability that these cotton varieties afford, according to data supplied by CSIRO.

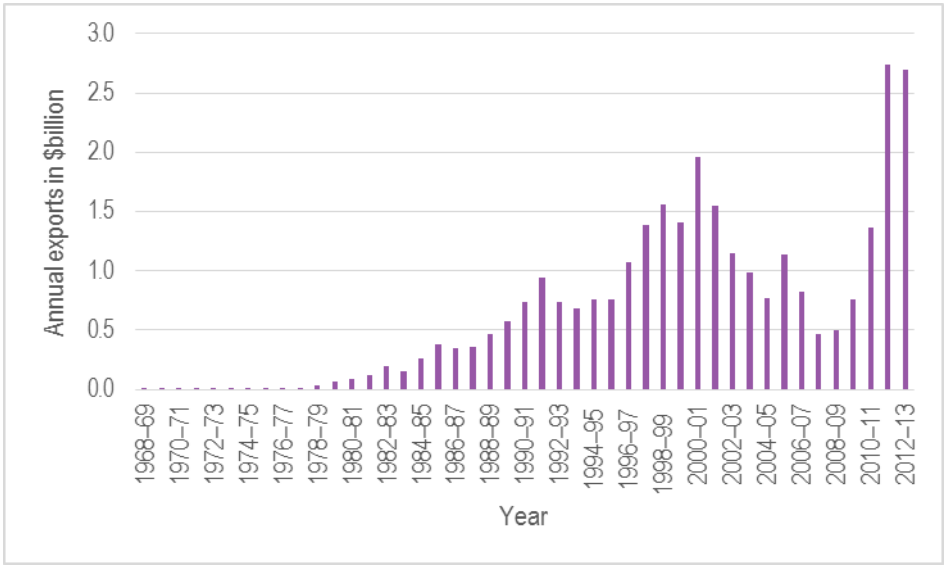
In addition, increased cotton lint yield has led to increased revenues from 'fuzzy seed'. Fuzzy seed refers to the process by which cotton seeds picked up in lint harvesting machines are separated out by cotton ginners (i.e. downstream processors of the lint) and either sold as feed for livestock or sold to cotton seed oil producers. Part of the revenues from the sale of fuzzy seed by cotton ginners are passed back to the cotton farmer that supplied the fuzzy seed. CSIRO estimates that the average value of fuzzy seed is equal to roughly 10 per cent of the revenue from the sale of cotton lint (CSIRO, 2014).

CSIRO has enabled increased cotton production and exports

Increased international exports

Improved productivity and cost effectiveness of cotton production in Australia, as well as the high quality of cotton lint from new cotton varieties has been an important driver behind increased cotton exports, the value of which stood at roughly $2.7 billion in 2012-13.

Figure C5 **Australia's annual cotton exports**



Source: ABARES 2013

Apart from Australian-grown cotton, CSIRO-developed cotton strains have also become an important export commodity. CSIRO-developed cotton strains have proven to be competitive against seed suppliers in the international market, with strong uptake in countries such as the US (just above 25 per cent of cotton varieties sown in 2013, up from 2 per cent in 2000) as well as Brazil, Greece and Turkey (30-40 per cent of cotton varieties sown).

Employment, contribution to GDP

New cotton varieties are likely to have contributed to increased employment in cotton industries

In the 2011 national census, 1,740 people self-identified as being employed in the cotton growing industry. CSIRO cotton varieties now account for 100 per cent of the cotton grown in Australia. These new varieties are likely to have contributed to Australia maintaining its competitive advantage (in terms of lint production per hectare) over other international producers. It is therefore likely that CSIRO's cotton varieties have therefore contributed to maintaining on-farm employment levels.

By the same token, the employment benefits of higher-yield cotton varieties are likely to extend down the cotton production value chain. The expansion of Australia's cotton farming industry has flow on effects for employment in downstream services such as transport and cotton ginning. It is also likely to have boosted secondary industries, such as farm equipment manufacturers and farm suppliers, and the retail sector providing goods and services in cotton growing areas to a certain extent.

C.5.2 Potential future impacts

Current research seeks to extend the existing benefits and explore new opportunities to innovate

Ongoing research will continue to build upon the gains of the last 30 years of cotton breeding to continue to provide cotton varieties with greater disease and pest resistance, including resistance to new threats. For example, since 2009 CSIRO's cotton breeding project has been introgressing Bollgard® III into CSIRO germplasm, which is designed to enhance resistance to Helicoverpa. Release is scheduled for about 2016, depending on regulatory approval. Ongoing research will also focus on production of higher quality cotton fibre, greater adaptability of cotton strains to climatic variability, and improved water efficiency. Based on the success of CSIRO's work on cotton varieties breeding so far and current 100 per cent adoption rate in Australia, this further research can be expected to continue to improve the productivity and competitiveness of Australian cotton.

In addition, CSIRO is pursuing research outcomes in new areas of innovation. A number of sub-projects are focused on improvements in nutrition, seedling vigour and genetic material to produce cotton that requires less energy in ginning. These ideas will flow into new varieties and have potential high commercial impact.

C.5.3 Cost Benefit Analysis

Benefits of CSIRO's cotton research are around $150 million between 2006/07 and 2013/14

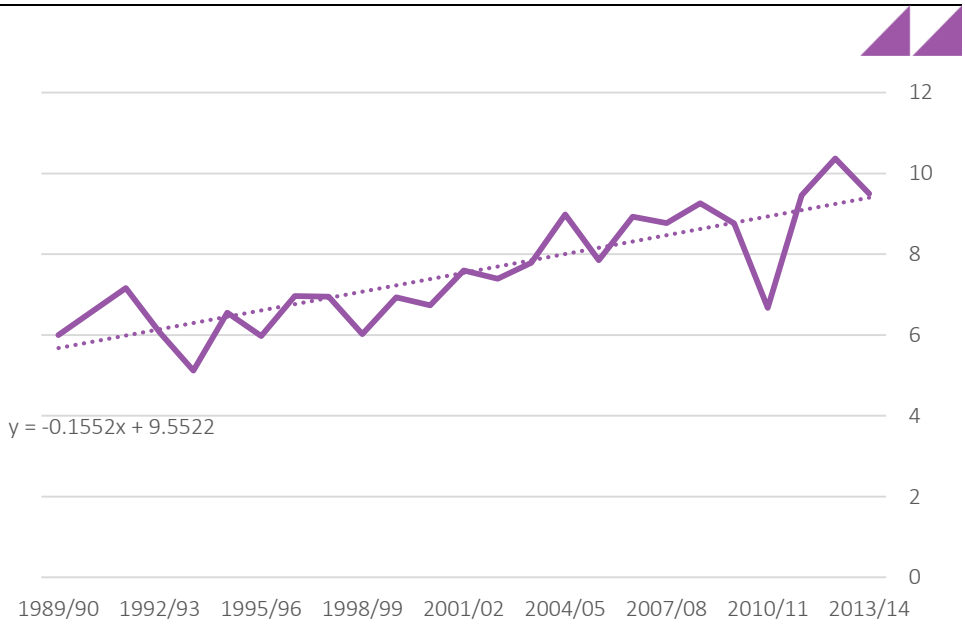
ACIL Allen finds that CSIRO's cotton varieties project has delivered a net benefit of $149.3 million between 2006/07 and 2013/14. This builds upon impressive net benefits delivered between 1973 and 2001 ($5 billion according to a 2002 CIE study), and between 2002 and 2005 ($65 million per annum, according to a 2006 ACIL Tasman study), noting that these two studies based their analysis on reduction in input cotton farming input costs, whereas this analysis focuses only on benefits from yield productivity gains (CIE 2002, ACIL Tasman 2006).

The data underlying this net benefit calculation is laid out in Table C8. The methodology underlying this cost benefit analysis is described below.

Calculation of cotton yield baseline and counterfactual

The cotton yield in Australia between 1989/90 and 2013/14 is shown in Figure C6. A linear trend has been fitted to remove the volatility arising from factors such as weather variations between years.

Figure C6 **Australian cotton yield (bales per hectare) - 1989/90 to 2013/14**



Source: Cotton Australia, Australian Cotton Production Statistics

The cotton productivity level in 2006/07 (based on the value of the fitted trend line in 2006/07 rather than the actual value) is the assumed baseline for this cost-benefit analysis.

To establish a counterfactual, we have made various assumptions

To establish a counterfactual, we assume no further increase in cotton yield productivity post-2006. As stated in the discussion of the counterfactual in Section C.4.2, in the period 2006/7 to 2013/14, average cotton productivity (measured as cotton produced per hectare) increased by approximately 15 per cent. Given that CSIRO cotton varieties accounted for over 90 per cent of cotton seeds sold in Australia by 2005, and 100 per cent of cotton seeds sold in Australia by 2009, it is highly unlikely that such a large increase in productivity would have taken place absent CSIRO. Therefore, to establish a counterfactual scenario against

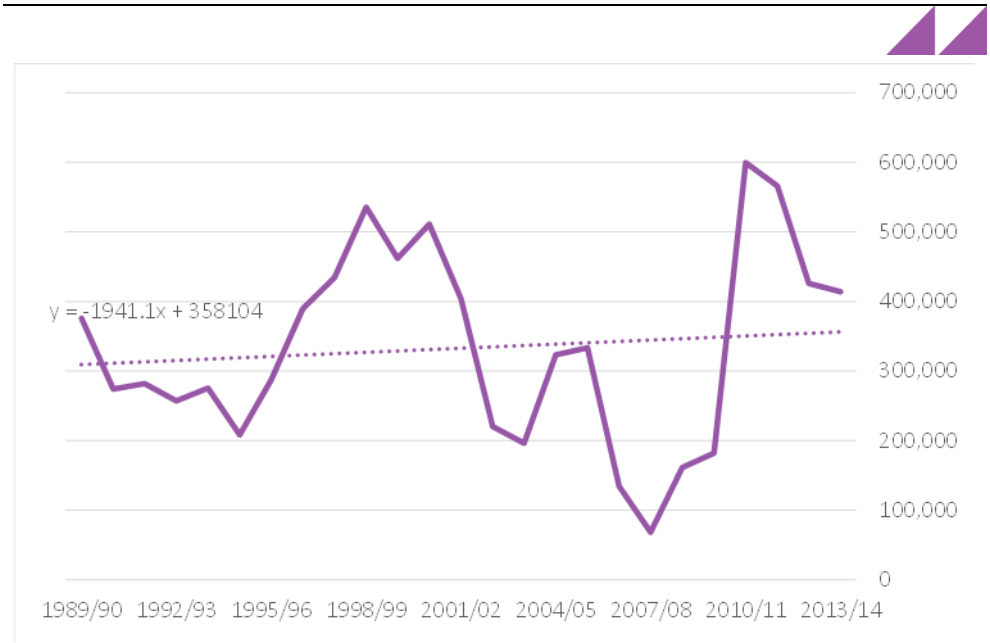
which the additional benefits of CSIRO's cotton varieties can be measured, this analysis freezes yield productivity levels at the baseline (2006/7).

In addition to revenue from increasing cotton production per hectare, this CBA also measures revenue from increased production of 'fuzzy seed' per hectare. Fuzzy seed refers to cotton seeds that are picked up in lint harvesting machines by cotton ginners, which are then processed into cotton seed oil or livestock fodder. CSIRO estimates that the average value of fuzzy seed is equal to roughly 10 per cent of the revenue from the sale of cotton lint (CSIRO, 2014). This means that increased cotton growing productivity leads to increases in revenue from both lint and cotton seed production per hectare.

Calculation of cotton prices and area under cultivation

To analyse the expected future benefits between 2014/15 and 2024/25, ACIL Allen has assumed that the future cotton price in real terms will remain static at $470 per bale from 2014/15 onwards. This price has been calculated based on our analysis of historical cotton prices from 1997 to 2013. Real production costs are assumed to be constant at $360 per bale in 2014-15 dollars based on the average production cost per bale between 2011 and 2013 as reported by CRDC in its 'Australian Cotton Comparative Analysis 2013 Crop' publication. All historical cotton prices are inflation adjusted to 2014 real prices.

Figure C7 **Total cotton cultivation area in Australia, 1989/90 to 2013/14 (hectares)**



Source: Cotton Australia, Australian Cotton Production Statistics

For the purposes of this analysis, ACIL Allen has frozen the total area of land under cotton cultivation between 2014/15 and 2024/25 at 300,000 ha. The decision to hold total area under cultivation constant for the purposes of our forecast is underpinned by two considerations. First, according to CSIRO researchers, this is the figure most commonly used in the cotton industry itself when forecasting future levels of cotton production. Second, this figure closely corresponds with the historical annual average number of hectares under cotton cultivation between 1989/90 and 2013/14, which sits at 322,870 hectares according to data from Cotton Australia (Cotton Australia, 2014a). While historic data in Figure C7 (above) would suggest a gradual increase in total hectares under cotton production, high levels of year-to-year volatility suggests that resting this cost benefit analysis on an assumption that total hectares under cotton cultivation will continue to expand may risk

overstating future benefits. Moreover, expectations of increasingly extreme weather events within a broader trend of increasing dryness in south-east Australia as a result of climate change serves to heighten the dangers of seeking to predict total area under cotton cultivation over the coming decade. Historically high levels year-to-year volatility in total area under cotton cultivation can be expected to continue.

Attribution level and exclusions

We have assigned a conservative 60 per cent attribution rate to CSIRO

We assume that some of the increase in yield productivity is due to breeding of new cotton varieties, some yield productivity increase is due to changing farm management practices, and some yield productivity increase is due to the interaction of the two. Using the findings of Liu *et al* (2013) (which suggested that 48 per cent of the yield productivity gain in Australian cotton farming can be attributed to genetics, 28 per cent to farm management and 24 per cent to genetics-management interaction), we attribute 60 per cent (48% + [24%/2]) of the increased cotton yield productivity since 2006/7 to CSIRO's cotton strains research.

We do not count the benefits of decreased pesticide use and greater water efficiency in this cost-benefit analysis, although these have certainly been valuable benefits that have been delivered over the lifespan of the cotton varieties research project as a whole. Data from Cotton Australia suggests that water efficiency has levelled out at around 2.5 ML per tonne of cotton produced since 2008. This suggests that the largest efficiency gains in water use took place largely prior to our analysis period of 2006/7 to 2013/14.

Similarly, pesticide use is already extremely low, currently sitting at around 0.2g per kg of cotton lint produced (a 95 per cent reduction in pesticides use over the last 15 years) (Cotton Research and Development Corporation, 2014b). With pesticide use at very low levels, the marginal benefits of additional reductions will also be low. This indicates that the greatest gains in pesticide use reduction also took place prior to 2006/7.

Results

The internal rate of return on investment over last eight years is almost $150 million

From 2006/7 to 2013/14, the total value of additional cotton production due to CSIRO's cotton varieties research project is equal to approximately $206.7 million in 2014 dollar terms. Total project input costs of $52.08 million adjusted for inflation are equal to approximately $57.37 million in 2014 dollar terms (see Table C7 – note that the same consumer price index figures applied to input costs also apply to the benefit valuation in Table C8). When total input costs of $57.37 million are factored in, net benefits attributable to CSIRO stand at $149.3 million in 2014 dollar terms, representing an internal rate of return of 93 per cent.

Future benefits attributable to CSIRO are projected to be over $379 million

Forecasts to 2024/25, based on expected bales/ha yield gains provided by CSIRO scientists, suggest that CSIRO's cotton varieties research could deliver additional benefits equal to approximately $632.4 million under a 5 per cent discount rate, assuming cotton lint prices, production costs and area under cotton cultivation are held constant. Remembering that this case study attributes 60% of increasing cotton yield to CSIRO's cotton breeding project, this brings net benefits attributable to CSIRO between 2014/15 and 2024/25 to $379.45 million.

Table C7 **CSIRO input costs adjusted for inflation**

Year	Total actual input cost ($ million)	CPI (Dec)	Total real input cost ($2014 million)
2006/07	4.573	86.6	5.677
2007/08	4.878	89.1	5.885
2008/09	5.01	92.4	5.829
2009/10	5.313	94.3	6.057
2010/11	5.78	96.9	6.412
2011/12	6.006	99.8	6.469
2012/13	6.218	102	6.553
2013/14	7.051	104.8	7.233
2014/15	7.252	107.5	7.252
Total	**52.081**		**57.367**

Source: ACIL Allen Consulting; CSIRO

Table C8 **CSIRO cotton varieties benefit valuation**

Year	Area cultivated	Yield	Counterfactual yield	Increase in yield	Price in $2014	Production cost	Net value of additional production	Additional fuzzy seed revenue	CSIRO-attributed benefit
	(ha)	(bales/ha)	(bales/ha)	(bales/ha)	($2014/bale)	($/bale)	($)	($)	($)
2006/7	134,290	8.3106	8.1554	0.1552	$464	$338	2,631,507	263,151	1,736,795
2007/8	68,585	8.4658	8.1554	0.3104	$481	$382	2,103,205	210,321	1,388,115
2008/9	161,390	8.621	8.1554	0.4656	$492	$426	4,968,965	496,897	3,279,517
2009/10	182,000	8.7762	8.1554	0.6208	$555	$449	11,995,644	1,199,564	7,917,125
2010/11	599,630	8.9314	8.1554	0.776	$534	$388	67,757,527	6,775,753	44,719,968
2011/12	566,000	9.0866	8.1554	0.9312	$567	$346	116,260,387	11,626,039	76,731,856
2012/13	425,786	9.2418	8.1554	1.0864	$512	$371	65,318,157	6,531,816	43,109,984
2013/14	414,000	9.397	8.1554	1.2416	$438	$356	42,150,327	4,215,033	27,819,216
2014/15F	300,000	9.5522	8.1554	1.3968	$470	$360	46,094,400	4,609,440	30,422,304
2015/16F	300,000	9.7074	8.1554	1.552	$470	$360	51,216,000	5,121,600	33,802,560
2016/17F	300,000	9.8626	8.1554	1.7072	$470	$360	56,337,600	5,633,760	37,182,816
2017/18F	300,000	10.0178	8.1554	1.8624	$470	$360	61,459,200	6,145,920	40,563,072
2018/19F	300,000	10.173	8.1554	2.0176	$470	$360	66,580,800	6,658,080	43,943,328
2019/20F	300,000	10.3282	8.1554	2.1728	$470	$360	71,702,400	7,170,240	47,323,584
2020/21F	300,000	10.4834	8.1554	2.328	$470	$360	76,824,000	7,682,400	50,703,840
2021/22F	300,000	10.6386	8.1554	2.4832	$470	$360	81,945,600	8,194,560	54,084,096
2022/23F	300,000	10.7938	8.1554	2.6384	$470	$360	87,067,200	8,706,720	57,464,352
2023/24F	300,000	10.949	8.1554	2.7936	$470	$360	92,188,800	9,218,880	60,844,608
2024/25F	300,000	11.1042	8.1554	2.9488	$470	$360	97,310,400	9,731,040	64,224,864

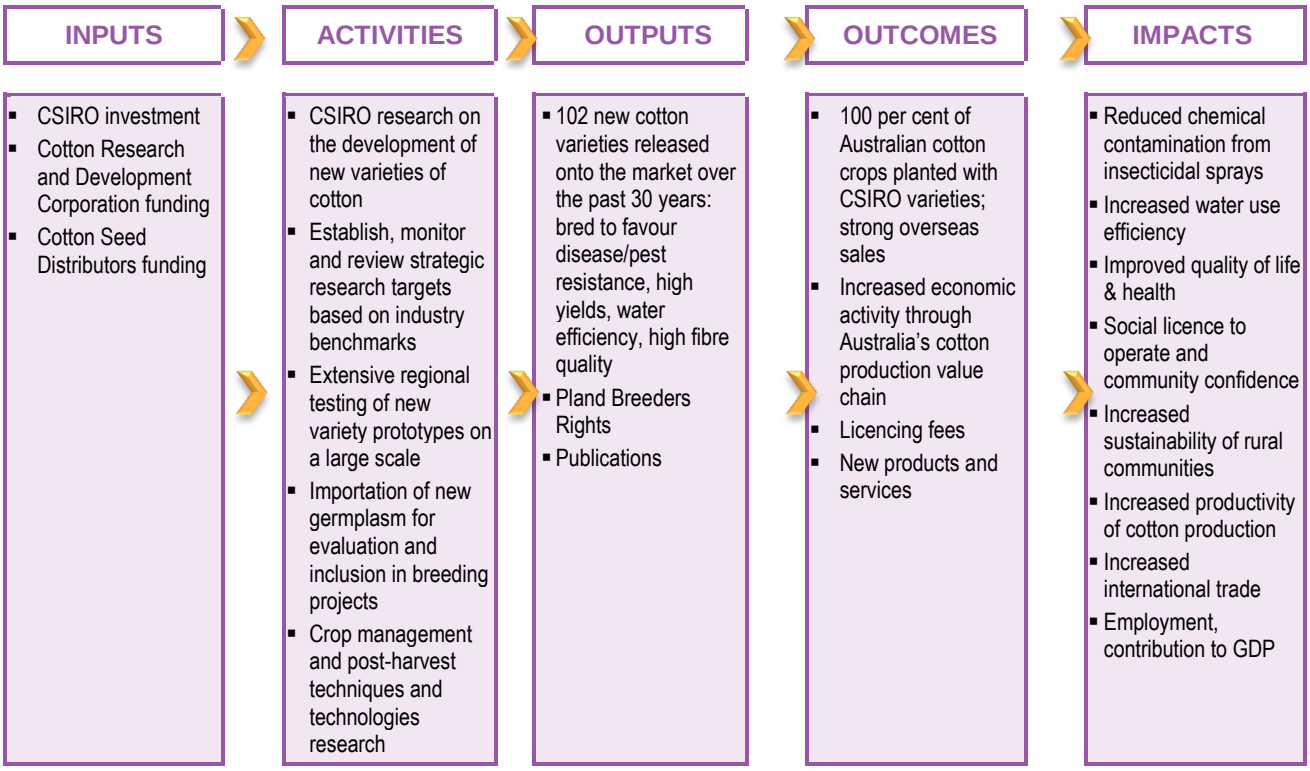
Note: All forecasts are marked by an 'F' next to the year in column one and are highlighted in purple. Figures in purple are forecasts based on analysis of historical data.

Source: ACIL Allen Consulting, CSIRO, Cotton Research and Development Corporation (CDRC) 2014a

C.5.4 Impact pathway diagram

Table C8 presents CSIRO's impact framework for its work on cotton varieties.

Figure C8 **CSIRO Cotton varieties - impact**



Source: ACIL Allen Consulting

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Appendix D Case study: LASC Longwall Automation

SUMMARY OF KEY FINDINGS

The key findings of this case study are that the CSIRO's research into longwall automation has:

- Improved underground longwall coal mine productivity by around 5 per cent. In present value terms, the stream of total net benefits attributable to CSIRO over the period from 2001-02 to 2024-25 is estimated to be almost $785.6 million in 2014-15 dollars under a 5 per cent real discount rate.
- Contributed to improving the working conditions and safety of coal mine employees. In addition to the social benefits associated with contributing to the reduced numbers of accidents and deaths, the costs that are avoided as a result are likely to save mining firms millions of dollars a year.
- Improved the accuracy of longwall mining operations and reduced the amount of waste rock that is mined along with the coal. This will lead to less environmental disruption from rock spoil stockpiles and reduced rehabilitation costs.

The benefit cost ratio of the longwall automation project is 51.4 if we use a 5 per cent real discount rate.

D.1 Introduction

D.1.1 Purpose and audience

This independent case study evaluation has been undertaken to assess the economic, social and environmental impact of the Longwall Automation Steering Committee (LASC) Longwall Automation project. This case study has been prepared so it can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of CSIRO's activities.

The report is provided for accountability, reporting, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, CSIRO and the general public.

D.1.2 Background

The longwall mining process involves a shearing machine with large rotating cutting drums that are driven back and forth across a coal seam. Significant 'slices' of coal are ground off with each pass of the shearing machine. The coal falls onto a conveyor system that carries it away from the mine face. The longwall mining process is currently used to supply approximately 90 per cent of the coal from underground mines in Australia (CSIRO, 2014a).

The alignment of the shearing machine to the coal seam is crucial to its performance. Failure to correctly align the mining equipment can lead to either some of the coal in the seam not being recovered and / or unwanted spoil (rock) being mined along with the coal. Either of these events reduces the efficiency of the mining process.

CSIRO has developed and patented a technology to help automate longwall mining

In the past, ensuring the correct positioning of the mining machine required stopping it periodically and carrying out manual adjustments. Doing so took time and involved miners working in close proximity to the coal face and machinery, which is an inherently higher risk place to be working. In the late 1990s CSIRO researchers developed and patented an

enabling technology which revived the potential to further automate this process in order to improve mining efficiency, reduce risk and avoid potential accidents and injuries (CSIRO, 2014a).

Around the same time ACARP prioritised research to improve mining efficiency

CSIRO's research and patenting coincided with a decision by the Australian Coal Association Research Program (ACARP) to address a specific need identified by the industry and give priority to research into improving the efficiency of the longwall mining process. ACARP decided that automating the longwall mining process was a key way to drive significant improvements in efficiency and safety and they consequently set this as a key priority for future R&D (CSIRO, 2014a). ACARP subsequently provided funding to CSIRO to support longwall automation R&D.

D.1.3 Approach

This approach taken in this case study aligns with the nine-step process described in the CSIRO's impact evaluation guide, namely:

5. Initial framing of the purpose and audience of the impact evaluation
6. Identify nature of impacts and the impact pathway
7. Define a realistic counterfactual (*what would have occurred in the absence of CSIRO*)
8. Attribution of research (*CSIRO vs. others' contribution*)
9. Adoption (*to date and in future*)
10. Impact (*timing, valuation, distributional effects among users, effects on non-users*)
11. Aggregation of research impacts (*within program of work*)
12. Aggregation of impacts (*across program of work*)
13. Sensitivity analysis and reporting.

Note that steps 7 and 8 above are less relevant for this individual case study as the longwall mining automation project is being considered in isolation. Of course, the aggregation of the impacts of all the case studies will occur in order to help estimate a lower bound for the value of CSIRO research activities.

D.1.4 Project origins and inputs

The aim of the CSIRO's Energy Flagship is to collaborate with industry, research organisations and government to create cost-competitive, low-emission energy technologies to plan for a secure and clean energy future in order to help Australia to protect and ensure its long term environmental, economic and social welfare (CSIRO 2014b). The stated goal of the Energy Flagship at the time was to:

> Deliver by 2020 technology options and science that will enhance Australia's economic competitiveness and regional energy security while enabling the transition to a lower emissions energy future, by unlocking $100 billion of *in-situ* value from our energy resources and contributing 32 Mt p.a. of greenhouse gas abatements by 2030.[7]

[7] The restructuring of the CSIRO National Research Flagships in July 2014, led to a change to the goal of the Energy Flagship. The revised goal is: "*To develop, demonstrate and ensure deployment by 2020 of integrated low carbon pathways for Australia and alternative stationary and transport energy solutions that realise a reduction of Australia's CO2e emissions by >20Mtpa by 2030 and by >50Mtpa by 2050*".

Specifically in relation to the coal mining theme of the Flagship, the then stated objective was to:

> Develop coal mining automation technologies and facilitate the remote management of longwall mine operations in Australia, removing people from the most hazardous areas and increasing coal mining productivity that will lead to increased mineable resources by at least one billion tonnes by 2020.

The Longwall Automation project provides an excellent example of CSIRO's ability to deliver on its goals of enhancing productivity and providing a safer working environment in the coal mining sector in close cooperation with industry. Successful implementation of the technology has helped position the Australian coal industry ideally for the future through improvements to productivity, competitiveness and worker safety (CSIRO, 2008).

History of project

CSIRO patented a technology to advance automation of the longwall mining process in the late 1990s. The innovation that CSIRO successfully patented was to use an Inertial Navigation Sensor (INS) that could be used in underground environments to accurately position and guide a longwall mining machine.

At the time, the deployment of the technology was expected to lead to improved mining efficiency, reduced risk of accidents and injuries to mine staff (CSIRO 2014a). Industry also clearly saw the potential of this technology to address an improvement need that it had identified and in 2001 the LASC Longwall Automation project attracted funding support from the Australian Coal Association's (ACA) research arm, ACARP.

The project was conducted by CSIRO's Exploration and Mining Division with support from the Cooperative Research Centre for Mining Technology and Equipment (LASC Longwall Automation 2008). The project was overseen by the Longwall Automation Steering Committee, which consisted of industry and ACARP representatives. The resulting research and technology provided a model of implementation and was regarded as an innovative success (CSIRO, 2014a).

Project inputs

ACARP has provided significant funding support to CSIRO's longwall R&D

ACARP provided two tranches of funding to CSIRO to support its ongoing R&D into longwall automation. The ACARP grants funded labour and operating costs.

- $3,237,000 (excluding GST) over a three year period from 1 July 2001 (ACR & CSIRO 2001)
- $2,419,000 (excluding GST) over a two year period from 1 April 2005 (ACR & CSIRO 2005)

CSIRO provided funding of approximately $1.5 million over the period of the initial ACARP grant. These funds covered the difference between CSIRO's full labour cost recovery and the labour charge made to ACARP.

As part of the second tranche of funding there was also additional cash (about $1 million) and in-kind support (some $1.5 million) provided to the project. In-kind support from mine operations included access to senior staff and open access to longwall production systems and mine ICT infrastructure. OEM (original equipment manufacturers) suppliers made available mining equipment on which the CSIRO mining technology could be installed and tested. CSIRO also provided $555,000 in funding for the second stage of the project.

Table D1 shows the CSIRO's costs associated with the longwall mining technology project and the sources of funds used to meet those costs. Since the end of the second stage of the

project ongoing research has been funded from the royalty and licence stream received from companies who have licensed the technology.

Table D1 **Longwall project: Costs and funding**

Period	Project expenditure	CSIRO funding[f]	ACARP funding	Other support	In kind support	Net intellectual property payments
	($M)	($M)	($M)	($M)	($M)	($M)
Stage 1 (2001-04)	4.737	1.5[b]	3.237	-	-	-
Stage 2 (2005-07)	2.969	0.55	2.419	1[a]	1.5[e]	-
2008-09	0.4 [c]	1.1	-			-0.7[d]
2009-10	0.4 [c]	0.155	-			0.245 [d]
2010-11	0.5 [c]	0.035	-			0.465 [d]
2011-12	0.6 [c]	-0.165[g]	-			0.765 [d]
2012-13	0.6 [c]	-0.217[g]	-			0.717 [d]
2013-14	0.6 [c]	-0.789 [g]	-			1.389 [d]

[a] Cash grant.

[b] In-kind support representing the difference between CSIRO's full labour cost recovery and the labour charge to ACARP.

[c] Total of $3.1 million spent over period 2008 to 2013.

[d] CSIRO.

[e] Includes provision of OEM equipment and use of mines for testing.

[f] CSIRO funding from appropriations.

[g] A negative number signifies that some of the net IP revenue is available for other CSIRO coal mining research.

Source: CSIRO.

The first technology licensing agreements were put in place in 2007. The revenues received by CSIRO have been used to fund ongoing R&D to improve and further extend the initial research outcomes.

The research funding agreement with ACARP specifies that once CSIRO has recovered its costs ACARP will receive a share of net intellectual property (IP) payments such as royalties. Moreover, through its partial funding of the longwall automation projects, ACARP is delivering on its primary mission, which is to create value for its members and stakeholders in the industry.

In 2014, the CSIRO made its first royalty payment to ACARP under the agreement. The longwall automation project remains one of the few ACARP projects to have paid a royalty to ACARP. Licensing and royalty costs and revenue flows to date are shown in Table D2.

Table D2 **Net IP revenue for CSIRO's longwall mining technology**

Year	Gross IP revenue	IP costs	Payments to ACARP	Net IP Revenue
	($m)	($m)	($m)	($m)
2008-09	0.225	0.927		-0.702
2009-10	0.705	0.460		0.245
2010-11	0.990	0.525		0.465
2011-12	1.350	0.585		0.765
2012-13	1.380	0.630	0.033	0.717
2013-14	1.930	0.510	0.031	1.389

Notes: In 2008-09 IP related costs exceeded IP revenue. Numbers may not add due to rounding.
Source: CSIRO personal communication.

D.2 Project activities

D.2.1 Activities prior to 2011

The longwall automation project utilised a wide range of CSIRO's skills and expertise. Table D3 lists the key capabilities and summarises the activities undertaken for each of those capabilities.

Table D3 **Key CSIRO capabilities used in longwall automation project**

CSIRO capability	Activity
Mining Engineering	Liaison with ACARP and collaborating mines, integration of automation systems onto longwall coal mining.
Geotechnical Engineering	Specification of control system performance and research into interaction of automation systems with ground conditions.
Electrical Engineering	Design of automation components, explosion protected enclosures and integration with OEM systems.
Mechatronic Engineering	Research into application of inertial navigation to the longwall guidance and automation problems. Implementation of the INS guidance solution.
Electronics Engineering	Design of guidance system components; embedded computer systems, hazardous area uninterruptable power supply systems.
Communications and Network Engineering	Design and implementation of wireless Ethernet for underground usage.
Process Control Engineering	Specification of Open Systems Architecture-based interconnection protocol for multi-vendor navigation and automation system components.
Software Engineering	Specification and development of embedded and user interface software for the automation and visualisation systems.
Mechanical Engineering	Design of mechanical systems and components for embedding automation system elements into OEM equipment and for installing stand-alone components on face equipment.
Geology and Geophysics	Input into specification of guidance system.
Project Management	Management of individual project components, co-ordination of overall project, reporting to ACARP Steering Committee.

Note: Only the key CSIRO capabilities are listed in the above.
Source: CSIRO.

CSIRO research

The duration of the first stage of the project was three years. The aim of this first stage of the project was to assess the feasibility of using inertial navigation technology to accurately measure the position of a longwall shearer in three dimensions (CSIRO, 2012).

The research undertaken and subsequent technology developed during this stage of the project included automatic face alignment, sensors and software for automatic horizon control, open communication systems between longwall components, a robust information system to allow online 3D monitoring of the longwall system and various geotechnical monitoring systems (ACR & CSIRO, 2005). The resulting technology allowed longwall mining equipment to operate automatically within pre-defined constraints.

Development and testing of prototype

Following the promising results of the first stage of the project ACARP provided a second tranche of funding to CSIRO to conduct additional R&D into the technology between April 2005 and March 2007. The aim of the second stage of the project was to allow the outcomes of the first stage to be tested and verified through large scale field trials. In addition, the extension sought to transform several technologies from laboratory concepts into demonstrable prototypes that would be ready for commercialisation. Box D1 provides more information on the goals of the longwall automation extension project.

Box D1 **Goals of LASC Longwall Automation extension project: 2005 – 2007**

The extension project had the following goals:

- **Longwall Automation System (LAS)**: Install at three demonstration sites, make improvements to software quality to meet industry standards and develop and test new control strategies.
- **Shearer Position Measurement System**: implement an improved capacity INS-based system with resolution appropriate for real time horizon control and face straightening.
- **Horizon Control**: Develop and demonstrate to production standard:
  - improved horizon control compatible with Original Equipment Manufacturers' (OEM) control system
  - optical marker band
  - infra-red detection of strata
  - controlled traversing cut for a pre-determined path.
- **Technology Development**: Develop Landmark compatible technologies for:
  - gateroad convergence and shield pressure and convergence monitoring to production standard
  - coal flow optimisation and void detection to prototype standard.
- **Information System**: Develop and demonstrate production standard information systems for:
  - face management
  - operator interface
  - data management
  - training simulator.
- **OEM Commitment**: Commitment from participating OEMs to embrace Landmark Longwall Automation standards into their core products.

Source: ACR & CSIRO 2005

Create a commercial product

The goals listed in Box 2 were designed to enable a commercial full longwall automation mining system to become available to Australian coal mines. That desired outcome was realised when the technology was licensed to five OEM firms. As part of the licensing agreement the licensees get access to a package of hardware designs, software and source code. This allows them to fit the technology to their own equipment. Importantly CSIRO's technology was always designed to be non-equipment specific so that any mining equipment manufacturer could incorporate the technology into their own equipment.

OEMs were given non-exclusive licences to the technology

The coal industry through ACARP and LASC required a non-exclusive technology licensing model so that the benefits of the industry-funded research would potentially be available to the industry from all major equipment suppliers. The equipment manufacturers recognised the strong interest and commitment of the industry to the technology and consequently accepted the non-exclusive licensing model. Support for this commercialisation model was reinforced by CSIRO's assurance that it would use a portion of its intellectual property revenue to provide technical assistance to manufacturers in the early developmental stages of the product. This commitment by CSIRO gave the mining equipment manufacturers the assurance they needed that they would be able to draw on CSIRO's experience to help minimise development costs and that the technology would continue to be supported and further developed and improved over time by the CSIRO (CSIRO, 2014a).

The inertial sensor currently used in the technology is supplied by an American company. The rest of the hardware and software was initially designed and built by CSIRO. However, more recently CSIRO has licensed a company in Canada to build the hardware to provide power to the sensor and to supply an embedded computer to get navigation information from the sensor to the mining machine.

Provide support to firms that bought the technology

CSIRO's aim was to achieve full technology transfer to OEMs. To help ensure this outcome CSIRO provided technical support and advice to OEM licensees during the initial stages of the technology transfer. However, CSIRO also provided some initial support to mining companies. It is important to note that that support was provided through the OEMs rather than through any direct contract with the users. The aim was to provide CSIRO's support in partnership with the OEMs. By doing so the latter would gain the skills needed to provide the full suite of support services for the product they were providing to their mining company customers, without the need for any CSIRO assistance.

Activities during the current strategy period

Research to further improve the technology is continuing

The first commercial-ready outcome of the initial research delivered a system that is capable of robustly providing optimal alignment between the mining machine and the coal face being mined. The current research is concentrated on better 'horizon control'. This technology enables the longwall mining machines to consistently vertically align themselves with the coal seam.

While an INS-based implementation of horizon control was developed to a working prototype stage at the conclusion of the Extension Project and was included in CSIRO's original technology licensing agreement, the maturity and consequently the take up of this aspect of the technology has to date been more limited. Consequently CSIRO are continuing to develop this aspect of the technology.

Moreover, more sensitive methods of implementing effective horizon control based on directly sensing coal-rock interfaces at seam roof and floor using optical and thermal infra-red techniques, which were identified during the course of the original projects, are currently also being developed.

The longwall guidance methods developed during the Landmark projects have been transferred to continuous miner operations which are used to drive the underground roadways necessary to prepare for longwall operations. Currently, CSIRO is trialling pre-commercial installations of the technology in the field. This technology will significantly improve the speed of roadway development, which currently is a limiting factor in a number of longwall mines and will also enhance safety by removing miner operators from the vicinity of the machine and working face.

D.3 Project outputs

D.3.1 Key outputs of the project

The main output of the longwall project is the enabling technology that provides significantly higher levels of automation for the underground longwall mining process. The technology consists of the hardware and software necessary to automatically operate and monitor the longwall mining equipment (see Box D2).

Box D2 **Outputs of LASC Longwall Automation project**

The primary outputs of the LASC Longwall Automation project consist of four licensed technologies:

- ***Shearer Position Measurement System (SPMS)*** – Hardware and embedded software mounted on the shearer and application software that resides in generic networked platforms. The SPMS hardware's purpose is to measure and communicate the 3D position of the shearer to the face data network. The off-shearer applications then process the raw SPMS information to provide both industry standard data streams and user-accessible displays of face and/or floor profiles.
- ***Automated Face Alignment*** – Software whose functions are to manage transfer of recommended position corrections (RPCs) to the OEM powered roof support control system and to provide a user interface to the automatic face alignment system for:
  - … entry of designed face alignments
  - … display face alignment information
  - … management and monitoring of system performance.
- ***INS-Based Automated Horizon Control*** - This technology comprises software whose functions are to Manage transfer of horizon information to the OEM shearer control system and provide a user interface to the horizon control system for:
  - … entry of designed cutting horizons
  - … display roof and floor horizon information
  - … management and monitoring of system performance.
- ***Automated Creep Control*** – This technology comprises hardware and software components. The hardware component is a pair of scanning laser-based sensors mounted adjacent to the main gate that measure the cross-gate road creep distance of the main gate drive hardware. The software component displays and logs creep measurement values and computes corrections to add to basic face alignment RPCs to implement creep control.

In addition, there are the following outputs that assist in implementing the LASC technologies above.

- ***Reference Designs*** – Documentation describing the design of all system components to implement the above technology solutions. This information has been issued to all licensees.
- ***Open System Communications*** – Specifications for implementation of industry-standard communications protocols to interconnect the LASC and OEM system components necessary to implement the above technology solutions. These specifications are available on-line at www.longwallautomation.org.
- ***Cross-face wifi communications*** – Implementation details for cross-face wireless Ethernet communications. This information was made freely available through publications and individual advice to OEMs.

Source: CSIRO 2005

CSIRO has also provided technical support (through the OEMs) to companies who install the automated mining machinery.

D.3.2 Key publications

CSIRO also published some 25 papers (4 journal articles and 21 refereed conference papers). Examples of some of the papers with the greatest impact in the field are provided below:

— C. O. Hargrave, J. C. Ralston and D. W. Hainsworth, (2007) "Optimising Wireless LAN For Longwall Coal Mine Automation", *IEEE Transactions on Industry Applications, January,* Volume 43, pp 111–117.

— D.C Reid, J.C Ralston, M.T. Dunn and D.W. Hainsworth, (2010). "Longwall Shearer Automation: From Research to Reality". *16th International Conference on Mechatronics and Machine Vision in Practice, Brunei,* 9, pp. 22-24 June.

— D. C. Reid, D. W. Hainsworth, J. C. Ralston and R. J. McPhee, 2006. "Shearer Guidance: A Major Advance in Longwall Mining", *in Field and Service Robotics: Recent Advances in Research and Applications. S. Yuta, H. Asama, S. Thrun, E. Prassler, T. Tsubouchi (Eds) Series (Springer Tracts in Advanced Robotics),* pp. 469-476, (book chapter). ISBN 978-3-540-32801-8.

— J. C. Ralston, D. W. Hainsworth R. J. McPhee, D. C. Reid and C. O. Hargrave, "Application of Signal Processing Technology for Automatic Underground Coal Mining Machinery", *Proceedings of the Conference on Acoustics, Speech and Signal Processing (ICASSP'03),* 6-10 April 2003, Volume 2, pp. 249-52, Hong Kong.

— J. C. Ralston and A. D. Strange, "Developing selective mining capability for longwall shearers using thermal infrared-based seam tracking," *International Journal of Mining Science and Technology,* vol. 23, pp. 47-53, 2013.

D.3.3 Awards and public recognition

In 2004 CSIRO was awarded the ACARP Research and Industry Excellence Award for the initial longwall automation project (July 2001 – July 2004) (ACARP 2012).

The success of this project has been a significant factor in the strength of the ongoing collaborative relationship between CSIRO and ACARP. While CSIRO's contribution to the ACARP research portfolio covers a broad capability and science base, its track record in longwall automation has resulted in ongoing research funding in other projects related to that domain of around $1 million a year being provided to CSIRO by ACARP following the completion of the longwall automation projects

D.4 Status of Outcomes and Impacts

D.4.1 Nature of Outcomes and Impacts

Outcomes

The primary outcome of this project is the commercialisation of technology to enable a higher level of automated operation of underground longwall mining equipment. The technology was delivered to the industry as a critical part of longwall mining equipment rather than an optional add-on. ACARP required that the technology could not be exclusive to a single manufacturer and CSIRO stipulated that, being an R&D entity, it would not be able to support the technology directly in the field (CSIRO 2014a).

As part of the licensing agreement CSIRO assisted OEMs with its roll out

The equipment manufacturers recognised the level of interest and commitment from the industry and subsequently accepted a non-exclusive licensing model. The commercialisation model was reinforced by CSIRO's assurance to use a portion of its intellectual property revenue towards the provision of technical assistance to manufacturers in the early stages of the product. This commitment by CSIRO gave mining equipment manufacturers the assurance they needed that they would avoid any additional development costs and that the technology would continue to be supported and further developed and improved over time by the CSIRO (CSIRO, 2014a).

The assistance provided to commercialisation partners early in the technology transfer process has proved to be very successful. Early implementation of the technology has delivered good performance due in part to support from CSIRO. This has enhanced the

reputation of the technology and has increased customer confidence in longwall automation. It is highly likely that this has accelerated the level of market penetration achieved to date.

CSIRO has subsequently employed this approach in the commercialisation of Sirovision and NEXSYS.

The LASC Longwall Automation project has provided licensed OEMs with an opportunity to sell a successful new product, delivering increased business and revenue for those OEMs.

Uptake has been extremely rapid

The adoption of the technology has so far been outstanding. To date, CSIRO's longwall automation technology has been adopted in 20 longwall mines in Australia, representing around 60 per cent of operating longwall coal mines in Australia. The generally accepted view of the industry is that a maximum of 80 per cent of the longwall coal mines in the Australia are candidates to use mining machines which incorporate CSIRO's longwall mining technology.

The industry itself has played a large part in the rapid uptake of the LASC technology. Through close involvement of LASC in the research projects, ensuring that the research was directed towards generating industry-needed solutions. As a result of the participation of the major mining companies during the demonstration phase, the industry was able at an early stage to translate the technical IP generated by CSIRO into value for their operations. This generated an enthusiastic market for LASC outcomes.

Impacts

The LASC Longwall Automation project has had a range of impacts. Table D4 summarises the social, environmental and economic impacts to date.

Benefits of the technology include improved productivity and safety

The main beneficiaries of the project include: equipment manufacturers who benefit through the sale of the technology; mining companies who save on operating costs and achieve greater productivity; and employees of mining companies who install and use the technology through safer working conditions.

The LASC Longwall Automation project has also had a number of unintended benefits. The most significant of these is the decreased time required for maintenance of mining equipment in mines that use CSIRO's longwall automation technology. This has occurred due to the need to ensure that all parts of the mining operation, including equipment-specific automation technology developed by individual equipment manufacturers are fully optimised to maximise the benefit of this technology. As a result, all machines are consistently operating in a manner that optimises their performance. This results in fewer stoppages, better alignment in the workloads of the various components of the mining operation and optimal maintenance of machinery. While precise information on the productivity gain due to the automated longwall mining technology is difficult to obtain due to the commercially sensitive nature of such information, it is broadly accepted within the industry that adoption of LASC Longwall Automation technology has increased peak productivity by around 10 per cent. However, the major benefit to the industry of LASC has been greater consistency in operations because of the factors described above, which, with other enhancements has generated a long term productivity improvement in the order of 5%.

The extremely rapid adoption of the technology by Australian underground coal mines is an excellent indication that mine operators expect that the productivity gains will ensure that the return on investment for installing the technology will be very attractive. That productivity gain results a number of factors, including:

— significantly reduced down time for periodic realignment of the longwall mining machine

— less waste rock (spoil) being produced during the mining process

— the optimisation of the operation of all other elements of the mining operation that is required to ensure that full benefits of the longwall mining technology can be captured. This results in improved equipment performance due to more consistent and optimal rates of production and a resultant reduction in the frequency of machinery maintenance that is required.

Table D4 **Outcomes and Impacts of CSIRO Longwall mining technology**

Outcome / impact	Detail
Economic	
Technology Adoption *Category: New products or services* *Reach: Global*	The new technology has been widely adopted by OEM suppliers of underground mining equipment. Licencing agreements have been entered into with five OEMs. To date, CSIRO's LASC Longwall Automation technology has been installed in 20 longwall mines, or about 60 per cent of total underground coal mines in Australia.
Reduction in operating costs *Category: New products or services* *Reach: Global*	The technology contributes to lower operating costs and has increased returns from export earnings. The technology reduces costs associated with shearing of spoil rock. It also reduces environmental management and remediation costs, as there is less waste rock to be processed, stored and (ultimately) remediated.
Higher productivity *Category: New products or services* *Reach: Global*	The technology is estimated to deliver productivity increases of up to 10 per cent peak due to: timely maintenance to ensure peak performance of other parts of the overall mining operation; less shearing of spoil rock; lower levels of volatility in machinery activity; and lower risk of accident and injury. This has resulted in less work stoppages and greater efficiency of the overall mining operation.
New model of industry collaboration and commercialisation developed *Category: Management and productivity* *Reach: National*	As part of the commercialisation of longwall automation technology, CSIRO developed a new model for collaborating with OEMs. Under that model OEMs accept a non-exclusive licensing arrangement and CSIRO undertakes to provide a certain number of hours of training and support during the first phase of commercialisation. This gives the OEMs confidence that they can draw on CSIRO's skills to help minimise the costs of any further technology development and commercialisation. This model of industry collaboration for the commercialisation of new technologies has now been applied in a number of other CSIRO projects.
Environmental	
Reduced environmental footprint *Category: Sustainable industry development* *Reach: Industry*	The improved accuracy of the underground mining equipment reduces the amount of unwanted rock (spoil) that is mined along with the coal. That spoil has to be disposed of in some way. One form of disposal is to store the rock in above ground spoil dumps. There are potential environmental impacts associated with spoil dumps, such as runoff. Reducing the amount of spoil reduces the size of any spoil dump that has to be used and the scale of any potential impact on the environment.
Social	
Increased coalminer safety *Category: Life & Health + Safety* *Reach: Industry*	Employees of mining firms are required to manually adjust the large machines where automation is not installed – thereby increasing the likelihood of an accident or injury. Automation of some of the longwall mining processes has removed miners from noisy, dusty and hazardous areas.

Source: ACIL Allen Consulting, CSIRO 2008 and CSIRO 2014a

Industry sources suggest that the cost of lost production can be as high as $1,000 a minute. While this figure is likely to vary significantly from coal mine to coal mine, it provides an indication of the scale of benefits that can result from the productivity gains that result from the use of the automated longwall mining technology itself and the system-wide efficiencies that use of this technology encourages.

D.4.2 Counterfactual

In 1994, CSIRO reviewed global research efforts to develop technologies to help automate and control Longwall mining equipment. The review showed that research was mainly being

done by government research institutions, for example in the United States (US), United Kingdom, France and South Africa. However, at that time there had been few useful outcomes from any of that research.

It is of course possible that other individuals or organisations might have developed similar technologies over time. However, it is difficult to determine when such technologies might have emerged in the absence of CSIRO's activities. ACIL Allen notes that the CSIRO technology is used in 60 per cent of the automated underground coal mining equipment in use in Australia today.

One of the licensees, Caterpillar, had previously developed advanced software and control systems to automate the motion of longwall shields to implement face alignment and continued to develop this system while the Landmark projects were being conducted. However, this system suffered from the lack of an effective sensor to measure the position of the longwall shield units. This problem was only overcome by measurement of the shearer position using CSIRO's LASC technology. Therefore, this OEM is able to offer a longwall automation product that requires only one technology from the LASC family, which when linked with their OEM system can achieve state-of-the-art face alignment performance.

Other automation developments have been produced by shearer manufacturers during the period of the LASC technology development. "State based" automation of shearer motion depending on location along the face have also resulted in considerable productivity improvements. These advances have been able to achieve higher levels of effectiveness through integration with LASC control.

CSIRO's technology is recognised as world leading

This provides strong support for the view that CSIRO's technology is still regarded as being the best available some five to six years after it was first commercialised. For the purposes of our economic analysis we have estimated that CSIRO's activities brought forward the date when this technology was commercially available by 10 years.

CSIRO continues to carry out research to continually improve the longwall mining technology and any incremental technology improvements are passed on to its licensees. As long as CSIRO continues to support the further development of the technology it is likely to retain its high level of acceptance and use within the industry. In the event that CSIRO ceased work on further developing the technology then we estimate that it would take the industry roughly five years to catch up to CSIRO's current research position in this technology.

D.4.3 Attribution

CSIRO's ground-breaking innovation in this area was to recognise and subsequently demonstrate that the position of all the relevant components in the longwall system could be inferred accurately from a 3D measurement of the position of the shearer component. This is the crucial element of the intellectual property covered by CSIRO's patents. CSIRO also implemented a robust, highly accurate method based on inertial navigation to make the necessary 3D measurement of shearer position. While the LASC system currently relies on a high-performance inertial navigation system developed in the US to measure the shearer position and this needs to be acknowledged, the inventive step in LASC technology is the use of the measured shearer position to infer the location of the other longwall components and any form of position measurement could be used.

ACIL Allen understands that CSIRO is now the recognised world leader in automated longwall mining, with little or no serious competition from other researchers for the last fifteen years. Certainly no competitive technology solutions have surfaced in the market and

no major technology developments have been reported in the literature. OEMs are regularly in communication with CSIRO regarding the implementation status of further LASC developments and have approached the organisation to undertake further underground automation research.

While funding from ACARP (particularly the second tranche of funding) was integral to commercialising the technology that organisation conducted no actual R&D activities themselves. However, the management role undertaken by ACARP through the Steering Committee and the facilitation of a co-ordinated industry-wide development and testing process meant that the technical IP generated by CSIRO was fast-tracked to a mature stage, capable of generating value for the industry, which accelerated the market for the LASC technology.

Participating mines contributed greatly to the success of LASC technology demonstration programs, contributing in-kind support and taking on risk to incorporate experimental technology into their core revenue-generating operations. Similarly, OEM firms supplied mining machines as test beds for the CSIRO technology, and provided in-kind input to modify their shearer products to accommodate LASC hardware. However, none of the above participants conducted any actual research into the automation technology.

We have attributed 60 per cent of the impacts to CSIRO's R&D efforts

ACIL Allen would therefore argue that 60 per cent of the current impacts with respect to longwall mining technology should be attributed to CSIRO's research and development efforts, with coal mining companies/ACARP and OEMs collectively accounting for 40 per cent of the current impacts of the technology.

D.4.4 Adoption

Five OEMs have adopted the technology in the machines

The close involvement of OEM equipment suppliers and participating mines in the second stage of the R&D program helped ensure the relatively rapid commercialisation of the technology. The first commercial installations of mining machines using CSIRO's automation technology occurred in 2008. The firms that have adopted the CSIRO technology for use in their mining machines are: Joy Global; Eickhoff; Kopex; Nepean; and Caterpillar.

Two thirds of Australian underground coal mines use the technology

Longwall mining accounts for approximately 90 per cent of the 70 million tonnes of underground coal that is annually mined in Australia (CSIRO, 2012). In Australia approximately 20 out of a total of 30 longwall mining systems are currently operating with (or are about to install) CSIRO's automation technology (CSIRO, 2014a). Gaining a 60 per cent market share in the seven years since the technology was first licensed represents an extremely rapid adoption rate for the technology.

However, the rate of growth in market penetration is expected to slow going forward. CSIRO anticipates that the market share of LASC Longwall Automation technology will peak at around 80 per cent in five years' time. This is because some underground coal mines are not suitable candidates for adoption of the longwall automation technology.

The technology is now also being marketed overseas

In 2012, the technology was contracted for installation in a mine in the US and it is expected to be installed in another mine in Norway in late 2014. One commercialisation partner is actively pursuing the US market and CSIRO expects continued growth in this market over the next 10 years. This would represent a considerable expansion of use of the technology. The production of coal from US longwall underground coal mines in 2012 was around 166 million tonnes a year, more than twice Australia's average production from underground longwall coal mines over the last five years..

China is seen as another major potential market for the longwall automation technology. However, the International Traffic in Arms Regulations (ITAR) are a major barrier to the adoption of the technology in that country. The longwall automation technology employs

advanced inertial positioning sensors. The manufacturer of the sensor used by CSIRO also supplies the same sensor to the US defence force and it is therefore subject to ITAR. As a signatory to ITAR, Australia is required to abide by its conditions on the sales of dual use technology. OEM firms are therefore currently unable to sell mining machines containing the inertial positioning sensor to mining firms in China

D.5 Assessment of impacts

D.5.1 Impacts to date

The commercialisation of CSIRO's longwall automation technology has had a range of economic, environmental and social impacts.

Economic impacts

New products and services

The fact that over 60 per cent of the underground coal mines had switched to using mining machines that incorporated the CSIRO technology within some six years of it becoming commercially available strongly suggests that the mining industry's view was that the likely productivity improvements would be significant.

Better management and productivity

The main economic impact of CSIRO's automated longwall mining technology flows from the improved productivity of the underground mine. Those benefits would have begun to flow from the date the first automated mining machine was put on the market in 2008. The benefits flow to coal mining firms.

Importantly, not only is there a direct improvement in productivity due to the automation of the longwall mining machine, but there is also an indirect benefit due to the need to ensure that the operations of all other elements of the mining process are optimised in order to fully realise the benefits of the CSIRO technology. Hence, the use of LASC Longwall Automation technology encourages wider system efficiencies beyond the immediate productivity gains that result from the use of the technology itself. The fact that all the mining equipment is operating at, or close to, an optimal level helps reduce ongoing maintenance costs and leads to more consistency in the longwall operation.

The technology is conservatively estimated to improve productivity by 5 per cent

Obtaining first-hand information about the productivity improvements achieved by mines using the CSIRO technology is difficult as that information is regarded as highly commercially sensitive. A common figure for the productivity improvement among industry insiders is around 10 per cent peak, with the consistency in overall operation obtained leading to an average of around 5 per cent.

The value of Australian coal exports over the last few years has been of the order of $30 billion a year. Consequently a productivity improvement of 5 per cent would suggest that the potential increase in the value of exports as a result of this technology could be of the order of billions of dollars.

See also the discussion in section D.5.3.

Environmental benefits

Environmental benefits associated with the use of the CSIRO automated mining technology are principally a reduction in the amount of spoil that is mined along with the coal. There is

an environmental benefit associated with the need for less above ground storage area to store the spoil. The benefits flow to coal mining firms.

There are also likely to be some economic benefits associated with the reduction in the amount of spoil. The main ones would be:

- Reduced costs for separating spoil from coal
- Reduced rehabilitation costs.

Rehabilitation costs can be considerable. Information on the Oresome Resources website suggests that the cost of rehabilitating spoil dumps is around $25,000 a hectare. (OR, 2014) Another source states that rehabilitating waste rock dumps costs closer to $50,000 a hectare. (DJW, 1995) Adjusting this figure for movements in Consumer Price Index (CPI) since 1995 suggests that the cost of rehabilitating a rock spoil dump could now be as much as $80,000 a hectare.

Recent Queensland government statistics on coal production, for the year ended March 2014, report that the percentage of saleable coal from total raw coal production was 81 per cent for open cut mining and 63 per cent for underground mining, the remainder being spoil or 'ash'.[8] This is a significant difference. Some factors in the production of spoil are common to both mining methods but a major difference is the better identification of seam boundaries that is possible in open cut versus underground mining. A conservative assumption would be that on average, the percentage of saleable underground coal could be increased by 10 per cent through effective identification of seam/rock boundaries. In Queensland in the year ending March 2014, this would equate to reducing the amount of spoil that had to be first dealt with then rehabilitated by some 4 million tonnes. If the extraction cost of the coal was $40/tonne, then this would represent a saving to the industry of over $150 million/year in production costs alone.

However, the improved horizon control that is necessary to help reduce the amount of spoil that is mined along with the coal is part of the work that is still underway and we have therefore not included the reduction in spoil as a benefit at this point in time.

Social impacts

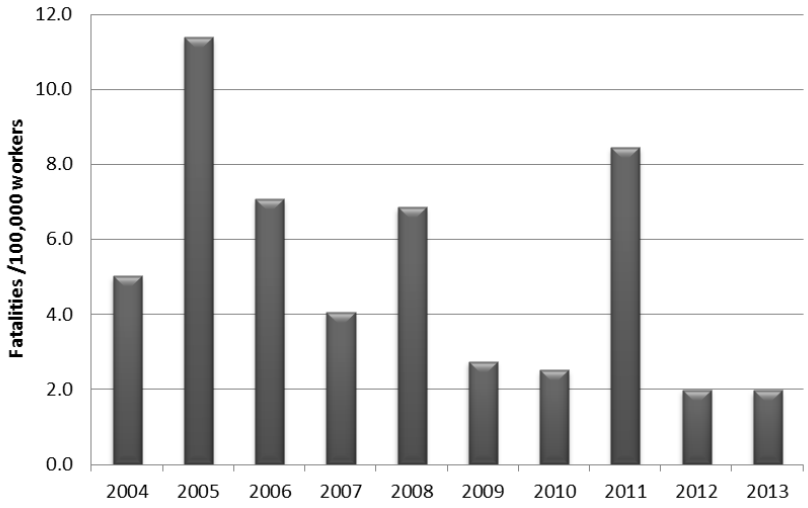
The main social impact from the implementation of the technology is improved worker safety since the use of automated mining machines reduces the amount of time that workers have to spend at the mine face to monitor and adjust the alignment of longwall mining machine and the coal seam. As LASC Longwall Automation removes the need for a worker to be in the mine wall to monitor a longwall mining machine, it also reduces that worker's exposure to noise and dust. The benefits flow to mine employees and mining firms.

An April 2008 report on mine fatalities found that between 1980 and 2008 there were 1005 fatalities in Australian coal mines. Of these 919 (over 91 per cent) occurred in underground mines. (DPI, 2008) This is an average of almost 33 deaths a year in underground coal mines.

Safe Work Australia publishes information on fatality rates (deaths per 100,000 employers) for a range of occupations. The fatality rates for coal mining between 2003 and 2013 are shown in Figure D1.

[8] See: http://mines.industry.qld.gov.au/assets/coal-stats/quarterly-reports/Quarterly%20coal%20report%20for%20the%20three%20months%20ended%2031%20March%202014%20FINAL%20v1.0.pdf.

Figure D1 **Fatality rates from coal mining**



Source: SWA 2014

The technology improves worker safety

The data in Figure D1 shows a clear decline in fatality rates over time. The average fatality rate between 2004 and 2008 was almost 7 deaths per 100,000 workers per year. However, for the period between 2009 and 2013 the fatality rate almost halved to an average of around 3.5 deaths per 100,000 workers per year. This coincides with the period during which the use of CSIRO's automated mining technology became increasingly adopted by underground coal mining firms in Australia.

The data in Figure D1 includes any mining related deaths in open cut coal mines. This makes it difficult to argue that the observed decline in fatality rates is due to the introduction of CSIRO's automated mining technology. However, the fact that historically coal mining fatalities have almost exclusively been in underground coal mines provides some confidence that the technology is at least contributing to improved worker safety.

Finally, it is worth noting that much of CSIRO's ongoing work is aimed at further refining the technology to provide additional safety benefits. These will be progressively released to licensees when they are ready for commercialisation. The importance of improving mine safety is illustrated by Box 4. The information it contains illustrates how avoiding the death of a mine employee can have significant economic benefits as well as the obvious social benefits.

Box D3 **A recent coal mine fatality**

A common problem when using a longwall continuous mining machine occurs when you extend the mining into areas which have not previously been disturbed. Sometimes when the coal is mined, the stress on the remaining coal builds up and this can cause the collapse of the remaining coal into the area being mined. Exactly such an event was behind a recent fatality in an underground coal mine in New South Wales.

CSIRO are in the process of improving the inertial guidance technology as part of their ongoing work on this project to guide a continuous mining machine. They expect that in a year's time the mining machine will be able to be more accurately guided without the need for human intervention. By reducing or removing the need for people to be in the vicinity of the machine fatalities such as this one would have been avoided.

While the major concern with any such accident will always be injury or loss of life, there are also considerable economic costs associated with such accidents. The statistical value of a life alone is $4.3 million. In addition, industry sources suggest that the cost of lost production due to the accident was around $1,000 a minute, although this varies significantly from mine to mine. Based on this figure, one day of lost production would cost the mining company $0.72 million (assuming the mine operates twelve hours a day).

If we made the conservative assumption that a coal mine fatality would lead to one day of lost production the total cost of such an event would be of the order of $5 million.

Source: Discussions with CSIRO officials

D.5.2 Potential future impacts

The first sales of mining equipment incorporating CSIRO's automation technology to overseas mining firms have occurred. One machine has been sold to the US and one to Norway. Although ITAR has prevented deployment of the CSIRO technology to China, the organisation is currently exploring potential options that would allow it to support commercialisation partners entering the Chinese market and also to develop new licensing opportunities there.

The nature of benefits from overseas sales would be similar to those experienced in Australia. The majority of those benefits will accrue overseas. The initial benefit that will accrue to Australia will be a revenue stream to CSIRO from licensing fees and royalty payments, accompanied by a mixture of tangible and intangible benefits through export of its capability to conduct further research projects built on the reputation of this technology.

CSIRO has identified a number of other potential uses for the underground inertial guidance sensor technology it has developed. It is applicable to a range of industries – particularly those involving excavation activity with mobile equipment where access to alternative guidance methods such as Global Positioning Systems are unavailable. CSIRO is currently working on other underground mining and tunnelling applications such as continuous miner and tunnel boring machine guidance.

D.5.3 Cost Benefit Analysis

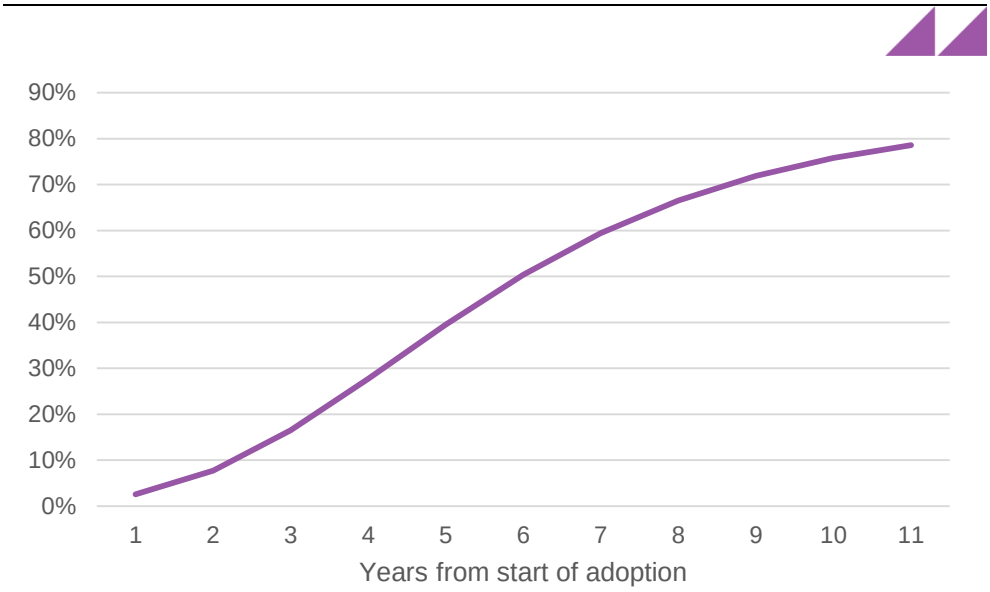
Assessment of benefits

Assessing the benefits of longwall automation developed by CSIRO requires estimating the historical and future increase in production relative to the Base Case where the development and adoption of longwall automation technology is delayed by 10 years in the absence of CSIRO's R&D.

The assumed rate of adoption of CSIRO's longwall automation technology in underground coal mining is shown in Figure D2. This is based on information from CSIRO that, as of mid-

2014, 20 out of the 30 underground mines in Australia have adopted (or are in the process of adopting) the technology and that, ultimately, approximately 80 per cent of all underground coal mining in Australia will be utilising the technology.

Figure D2 **Adoption of longwall automation in Australian underground coal mining**



Source: ACIL Allen

The estimated tonnage of underground coal production in Australia between 2001-02 and 2012-13 is shown in the third column of Table D5. This is based on ABS statistics on black coal production in Australia (see the second column in the table) and advice that about 22 per cent of black coal mining in Australia takes place underground.[9]

Using the adoption rate assumed previously and the assumption that longwall automation results in a 5 per cent productivity improvement (based on studies such as the December 2008 report that Heuris Partners prepared for CSIRO titled 'ACAP Extension 2010-2015 Case Studies'[10]), ACIL Allen has estimated the production that would have occurred in the Base Case between 2008-09 and 2012-13 without the CSIRO-developed longwall automation technology (that is, the 'baseline' production level). This is shown in column 6 of Table D5.

[9] Minerals Council of Australia, personal communication August 2014

[10] The Heruis Partners study suggests that longwall automation enables the elimination of string lines that disrupt production twice a day, resulting in an increase in the baseline cutting rate by 130 tonnes per hour. In addition, longwall automation enables a further 5 per cent increase in the cutting rate, resulting in a combined productivity gain of approximately 13.7 per cent.

Table D5 **Calculation of the value of additional coal production enabled by longwall automation**

Year	Actual black coal production	Estimated underground coal production	Adoption rate of CSIRO innovation	Adoption rate of substitute technology	Baseline production	Additional production	Australian coal price	CPI (Dec)	Real price of coal	Value of additional production
	kt	kt	%		kt	kt	$/tonne		2014 $	2014 $
2001/02	273,236	60,112					32.31	75.40	46.07	0
2002/03	271,613	59,755					25.31	77.60	35.06	0
2003/04	280,753	61,766					26.09	79.50	35.28	0
2004/05	300,034	66,007					52.95	81.50	69.84	0
2005/06	303,431	66,755					47.62	83.80	61.09	0
2006/07	321,391	70,706					49.09	86.60	60.94	0
2007/08	322,163	70,876	2.6%				65.73	89.10	79.31	0
2008/09	335,630	73,839	7.8%		73,553	285	127.10	92.40	147.88	42,208,146
2009/10	363,330	79,933	16.5%		79,277	656	71.84	94.30	81.90	53,697,845
2010/11	344,400	75,768	27.8%		74,731	1,037	98.97	96.90	109.79	113,848,211
2011/12	362,709	79,796	39.5%		78,249	1,547	121.45	99.80	130.82	202,343,708
2012/13	396,095	87,141	50.4%		85,001	2,140	96.36	102.00	101.56	217,363,292
2013/14F		88,439	59.4%		85,887	2,552	84.56	104.80	86.74	221,342,355
2014/15F		91,149	66.5%		88,214	2,935		107.50	80.48	236,212,940
2015/16F		93,796	71.9%		90,541	3,255			80.48	261,953,617
2016/17F		96,388	75.8%		92,868	3,520			80.48	283,290,363
2017/18F		98,936	78.6%		95,195	3,741			80.48	301,092,191
2018/19F		101,423	80.0%	7.8%	97,900	3,522			80.48	283,493,979
2019/20F		103,843	80.0%	16.5%	100,675	3,168			80.48	254,982,443
2020/21F		106,263	80.0%	27.8%	103,594	2,669			80.48	214,829,844
2021/22F		108,683	80.0%	39.5%	106,569	2,114			80.48	170,172,869
2022/23F		111,103	80.0%	50.4%	109,520	1,583			80.48	127,429,144
2023/24F		113,523	80.0%	59.4%	112,400	1,123			80.48	90,393,139
2024/25F		115,943	80.0%	66.5%	115,193	750			80.48	60,376,172

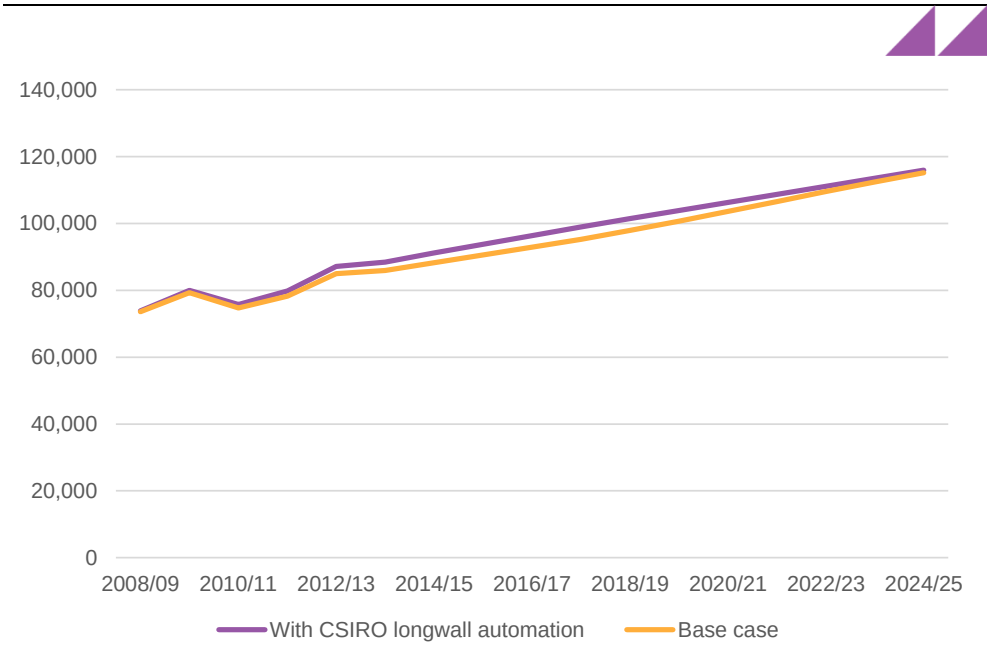
Source: ACIL Allen

The baseline production level for the years 2013-14 to 2024-25 is estimated by fitting a linear trend to the historical data on underground coal production between 2001-02 and 2007-08 combined with the estimated baseline production between 2008-09 and 2012-13 and extrapolating from this fitted line.

The projected production level for 2013-14 to 2024-25 with the CSIRO longwall automation technology is then calculated by combining the following information: the baseline production level for the years 2013-14 to 2024-25; the adoption rate of the CSIRO technology discussed previously; the assumed 5 per cent productivity gain; and the adoption rate of the substitute technology that would have developed a decade later in the absence of CSIRO (shown in column 5 of Table D5).

A comparison of the production level in the Base Case and the production level with the CSIRO longwall automation technology between 2008-09 and 2024-25 is presented in Figure D3.

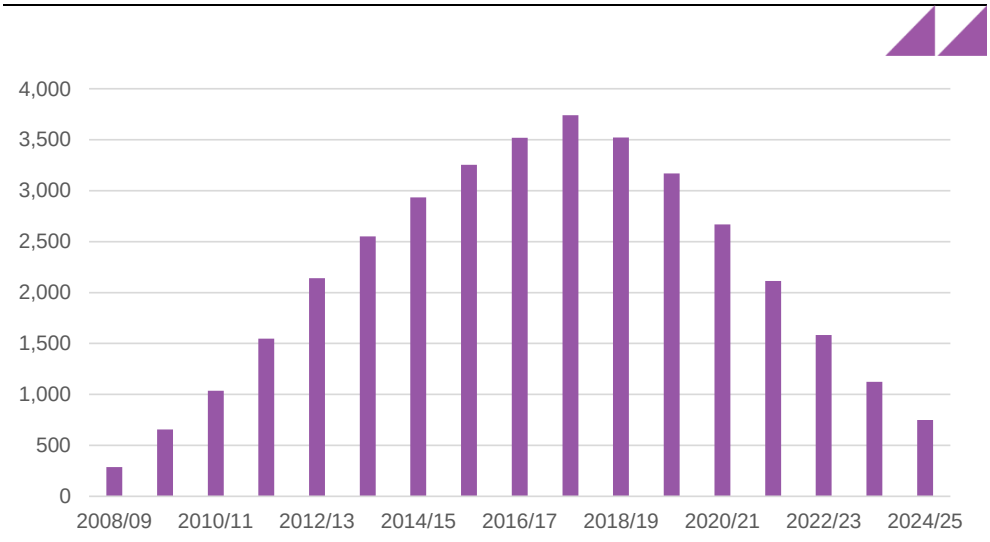
Figure D3 **Underground coal production in Australia in the Base Case and with CSIRO longwall automation technology: 2008-09 to 2024-25 (in kilo tonnes)**



Source: ACIL Allen

The estimated increase in historical and future underground coal production in Australia due to CSIRO's longwall automation technology is shown in column 7 of Table D5 and illustrated in Figure D4. This is calculated by subtracting the baseline production level from the actual production level for the years 2008-09 to 2012-13 and the projected production level for the years 2013-14 and 2024-25.

Figure D4 **Additional coal production in Australia due to CSIRO longwall automation technology: 2008-09 to 2024-25 (kilo tonnes)**



Source: ACIL Allen

Estimating the value of the additional production (the final column in Table D5) requires using the historical time series on the average coal price in Australia (adjusted for CPI inflation to bring the price in each year to equivalent 2014-15 dollars) and the projected Australian coal price for 2014-15 to 2024-25. This projected price is assumed to be the average historical price between 2001-02 and 2013-14 in equivalent 2014-15 dollars.

The total benefits of longwall automation also include an expected reduction in mining accidents. It is assumed that 1 death is avoided each year between 2011-12 and 2024-25 as a result of the adoption of the longwall automation technology (see column 2 of Table D6) and that the Value of a Statistical Life is $4.3 million in 2014-15 dollars (based on a 2008 Guidance Note on the Value of Statistical Life by the Australian Government Office of Best Practice Regulation, adjusted for CPI inflation between 2007-14). It is also assumed that a mining death would result in the stoppage of production at the affected mine for 2 days. CSIRO estimates that each minute of lost production costs $1,000, as discussed previously in this case study. It is assumed that the mine would normally be operating 12 hours per day.

As ACIL Allen does not have detailed and specific information on additional input costs that might be associated with the increased production enabled by longwall automation (such as higher operational costs and transport costs), it is conservatively assumed that such additional costs would reduce total benefits by 10 per cent. The resulting net benefits are shown in the penultimate column of Table D6. Finally, it is assumed that 60 per cent of these net benefits are attributable to CSIRO (see the final column in Table).

Total benefits attributable to CSIRO exceeds $800 million

In present value terms, the stream of total benefits attributable to CSIRO over the period from 2001-02 to 2024-25 is estimated to be $801.1 million in 2014-15 dollars under a 5 per cent real discount rate, or $599.5 million under a 7 per cent discount rate.

Table D6 **Estimation of total benefits of longwall automation attributable to CSIRO**

Year	Deaths avoided	Value of lives saved	Avoided down time due to mine death	Total benefits	Total benefits net of increased operational and transport costs	Total net benefits attributable to CSIRO
		2014 $	2014 $	2014 $	2014 $	2014 $
2001/02	0	0	0	0	0	0
2002/03	0	0	0	0	0	0
2003/04	0	0	0	0	0	0
2004/05	0	0	0	0	0	0
2005/06	0	0	0	0	0	0
2006/07	0	0	0	0	0	0
2007/08	0	0	0	0	0	0
2008/09	0	0	0	42,208,146	37987331	22792399
2009/10	0	0	0	53,697,845	40,328,060	28,996,836
2010/11	0	0	0	113,848,211	102,463,390	61,478,034
2011/12	1	4,300,000	1,440,000	208,083,708	187,275,337	112,365,202
2012/13	1	4,300,000	1,440,000	223,103,292	200,792,963	120,475,778
2013/14F	1	4,300,000	1,440,000	227,082,355	204,374,120	122,624,472
2014/15F	1	4,300,000	1,440,000	241,952,940	217,757,646	130,654,587
2015/16F	1	4,300,000	1,440,000	267,693,617	240,924,255	144,554,553
2016/17F	1	4,300,000	1,440,000	289,030,363	260,127,327	156,076,396
2017/18F	1	4,300,000	1,440,000	306,832,191	276,148,972	165,689,383
2018/19F	1	4,300,000	1,440,000	289,233,979	260,310,581	156,186,349
2019/20F	1	4,300,000	1,440,000	260,722,443	234,650,199	140,790,119
2020/21F	1	4,300,000	1,440,000	220,569,844	198,512,860	119,107,716
2021/22F	1	4,300,000	1,440,000	175,912,869	158,321,582	94,992,949
2022/23F	1	4,300,000	1,440,000	133,169,144	119,852,230	71,911,338
2023/24F	1	4,300,000	1,440,000	96,133,139	86,519,825	51,911,895

Year	Deaths avoided	Value of lives saved	Avoided down time due to mine death	Total benefits	Total benefits net of increased operational and transport costs	Total net benefits attributable to CSIRO
2024/25F	1	4,300,000	1,440,000	66,116,172	59,504,555	35,702,733

Source: ACIL Allen

Assessment of costs

The nominal R&D costs associated with CSIRO's development of the longwall automation technology (discussed previously in the case study) are reproduced in the second column of Table D7. Adjusting for CPI inflation, these costs in 2014-15 dollars are shown in the third column of the table.

It is assumed that machines with longwall automation are only installed when the previous machines are replaced due to wear and tear, and that a machine with CSIRO longwall automation technology costs $100,000 in 2014-15 dollars more than a machine without this technology. The useful life of a machine is assumed to be four years. The incremental capital costs of the machines with longwall automation technology are shown in the penultimate column of Table D7. Total incremental costs are shown in the final column of the table.

The stream of total incremental costs associated with longwall automation over the period from 2001-02 to 2024-25 is estimated to be $15.6 million in 2014-15 dollars in present value terms under a 5 per cent real discount rate.

Table D7 **Total incremental costs associated with longwall automation**

Year	Nominal R&D costs	Real R&D costs	Incremental capital costs of automated longwall machines	Total incremental costs
	$	2014 $	2014 $	2014 $
2001-02	1,184,250	1,688,420	0	1,688,420
2002-03	1,184,250	1,640,553	0	1,640,553
2003-04	1,184,250	1,601,344	0	1,601,344
2004-05	1,184,250	1,562,048	0	1,562,048
2005-06	1,823,000	2,338,574	0	2,338,574
2006-07	1,823,000	2,262,962	0	2,262,962
2007-08	1,823,000	2,199,467	19,251	2,218,718
2008-09	400,000	465,368	58,209	523,577
2009-10	400,000	455,992	124,055	580,046
2010-11	500,000	554,696	208,135	762,831
2011-12	600,000	646,293	296,505	942,797
2012-13	600,000	632,353	377,686	1,010,039
2013-14F	600,000	615,458	445,661	1,061,119
2014-15F	0	0	499,065	499,065
2015-16F	0	0	539,225	539,225
2016-17F	0	0	568,534	568,534
2017-18F	0	0	589,489	589,489
2018-19F	0	0	541,791	541,791
2019-20F	0	0	475,945	475,945

2020-21F	0	0	391,865	391,865
2021-22F	0	0	303,495	303,495
2022-23F	0	0	222,314	222,314
2023-24F	0	0	154,339	154,339
2024-25F	0	0	100,935	100,935

Source: ACIL Allen

Key cost-benefit analysis results

Benefits net of research costs that are attributable to CSIRO are equal to $785.6 million

The Net Present Value (NPV) of CSIRO's longwall automation technology over the period from 2001-02 to 2024-25, calculated by subtracting the present value of total incremental costs from the present value of total incremental benefits, is estimated to be $785.6 million in 2014-15 dollars between 2001/2 and 2024/25 under a 5 per cent real discount rate, and $585.8 under a 7 per cent real discount rate.

The project has a BCR in excess of 50 (with a 5 per cent discount rate)

The Benefit-Cost Ratio (BCR) of CSIRO's longwall automation technology, calculated by dividing the present value of total incremental benefits by the present value of total incremental costs, is estimated to be 51.4 under a 5 per cent real discount rate and 43.6 under a 7 per cent real discount rate.

The internal rate of return of CSIRO's longwall automation technology, the discount rate that would make the NPV exactly zero, is estimated to be 63 per cent.

Sensitivity analysis

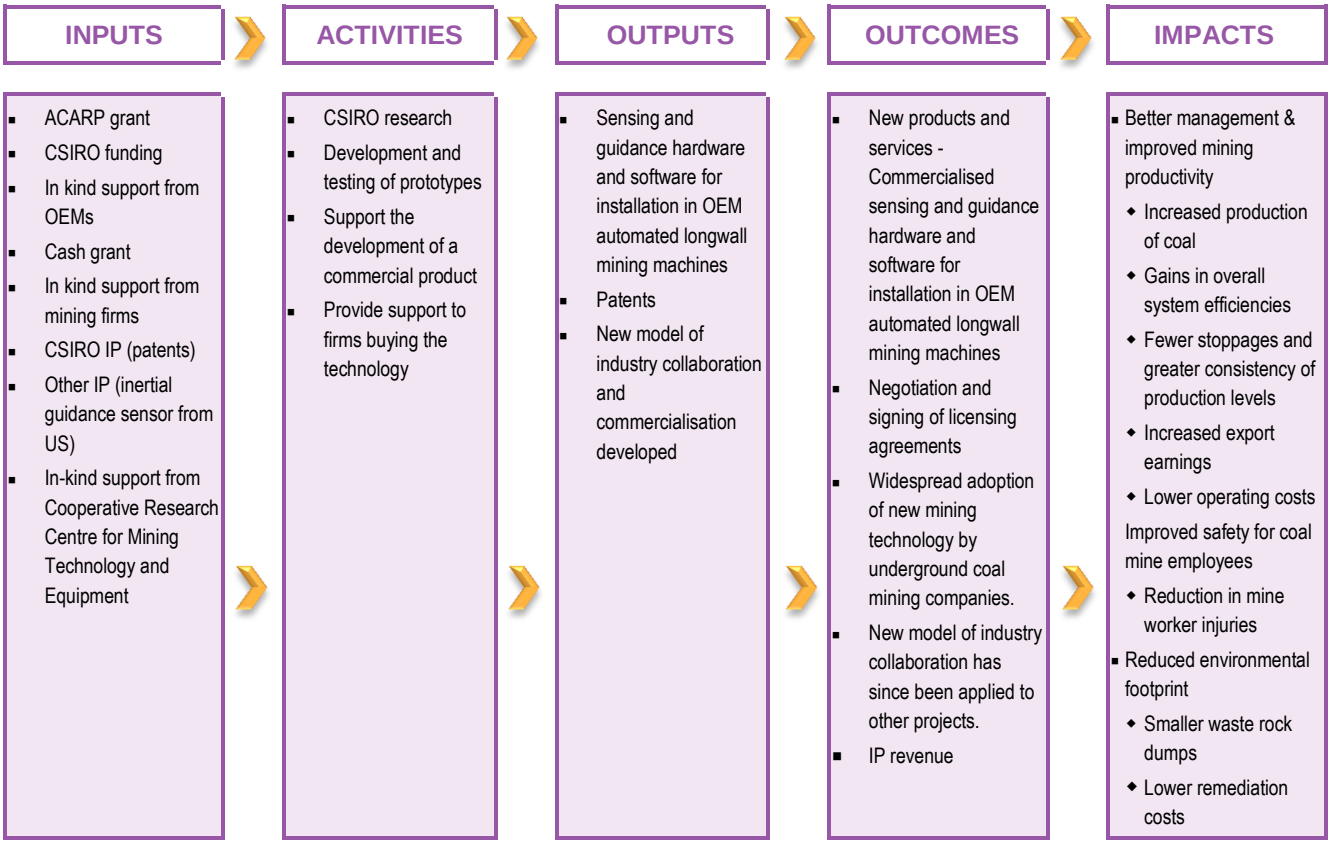
Should the increase in productivity enabled by longwall automation be 10 per cent instead of 5 per cent, the BCR increases to 101.1 while the NPV rises to $1.56 billion in 2014-15 dollars, both under a 5 per cent real discount rate.

If 40 per cent of benefits are attributed to CSIRO instead of 60 per cent, the BCR decreases to 34.3 under a 5 per cent real discount rate. NPV falls to $518.5 million in 2014-15 dollars under the same real discount rate.

If the adjustment of benefits for increased input costs is 20 per cent instead of 10 per cent, the BCR decreases slightly to 45.7 while the NPV falls to $696.5 million in 2014-15 dollars, both under a 5 per cent real discount rate.

D.5.4 Impact pathway diagram

Figure D5 **Longwall automation – impact**



Source: ACIL Allen

D.6 References

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D.7 Acronyms

ACA	Australian Coal Association
ACARP	Australian Coal Association Research Program
BCR	Benefit-Cost Ratio
CPI	Consumer Price Index
CSIRO	Commonwealth Scientific and Industrial Research Organisation
INS	Inertial Navigation Sensor
IP	Intellectual property
ITAR	International Traffic in Arms Regulations
LASC	Longwall Automation Steering Committee
NPV	Net Present Value
OEM	Original Equipment Manufacturers
US	United States of America

Appendix E Case study: OptiCOOL

SUMMARY OF KEY FINDINGS

- CSIRO research has created a building energy management system for heating, ventilation and air condition (HVAC) that can reduce the energy consumption in commercial buildings by between 10 and 30 per cent.
- CSIRO gains a revenue stream from licencing the OptiCOOL technology to BuildingIQ.
- The benefits generated as a result of the OptiCOOL technology include BuildingIQ's contribution to Australia's GDP, a reduction in energy costs for building tenants and reduced greenhouse gas emissions.
  - The present value of the benefits that can be attributed to CSIRO is estimated to be $79.7 million in 2014/15 dollars over the period 2014/15 to 2024/25, under a 5 per cent real discount rate.

E.1 Introduction

E.1.1 Purpose and audience

This independent case study evaluation has been undertaken to assess the economic, social and environmental impact of CSIRO research into building monitoring and control systems designed to improve the energy efficiency of commercial buildings. This case study has been prepared so it can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of CSIRO's activities.

The report is provided for accountability, reporting, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, CSIRO and the general public.

E.1.2 Background

The installation of heating, ventilation and air-conditioning (HVAC) systems in Australia has contributed to substantial flexibility in building design and form. HVAC systems have permitted indoor comfort regardless of external climatic conditions, particularly in buildings with inferior thermal performance.

HVAC systems account for 43% of energy use in buildings

However, HVAC systems have added significant costs to commercial buildings. In 2012, HVAC end use accounted for 43% of total building energy use, while commercial buildings contributed a total of 34.7 Mt of CO_2-e that same year (Department of Climate Change and Energy Efficiency, 2012). In addition, HVAC systems have been found to be an important driver of electricity demand across the network (Wall *et al.*, 2007).

CSIRO first began its research into ways to improve the efficiency of HVAC systems in the early 2000s. Its main goal was to develop new technologies to reduce electricity consumption in buildings by improving the efficiency of HVAC systems (CSIRO, 2010).

E.1.3 Approach

The approach taken in this case study aligns with the nine-step process described in the CSIRO's impact evaluation guide namely:

1. Initial framing of the purpose and audience of the impact evaluation.
2. Identify nature of impacts (*what is the impact pathway, what are the costs and benefits*)
3. Define a realistic counterfactual (*what would have occurred in the absence of CSIRO*)
4. Attribution of research (*CSIRO vs. others' contribution*)
5. Adoption (*to date and in future*)
6. Impact (*timing, valuation, distributional effects among users, effects on non-users*)
7. Aggregation of research impacts (*within program of work*)
8. Aggregation of impacts (*across program of work*)
9. Sensitivity analysis and reporting.

Note that steps 7 and 8 above are less relevant for this individual case study as the OptiCOOL project is being considered in isolation. The impacts identified in this case study will be aggregated with those from other aspects of CSIRO's work to provide an insight into the overall benefits arising from the Organisation's work.

E.1.4 Project origins and inputs

The aim of the CSIRO's Energy Flagship is to collaborate with industry, research organisations and government to create cost-competitive, low-emission energy technologies to plan for a secure and clean energy future in order to help Australia to protect and ensure its long term environmental, economic and social welfare (CSIRO, 2014b). The stated goal of the Energy Flagship is to:

> Deliver by 2020 technology options and science that will enhance Australia's economic competitiveness and regional energy security while enabling the transition to a lower emissions energy future, by unlocking $100 billion of *in-situ* value from our energy resources and contributing 32 Mt p.a. of greenhouse gas abatements by 2030.

CSIRO's OptiCOOL technology is illustrative of the organisation's efforts to deliver the Energy Flagship's goals. The technology functions as a supervisory control system that enhances heating and cooling operation and efficiency in commercial buildings. OptiCOOL further improves occupant comfort, reduces peak demand and can be retrofitted in the majority of existing buildings (CSIRO, 2012).

History of project

The OptiCOOL technology is some 10 years in the making

Interviews with an original member of the team that developed the OptiCOOL technology indicated that the genesis of the project can be traced back to June 2004. At the time, the project team was testing systems to intelligently control electricity loads and generators. These tests eventually extended to include functionalities to monitor and analyse advanced control strategies for those systems in order to save on energy and operating costs. The tests involved the placement of small wireless sensors around commercial buildings at high resolution in order to collect data seldom analysed on a large scale. Encouraging results from these tests led to a more substantial trial in partnership with Sustainability Victoria in 2006-2007.

The objective of the 'Smart Thermostats' trial in 2006-2007 was to provide sufficient evidence of the functionality of the technology and to examine:

- the costs and benefits of smart thermostat technology
- the potential energy reductions from variations in temperature set-points
- the appropriateness of thermostat technology for retail and network peak demand reductions
- the level of acceptance of smart thermostat technology by occupants of buildings (Ward and White, 2007).

Early trials demonstrated the potential of the technology

The trial successfully demonstrated the possibility of adjusting temperature set points as a method to reduce greenhouse gas emissions or for temporarily decreasing peak demand on the electricity industry. However, the results also showed that testing on additional buildings was required in order to collect a larger sample of successful implementations to improve confidence in the demonstrated performance of the technology (Ward and White, 2007).

Importantly, results from the trial showed that the system would have benefitted from more sophisticated controls that would allow for prediction, forecasting and include a self-learning capability (Ward and White, 2007). This finding inspired the research that ultimately led to the development of the OptiCOOL technology in June 2007.

The OptiCOOL technology is designed to achieve several goals, including: enhancing energy efficiency; reducing excessive energy consumption; and reducing operating costs without foregoing the comfort of building occupants. The technology can utilise feedback from occupants through online comfort feedback software that measures the comfort level of occupants, whereby individuals can register whether they are too cold/hot and dispatch this information to a controller. The OptiCOOL technology subsequently adjusts the air-conditioning accordingly.

OptiCOOL controls HVAC operations based on user feedback and weather forecasts

The intelligent controller can be installed onto any suitable HVAC control system and utilises weather data, energy market pricing and the aforementioned feedback from building occupants to modify the operation of the building's air conditioning in order to achieve:

- reductions in energy consumptions
- reductions in greenhouse gases
- cost savings
- increased productivity through enhanced staff comfort (CSIRO, 2013).

As OptiCOOL is primarily a software-based technology, there is limited additional capital cost or need to install additional hardware, assuming buildings are already fitted with modern HVAC and data collection systems.

Project inputs

CSIRO R&D contributions, including labour and operating costs, are outlined in Table E1.

Table E1 **CSIRO OptiCOOL R&D funding**

Date	Labour + Operating costs	External Revenue	Royalties
Jul 2006 – Jun 2007	-$11,532	$29,688	-
Jul 2007 – Jun 2008	-$212,836	-	-
Jul 2008 – Jun 2009	-$158,225	-	-
Jul 2009 – Jun 2010	-$7,758	-	-
Jul 2010 – Jun 2011	-$21,315	$48,487	$50,000
Jul 2011 – Jun 2012	-	$32,803	$75,000
Jul 2012 – Jun 2013	-	-	$100,000
Jul 2013 – Jun 2014	-	-	$100,000
Mar 2015	-	-	($100,000)
Mar 2016			($100,000)
October 2016			($540,000) incl. buyout + royalties
Total (to date)	***-$411,666***	***$110,978***	***To date: $325,000 With buyout: ($1,065,000)***

Source: CSIRO

Funding from other sources to CSIRO is also outlined in Table E1. In addition to the funding outlined below, Building IQ, which obtained the licence to sell OptiCOOL in 2009, pays ongoing royalties to CSIRO, the proceeds from which are dedicated to continuing CSIRO research that aims to extend CSIRO's technological innovation related to advanced HVAC system control, peak demand management and self-learning fault diagnosis.

E.2 Project activities

E.2.1 CSIRO research

The invention of OptiCOOL technology can be attributed to Dr John K Ward, Dr Josh Wall, Mr Sam West and Dr Glenn Platt, with a range of underlying CSIRO R&D activities and capability also supporting the development of the technology. Development of OptiCOOL technology utilised the CSIRO's capabilities shown in Table E2.

Table E2 **CSIRO Capabilities used in developing OptiCOOL**

Capability	Description
Automatic Control	Advanced control theory for dynamic systems and process control.
Artificial intelligence	Mathematical modelling of dynamic multi-variable systems, including data driven self-learning models and prediction algorithms.
Computer Optimisation	Optimisation algorithmics and mathematical modelling.
Advanced HVAC Controls	Knowledge and application of advanced HVAC control techniques and human comfort models.

Source: CSIRO

Development and testing of prototypes

Development of OptiCOOL commenced in 2007 when a new tranche of funding was provided to enable CSIRO to expand on research into Smart Thermostat technology. The first complete prototype of OptiCOOL was developed in July 2007 and installed in the

CSIRO Energy Centre lab for testing. The prototype went through a number of improvements and enhancements following ongoing comprehensive testing and evaluation in the CSIRO Energy Centre lab and in a number of other CSIRO operated commercial office buildings.

Build commercial product

OptiCOOL was licensed to BuildingIQ in 2009

OptiCOOL was commercialised in December 2009 under an exclusive license to the start-up company BuildingIQ (CSIRO, 2013). As part of the license agreement, CSIRO provided regular support to BuildingIQ and developed an extension to the technology in 2010 to accommodate heating functions. CSIRO also provided support to BuildingIQ to guide the first few commercial installations of OptiCOOL, and provided BuildingIQ with training hours and guidance on building data collection. CSIRO's interaction with and support for BuildingIQ concluded in November 2011; however the licensing agreement specifies a royalty flow to CSIRO based on BuildingIQ's annual profits.

Current strategy period

CSIRO is continuing to improve the OptiCOOL technology

Since licencing OptiCOOL in 2009, CSIRO has engaged in research work to extend the technological innovations achieved as a result of the OptiCOOL project. Current research areas include adapting OptiCOOL for application in smaller buildings or residential homes, intelligent controls for large refrigeration systems and matching air conditioning load with distributed PV solar power output.

Lessons learnt as a result of the OptiCOOL project also formed the foundation for the development of CSIRO's fault detection and diagnostics (FDD) technology, which automatically senses faults and sub-optimal operation in HVAC systems to enable timely maintenance and more efficient operation of HVAC systems in commercial buildings.

E.3 Project outputs

E.3.1 Key outputs of the project

The major output of the project was the OptiCOOL technology. The technology improves energy efficiency, reduces energy consumption and reduces operating costs without sacrificing the comfort of building occupants, although it can only be installed in large buildings with a minimum floor space of 30,000 m^2 in order to be cost-effective.[11] It achieves these goals through an intelligent controller that can be retrofitted to any existing HVAC control system. The technology was licenced to BuildingIQ in 2009. In 2010 it was extended to include heating optimisation functionality.

CSIRO also transferred technology and knowledge of OptiCOOL to BuildingIQ, a process that involved the creation of manuals, specification standards and training materials.

[11] Personal communication with Textor, August 2014.

E.3.2 Key publications

CSIRO has published a number of conference and journal papers in relation to the OptiCOOL project, several of these were published in leading journals with strong citation rates. The papers with the greatest impact include:

- West S, Ward J.K., Wall J. (2014). Trial Results from a Model Predictive Control and Optimisation System for Commercial Building HVAC. Energy and Buildings, Elsevier, Vol. 72, 2014.
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E.3.3 Awards and public recognition

The technology has received a large number of awards

BuildingIQ has received a range of awards in Australia and globally for the OptiCOOL technology. These awards are outlined in the following table:

Table E3 **Awards and recognition**

Year	Award
2010	▪ Reader's Choice Award Winner for Environmental Design & Construction and Sustainable Facilities Magazines ▪ Tech23's Greatest Potential Award ▪ Red Herring Asia 100 Winner ▪ NSW government Technology Voucher grant winner (involving a government grant of $15,000)
2011	▪ AIRAH award for Excellence in Innovation ▪ Ed+C Readers' Choice Awards (Alternative Energy Systems category) ▪ EcoGen Award for Most Outstanding ▪ Sustainable Engineering Association Award for Excellence in Innovation (with Western Power) ▪ Connectivity Week's Buildy Award
2012	▪ Buildings Magazine names Building IQ a Top Money Saving Product ▪ GoingGreen 200 Winner ▪ Global Cleantech 100
2013	▪ Bloomberg New Energy Pioneers Award ▪ Global Cleantech 100 shortlisted ▪ Groom Energy Solutions Top-10 Enterprise Smart Grid Leaders ▪ Recognised by Gartner as a Cool Vendor in Green IT and Sustainability ▪ Environmental Design + Construction and Sustainable Award ▪ Fierce Innovation Award – Energy Edition – Best In Show
2014	▪ Global Cleantech 100 ▪ Selected by US Federal Government General Services Administration for its the highly selective Green Proving Ground Program ▪ Selected by the US Department of Energy for a multi-year Commercial Building Demonstration Grant

Source: BuildingIQ 2014a, 'Awards', <http://www.buildingiq.com/the-company-and-product-story/awards/>, accessed 21 July 2014.

E.4 Status of Outcomes and Impacts

E.4.1 Nature of Outcomes and Impacts

Outcomes

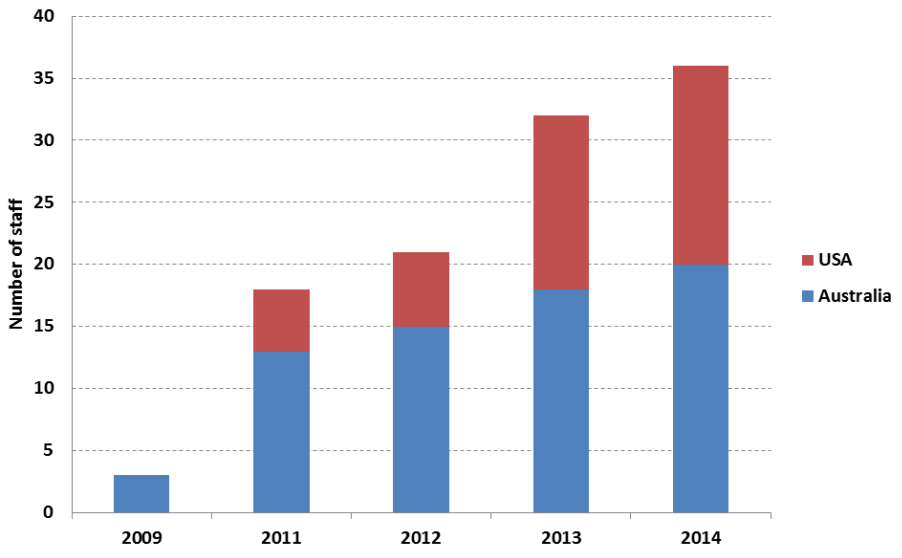
The chief outcome of the OptiCOOL project has been the licencing and commercialisation of the technology, followed by the installation of the technology by BuildingIQ in both Australia and the United States (US). As of August 2014, the technology was responsible for controlling approximately 15 million square feet (1.39 million square meters) of floor space in Australia and the US, including buildings such as the Rockefeller Centre in New York City (BuildingIQ 2014b). Adoption rates in the US are still relatively low as would be expected for a new technology (BuildingIQ, US Department of Energy, 2011). Adoption rates in Australia are also low. However, there is an expectation that adoption rates of OptiCOOL in Australia will increase now that the technology has been deployed and proven in the US market.

OptiCOOL has reduced energy consumption in buildings by 12-30%

OptiCOOL technology has assisted building owners to decrease their energy consumption by between 12 and 30 per cent (CSIRO 2013). The largest US science and engineering research laboratory, Argonne National Laboratories, confirmed that a trial of the OptiCOOL technology decreased HVAC energy consumption in their buildings by between 22 and 45 per cent (CSIRO, 2012 and BuildingIQ, 2014 (c)).

As a result of the commercialisation of OptiCOOL technology through BuildingIQ, development of the technology has also created employment opportunities in Australia (and the USA). At present BuildingIQ employs 20 staff in Australia and 16 staff in the USA (see Figure E1).

Figure E1 **BuildingIQ employment**



Note: No employment data was available for 2010
Source: BuildingIQ, personal communication, August 2014

Box E1 **Extensions of OptiCOOL capabilities: fault detection and diagnostics**

The techniques and capabilities developed as part of the OptiCOOL project have fed into further research on automation and optimisation of HVAC systems in commercial buildings. This extension research has yielded further technology development, such as CSIRO's fault detection and diagnostics (FDD) technology. FDD technology automatically scans HVAC systems to detect areas where the HVAC system is operating sub-optimally or to detect faults. Like OptiCOOL, FDD uses standard sensor systems, meaning that users of FDD do not need to invest in additional hardware upgrades, assuming that modern HVAC and sensor systems are already installed in the building. CSIRO has ongoing contact with BuildingIQ as well as other companies in the industry, which has helped to inform this further research. There is a patent pending on CSIRO's FDD technology.

Improperly controlled HVAC systems, degradation in performance over time and inadequate maintenance wastes an estimated 16% of total energy used in commercial buildings with a payback time of 1.1 years (Mills, 2009). By contrast, the faults identified by CSIRO showed average energy savings of 10% up to 25% on whole building energy consumption.

Source: CSIRO

Impacts

CSIRO's development of OptiCOOL technology has led to several impacts. These can be categorised as either environmental or economic impacts. Using CSIRO's triple bottom line benefit classification approach, Table E4 summarises the nature of the outcomes and impacts to date.

The main beneficiaries of the project include: commercial building owners who save on operating costs; building tenants who benefit from improved energy efficiency and reduced energy consumption; electricity grid utilities, who benefit from reduced peak demand, and; electricity users, who may benefit from lower peak electricity prices, depending on the degree to which the technology is used by large HVAC system users connected to any single grid/electricity market.

Table E4 **OptiCOOL R&D - impacts and outcomes**

Impact	Detail
Economic impact category	
Increased productivity and managerial oversight *Reach: National / Sector* *Category:* Management and productivity	OptiCOOL introduces the capability to influence the behaviour of commercial building managers by altering patterns of energy supply and demand, while at the same time reducing operating costs.
New products or services *Reach: Global* *Category: International trade, new products and services*	Through research and innovation CSIRO led the development of the OptiCOOL technology which was eventually commercialised as BuildingIQ. The technology has been widely adopted in both Australia and the US.
Greater electricity grid stability, reduced peak demand *Reach: National* *Category: The macro economy*	OptiCOOL technology can be calibrated to automatically reduce energy consumption when electricity prices are high, during times of peak electricity demand on the grid. Widespread use of OptiCOOL could potentially reduce peak electricity demand across the grid and contribute to increased electricity supply stability in times of extreme demand peaks, particularly when combined with smart grid technologies.
Potential for reduced peak electricity prices *Reach: National* *Category: The macro economy*	Potential for reduced peak demand could also contribute to lower peak electricity prices.
Environmental impact category	
Reduction in greenhouse gas	OptiCOOL allows commercial building owners to achieve

Impact	Detail
emissions *Reach: Global* *Category: Energy generation and use, Climate and climate change*	greater energy efficiency. Buildings that are more energy efficient have the impact of reducing greenhouse gas emissions by reducing peak energy demand from the electricity industry.
Social impact category	
Increased employee comfort *Reach: National* *Category: Life and health*	OptiCOOL can be calibrated to prioritise employee comfort. The technology involves an automated process in which employees can provide information on whether they are too hot or cold. Moreover, OptiCOOL uses weather forecasts to predict outside weather patterns and pre-emptively adjust the internal temperature. This creates a more consistent internal building temperature through the day. Increased employee comfort may deliver productivity gains.

Source: ACIL Allen Consulting; CSIRO

E.4.2 Counterfactual

CSIRO accessed global research that focused on smart controller technology in the preliminary stages of OptiCOOL's development. The research indicated that other organisations were unsuccessful in their efforts to develop similar technology because of their focus on pure-optimisation. CSIRO noted that pure-optimisation was too complex to implement practically as it included too many variables, such as: physical building characteristics; the existing HVAC system; building occupants; and the building's energy supply.

OptiCOOL adopts a different approach for optimising building operations

CSIRO and BuildingIQ contacted several academics and experts in the UK to determine the market gap for smart controller technology prior to the commercialisation of OptiCOOL. The feedback they received suggested that various efforts were then underway to successfully introduce a cost-effective technology that offered features similar to OptiCOOL. The feedback further emphasised that CSIRO and BuildingIQ would be the first to market their technology if their trials were successful.

This gave the technology a strong market advantage

Science and research bodies as well as private organisations were unable to develop technology that was cost-effective and capable of utilising existing HVAC systems prior to OptiCOOL's introduction in 2009. CSIRO's efforts to commercialise OptiCOOL through BuildingIQ successfully introduced the technology to a market with few competitors. Indeed, several of the BuildingIQ's largest and most well-established competitors in the HVAC systems market partnered with BuildingIQ by offering venture capital. This suggests that these industry leaders were unable to develop technology that is equivalent OptiCOOL in-house. Notable venture capital partners include Siemens and Schneider Electric.

Competitors to BuildingIQ currently include:

- **private start-up firms**: SCIEnergy, Viridity Energy, Optimum Energy, SureGrid
- **major vendors**: Honeywell, Siemens (BuildingIQ VC partner), Johnson Controls, Schneider Electric (VC partner), AE Smith (VC partner)
- **energy service companies**: EnerNOC, EPS

OptiCOOL's current and growing presence in Australia and the US may owe to circumstances where it was one of the earliest providers of cost-effective and environmentally efficient smart controller technology. However over time BuildingIQ's competitors may have developed similar technology to OptiCOOL in the absence of CSIRO.

OptiCOOL has a market lead of around 10 years

The commercial value of first mover advantage is difficult to determine precisely, but given the lack of equivalent technology available to even the largest players in the HVAC industry at the time that OptiCOOL was commercialised, ACIL Allen estimates that it would have taken roughly ten years for other researchers to develop technology that is similar to OptiCOOL in the absence of CSIRO. The counter-factual commercial case to establishment of BuildingIQ would have been reliance on imported solutions (either licenced to a domestic firm or provided from offshore) after a substantial lag time. The benefits to the Australian economy would therefore have been lower by an amount corresponding to roughly ten years' worth of net energy efficiency gains plus the returns to the economy from having a domestic rather than imported service provider.

E.4.3 Attribution

CSIRO's initial trialling of 'smart agents' in 2004 provided it with the direction and guidance for R&D in the OptiCOOL technology. Successful tests and recognition of a market gap eventually led to the commercialisation of the technology with BuildingIQ. Roughly 75% of the impacts of the smart controller technology can therefore be attributed to CSIRO. BuildingIQ played an integral role in successfully marketing, enhancing and implementing the technology on a global level, a process that involved a certain amount of adaptation work on the technology. The remaining 25% of the impacts of OptiCOOL can therefore be attributed to BuildingIQ.

E.4.4 Adoption

OptiCOOL technology is being installed in both Australia and the US. The technology is currently responsible for controlling some 1.4 million square metres of floor space in Australia and the US. Adoption rates are still relatively low. However, this is to be expected with any new technology. BuildingIQ is projecting that installation of the technology and revenue growth will grow dramatically over the coming years. While the projected growth is very significant, it is in line with projections of the potential market by industry analysts.

Patent applications have been submitted to several other countries in order to increase adoption rates of the technology in the future. These countries, and the patent applications, are outlined in Table E5.

Table E5 **OptiCOOL patents**

Patent organisation/country and number	Publication date
World Intellectual Property Organisation (WIPO): WO 2011/072332 A1	Jun 23, 2011
Australia: AU 2010/333708 A1	Aug 2, 2012
United States: US 2012/0259469 A1	Oct 11, 2012
Euro-zone: EP 2513/568 A1	Oct 24, 2012
Korea: KR 2012/0123335 A	Nov 8, 2012
China: CN 102812303 A	Dec 5, 2012
Japan: P 2013/514510 A	Apr 25, 2013

Source: Interviews with CSIRO.

The chief barrier to greater adoption of the technology, currently and in the future, is existing building management systems. Those systems need to meet a minimum set of criteria to be suitable for OptiCOOL installation.

E.5 Assessment of impacts

E.5.1 Impacts to date

OptiCOOL has economic, environmental and social impacts

The development of OptiCOOL technology led to several impacts that occurred over time and can be linked to its commercialisation through BuildingIQ in December 2009.

Economic impacts

Increase productivity and managerial oversight

OptiCOOL's smart controller introduces the capability to influence the behaviour of commercial building managers by altering patterns of energy supply and demand, while at the same time reducing operating costs. BuildingIQ notes that its energy management technologies can offer commercial buildings payback on the original cost of buying and installing OptiCOOL within 12 months (Renew Economy, 2012).

Potential for greater electricity grid stability and reduced peak electricity prices

OptiCOOL technology can be calibrated to automatically reduce energy consumption when electricity prices are high, during times of peak electricity demand on the grid. As a result, widespread use of OptiCOOL could act to reduce peak electricity demand across the grid and contribute to increased electricity supply stability in times of extreme demand peaks (for instance during heatwaves or cold snaps). When combined with smart grid technologies, OptiCOOL could give electricity service providers and utilities greater leeway to intervene in HVAC systems in order to reduce peak demand. BuildingIQ has partnered with Nirvana Energy, a US electricity utility, to explore uses of OptiCOOL in combination with smart grid technologies.

Were the OptiCOOL technology to be installed on many large HVAC systems across a single grid, then the technology's ability to respond automatically to high peak electricity prices by lowering demand could in turn lower the peak price of electricity, delivering savings to electricity users across the grid.

Environmental impacts

Lower greenhouse gas emissions

By making commercial buildings more energy efficiency, OptiCOOL reduces building energy demand and contributes to lower greenhouse gasses from electricity production. CSIRO estimates that use of OptiCOOL can help reduce energy consumption by 12-30%. Taking into account findings from the Australian Department of Climate Change and Energy Efficiency that HVAC systems account for 43 per cent of energy consumption in large commercial buildings, and that total CO_2-equivalent emissions from commercial buildings were 34.7 MT in 2012, if all commercial buildings in Australia were fitted with OptiCOOL, immediate CO_2 savings from lower power demand could range between 1.79 and 4.48 MT CO_2-e. Over the longer term, were OptiCOOL to be adopted on a widespread scale and used to lower peak demand, reduced need for peak electricity supply would feed into to lower electricity demand forecasts, potentially influencing investment decisions in the construction of new peaking electricity generation plants. Fewer peaking electricity plants (which are often natural gas powered or hydropower), would contribute to lower potential emissions as a result of lower overall electricity generation capacity.

Additional benefits for CSIRO

The successful commercialisation of OptiCOOL with BuildingIQ has led to an unexpected spill over benefit for CSIRO. The successful development of the technology, the partnership

with BuildingIQ and the licensing arrangements has enhanced CSIRO's reputation and credibility in the energy-for-business domain. CSIRO's increased credibility has led to better engagement with their other clients as well.

E.5.2 Potential future impacts

CSIRO is not expecting any impacts to occur in the future beyond an extension of the existing environmental and economic impacts outlined earlier in Table E3. However, it is currently undertaking research to extend the range of purposes that OptiCOOL technology can be applied to in the future. Current lines of research include:

- Intelligent control of commercial and industrial refrigeration systems (i.e. cool rooms, cold stores, refrigerated warehouses) by using self-learning models and predictive control systems.
- Model predictive control systems for residential air conditioners.
- Matching air conditioner system load (for both commercial and residential applications) to the output from solar photo-voltaic systems. This line of research is part of CSIRO's 'Virtual Power Station' initiative, which aims to link dispersed renewable energy generation and storage systems in order to establish a single virtual power station that can feed into electricity grids (CSIRO, 2009).
- Fault detection and diagnostics (FDD) systems, which can automatically sense mechanical faults, glitches, or situations in which certain parts of HVAC systems are operating sub-optimally.

CSIRO is also benefiting from a stream of royalty payments from BuildingIQ, which has the potential to grow in line with the US market. Royalty payments of $100,000 are scheduled to be paid to CSIRO in March each year. In 2016 Building IQ has the option to purchase the rights to the technology outright for an estimated $540,000.

OptiCOOL could potentially save the building sector $2.6 billion a year in energy costs.

The global market of suitable buildings is around 80,000, of which 32,000 are in the US; there is therefore huge upside potential for application of the technology. The US building market spends some $26 billion on energy a year, and Building IQ believes it is possible to reduce that by at least 10% (saving around $2.6 billion a year).

E.5.3 Cost Benefit Analysis

ACIL Allen has estimated the following benefits arising from CSIRO's development of the OptiCOOL technology for the period 2014/15 to 2024/25:

- BuildingIQ's contribution to Australia's GDP in terms of value added (which is approximately equal to its profits plus its payment of wages and salaries to its Australian employees)
- Reduction in energy costs for building tenants in Australia
- Value of the reduction in greenhouse gas emission enabled by the OptiCOOL technology.

The key assumptions underpinning the benefit valuation analysis and the sources for the assumed parameter values are shown in Table E6.

Table E6 **Key assumptions in benefit valuation analysis**

Assumption	Assumed value	Source
Annual revenue growth of BuildingIQ	15%	Navigant Research, *IT-Based Monitoring and Control Systems for Smart Buildings: Global Market Analysis and Forecasts*
Ratio of value added to revenue	63%	ABS input-output table of the Australian economy, corresponding to the 'Computer Systems Design and Related Services' sector
Australian share of BuildingIQ value added	60%	As of end August 2014, BuildingIQ had 20 employees in Australia and 16 employees in the US
Australian share of BuildingiQ's installed floor area	10%	The share was 11.6% in October 2012
Reduction in energy use enabled by Building IQ	20%	CSIRO estimates energy savings in the range of 12-30%
Annual energy cost per sq m	$35	NABERS, *Energy Management Guide for Tenants*
Annual GHG emissions per sq m	0.5 tonnes	NABERS, *Energy Management Guide for Tenants*
Carbon price per tonne of CO_2-e	$24	Based on Australian price for carbon in 2013-14 before the Carbon Tax was scrapped

Source: ACIL Allen

According to the consultancy Navigant Research, the global market for building energy management systems (BEMS) will grow from just under US$1.8 billion in annual revenue in 2012 to nearly US$5.6 billion in 2020, implying a compound annual growth rate (CAGR) of 15.2 per cent.

The three sources of economic benefits generated by BuildingIQ and the total benefits in each year between 2014/15 and 2024/25 are shown in the shaded columns in Table E7.

Table E7 **Estimation of benefits**

Year	Revenue	Value added	Value added (Australia)	Total floor area under management (sq m)	Total floor area in Australia under management (sq m)	Reduction in energy costs in Australia	Reduction in Australian GHG emissions (tonnes)	Value of reduction in GHG emissions	Total benefits to Australia
2014-15	$4,579,169	$1,450,933	$870,560	1,390,000	139,000	$973,000	13,900	$333,600	**$2,177,160**
2015-16	$9,603,333	$5,663,951	$3,398,370	2,915,078	291,508	$2,040,554	29,151	$699,619	**$6,138,543**
2015-16	$11,043,833	$6,957,615	$4,174,569	3,352,339	335,234	$2,346,637	33,523	$804,561	**$7,325,768**
2016-17	$12,700,408	$8,001,257	$4,800,754	3,855,190	385,519	$2,698,633	38,552	$925,246	**$8,424,633**
2017-18	$14,605,469	$9,201,446	$5,520,867	4,433,469	443,347	$3,103,428	44,335	$1,064,032	**$9,688,328**
2018-19	$16,796,289	$10,581,662	$6,348,997	5,098,489	509,849	$3,568,942	50,985	$1,223,637	**$11,141,577**
2019-20	$19,315,733	$12,168,912	$7,301,347	5,863,262	586,326	$4,104,284	58,633	$1,407,183	**$12,812,814**
2020-21	$22,213,093	$13,994,248	$8,396,549	6,742,752	674,275	$4,719,926	67,428	$1,618,260	**$14,734,736**
2021-22	$25,545,057	$16,093,386	$9,656,031	7,754,164	775,416	$5,427,915	77,542	$1,860,999	**$16,944,946**
2022-23	$29,376,815	$18,507,394	$11,104,436	8,917,289	891,729	$6,242,102	89,173	$2,140,149	**$19,486,688**
2023-24	$33,783,337	$21,283,503	$12,770,102	10,254,882	1,025,488	$7,178,418	102,549	$2,461,172	**$22,409,691**
2024-25	$38,850,838	$24,476,028	$14,685,617	11,793,115	1,179,311	$8,255,180	117,931	$2,830,348	**$25,771,145**

Source: ACIL Allen

Value added for each year is calculated by multiplying the projected revenue for that year (which is assumed to be growing at 15 per cent per annum) by the ratio of value added to revenue (assumed to be 63 per cent, based on information from the Australian Bureau of Statistics' input-output tables of the Australian economy corresponding to the 'Computer Systems Design and Related Services Sector', the closest match to the activities undertaken by BuildingIQ).

The total floor area of buildings adopting the OptiCOOL technology is assumed to grow at the same rate as BuildingIQ's revenue (that is, 15 per cent per annum). Drawing on information provided by NABERS (part of the NSW Office of Environment and Heritage) in its *Energy Management Guide for Tenants* on the average energy cost per square metre ($35) and the average greenhouse gas (GHG) emissions per square metre (0.5 tonnes) as well as a carbon price corresponding to that set by the Australian Government for 2013/14 before its abolition this year, we have calculated the value of the savings in building tenants' energy costs and the value of the reduction in GHG emissions in each year based on the assumption that the OptiCOOL technology enables a 20 per cent reduction in energy usage on average.

The present value of benefits from the OptiCOOL technology is around $79.67 million.

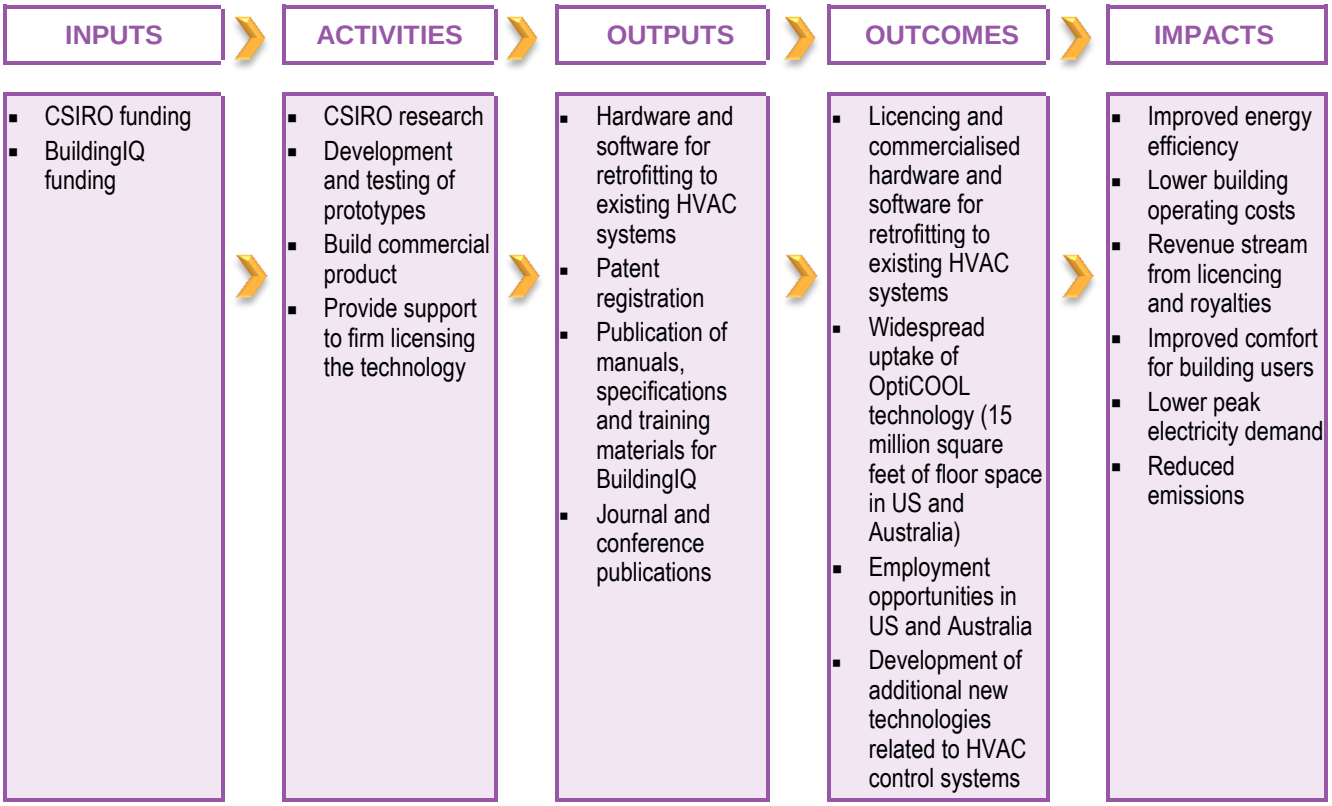
Our analysis shows that the stream of total benefits of BuildingIQ to Australia for the period 2014/15 to 2024/25 is approximately $106.2 million in 2014/15 dollars under a 5 per cent discount rate and $91.9 million in 2014/15 dollars under a 7 per cent real discount rate. Assuming that 75 per cent of these benefits are attributable to CSIRO (as discussed previously in Section E.4.3), the present value of benefits arising from CSIRO's development of the OptiCOOL technology is estimated to be $79.67 million in 2014/15 dollars over the 2014/15 to 2024/25 period, using a 5 per cent discount rate, and $79.67 million using a 7 per cent discount rate.

Should BuildingIQ's revenue growth turn out to be 25 per cent per annum instead of 15 per cent as assumed, the present value of benefits attributable to CSIRO over the 2014/15 to 2024/25 period will be approximately $133.5 million in 2014/15 dollars. Conversely, should BuildingIQ's revenue growth turn out to be 10 per cent per annum, the present value of benefits attributable to CSIRO will be approximately $62.2 million in 2014/15 dollars.

The commercialisation of the OptiCOOL technology represents a tremendous return to CSIRO's investment in the development of the technology, which totalled approximately $412,000 between 2006/07 and 2010/11 (see Section E.1.4).

E.5.4 Impact pathway diagram

Figure E2 **OptiCOOL – impact**



Source: ACIL Allen

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Appendix F Case study: Aquaculture feed and prawn breeding

SUMMARY OF KEY FINDINGS

CSIRO's research and development on prawn breeding and feed has led to:

- Improved productivity
  - Prawns that grow faster, have a more consistent size and are more resistant to common viruses.
  - Ponds stocked with CSIRO's selectively bred prawn broodstock had a 39 per cent increase in productivity compared to ponds stocked with wild stock.
- A more sustainable prawn industry
  - The prawn feed additive Novacq™ is made using agricultural waste and removes the need to use fish meal or fish oil obtained from the wild fish resources.
  - Prawns that are fed the additive are healthier and grow 30-40 per cent faster.

The uptake of the new prawn breeds has been rapid and significant to date and is expected to track the projected expansion in the industry. Benefits delivered to the industry to date are estimated to be around $73.5 million. Of this, 75 per cent, or $55.1 million, are attributable to CSIRO. ACIL Allen estimates that CSIRO's prawn breeding project will deliver total additional benefits of $452.5 million under a 5 per cent discount rate between now and 2023/24, of which 75 per cent or $339.4 million are attributable to CSIRO.

Use of Novacq™ only began during the last year so benefits to date are small. However there is very strong interest in licensing of the technology and this (plus the demonstrated benefits of the feed) is expected to drive strong uptake in Australia and overseas. ACIL Allen estimates that the cumulative benefits from the use of the novel prawn feed will be around $368.3 under a 5 per cent discount rate between now and 2023/24. In addition, CSIRO is expected to earn over $100 million in royalties from the domestic and overseas sale of Novacq™.

This adds up to total benefits of $882.2 million attributable to CSIRO, including royalties revenue.

F.1 Introduction

F.1.1 Purpose and audience

This independent case study evaluation has been undertaken to assess the economic, social and environmental impact of CSIRO research on prawn breeding and sustainable aquaculture feed. This case study has been prepared so it can be read as a standalone report or aggregated with other case studies to substantiate the broader impact and value of CSIRO's activities.

The report is provided for accountability, reporting, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, CSIRO and the general public.

F.1.2 Background

Wild prawn stocks are under pressure from overfishing

About half the prawns consumed in Australia are imported from overseas, for example from Vietnam and China. Global stocks of wild prawns have been under increasing pressure in recent years, as a result of overfishing. A 2009 report by the Food and Agriculture Organisation (FAO) pointed to serious overfishing of shrimp populations and associated environmental degradation in the majority of selected case study countries (although

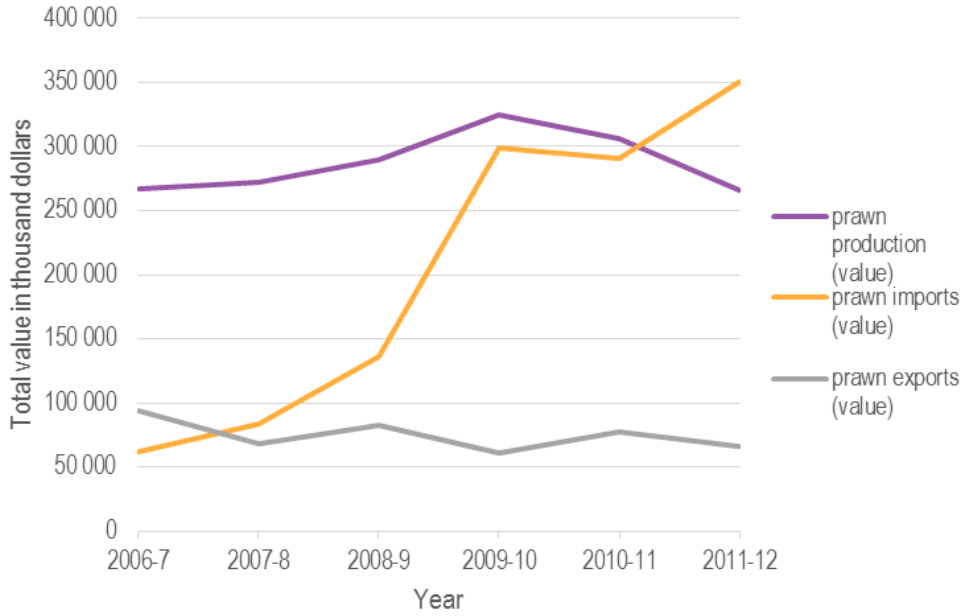
Australian prawn fisheries were ranked as some of the best managed of the countries surveyed in the report) due to capture of juveniles, coastal habitat degradation, illegal trawling, the destruction of seagrass beds and large volumes of non-shrimp by-catch, which is often thrown away (FAO, 2009).

Globally FAO estimates that in 2011, 28.8% of the world's fisheries were overfished, with another 61.3% of fish stocks fully fished (and therefore vulnerable to overfishing) and 9.9% of global fish stocks under fished (FAO, 2014).

Farmed prawns supply a growing share of Australia's demand

In Australia, wild caught prawns continue to comprise a large percentage of total prawn production, accounting for 77.8 per cent of the total dollar value of Australia's prawn production, which stood at $266.2 million, in 2011-12 (ABARES, 2013) (see Figure F1). In response to the decline in the stocks of wild prawns there has been a significant increase in the use of farmed prawns to meet consumer demand. While prawn imports account for a high proportion of total consumption in Australia, Australian produced prawns generally attract a higher market value. In 2011-12 the average price of imported prawns was $9,350/tonne. The average price for exported Australian prawns was $12,360/tonne, while the price of Australian wild prawns for the domestic market was $10,037/tonne. The domestic farm gate price for Australian farmed prawns in 2010-11 was $14,540/tonne (APSQ 2012).

Figure F1 **Australia's prawn production and trade by dollar value**



Source: ABARES 2013, 2010

CSIRO has two streams of prawn research …

In 2002 the CSIRO Future Foods flagship and its partners began its research to improve the sustainability and productivity of Australia's prawn industry. That research had two streams of activity, namely, prawn breeding and novel prawn feed.

Prawn breeding

… one is prawn breeding …

One of the primary tools for boosting productivity in the agribusiness sector is to use selective breeding to develop faster growing and or more disease-resistant species. CSIRO has undertaken a considerable amount of work into the domestication and selective breeding of the *Penaeus monodon* species of prawn (black tiger prawns). One aim of this

research was to domesticate *P. monodon*, eliminating the need to use wild caught prawns as broodstock to produce each new generation of farmed black tiger prawns. A second objective of this research was to develop a prawn with improved growth, survival and feed conversion rates as well as improved tolerance towards endemic prawn viruses.

Novel prawn feed

… the other is a novel prawn feed

Traditionally, fishmeal and fish oils have provided a major component of the prawn feed used in prawn aquaculture. However, the reliance on fish products for inclusion in prawn food has in turn caused a number of problems. Wild fishery sources have been an important source of fish-based prawn feed, which has put further strain on fish stocks and raised questions about the long-term sustainability of prawn aquaculture.

Until recently practical replacements for fishmeal and fish oils were largely ineffective as they were unable to provide the nutrition required to quickly grow large prawns that are able to compete in the market with prawns grown on feed that is based on fish products (Glencross *et al.*, 2014).

F.1.3 Approach

The approach taken in this case study is based on CSIRO's impact framework and aligns with the nine-step process described in the CSIRO's impact evaluation guide, namely:

1. Initial framing of the purpose and audience of the impact evaluation.
2. Identify nature of impacts (*what is the impact pathway, what are the costs and benefits*)
3. Define a realistic counterfactual (*what would have occurred in the absence of CSIRO*)
4. Attribution of research (*CSIRO vs. others' contribution*)
5. Adoption (*to date and in future*)
6. Impact (*timing, valuation, distributional effects among users, effects on non-users*)
7. Aggregation of research impacts (*within program of work*)
8. Aggregation of impacts (*across program of work*)
9. Sensitivity analysis and reporting.

Note that steps 7 and 8 above are less relevant for this individual case study as the prawn breeding and novel feeds projects are being considered in isolation. The impacts identified in this case study will be aggregated with those from other aspects of CSIRO's work to provide an insight into the overall benefits arising from the Organisation's work.

F.1.4 Project origins and inputs

The objective of CSIRO's Food Futures Flagship is:

> Transform the international competitiveness of the Australian Agrifood sector, adding $3 billion in annual value, by applying frontier technologies to high potential industries (CSIRO, 2014a).

The future *animal breeds and feeds* theme of work specifies its objective as being:

> To boost the value of our seafood and livestock industries through breed engineering and leading edge production technologies.

Prawn R&D will contribute to the Food Futures Flagship's objectives

The Food Futures Flagship roadmap states that the objective of this work is to boost the value of Australia's animal-based food industries by $350 million per annum for beef and $550 million for seafood over the next 10 plus years (CSIRO, 2013).

CSIRO's research into prawn breeding and prawn feed has made an important contribution to the Flagship's goal both through the development of a prawn breed that grows faster and

is more resistant to prawn diseases, and through the development of a new and more sustainable prawn feed additive.

History of project

CSIRO's expertise built up over 20 years

During the past 20 years CSIRO has worked closely with the Australian and international prawn farming industry to undertake research on a range of issues that are critical to that industry, including: environmental and health management; selective breeding; domestication; and nutrition.

Over that time CSIRO has established an excellent international reputation for its expertise in the selective breeding of farmed prawns. CSIRO has also developed novel prawn feeds that will help break the existing reliance of the prawn industry on wild fisheries as a source of prawn feed.

Project inputs

About $28 million spent on prawn R&D over last 10 years

CSIRO's inputs into the two streams of research, including labour and operating costs, are outlined in Table F1.

Table F1 **CSIRO support for prawn related R&D**

Date	Prawn breeding ($million)	Prawn feed ($million)
2004-05	1.20	0.85
2005-06	1.23	1.20
2006-07	1.22	1.35
2007-08	1.23	1.27
2008-09	1.25	1.40
2009-10	1.00	1.01
2010-11	1.20	0.80
2011-12	1.30	0.83
2012-13	1.20	0.99
2013-14	1.10	0.39
Total	**11.93**	**10.10**

Source: CSIRO

CSIRO has also benefitted from in-kind support from its industry partners in the prawn farming sector, who offered the use of their prawn stock for CSIRO to conduct its prawn breeding research project.

Industry has provided financial and in-kind support

External funding and in-kind support from other sources is shown in Table F2 and Table F3 respectively.

Table F2 **External support for prawn related R&D (cash co-invested)**

Date	Prawn breeding ($million)	Prawn feed ($million)
2004-05	.26	0
2005-06	.25	0
2006-07	.20	0
2007-08	.35	.2
2008-09	.27	.15
2009-10	.16	0
2010-11	.24	0
2011-12	.37	.4
2012-13	.54	.26
2013-14	.40	.50
Total	**3.04**	**1.51**

Source: CSIRO

Table F3 **External support for prawn related R&D (in-kind)**

Date	Prawn breeding ($million)	Prawn feed ($million)
2004-05	.09	0
2005-06	.08	0
2006-07	.07	0
2007-08	.12	.1
2008-09	.09	.07
2009-10	.05	0
2010-11	.08	0
2011-12	.12	.2
2012-13	.18	.13
2013-14	.13	.18
Total	**1.03**	**.69**

Source: CSIRO

F.2 Project activities

Prawn breeding

Broad spectrum of CSIRO capabilities used

CSIRO brought together a number of its core capabilities to use in its prawn breeding project. These are listed in Table F4.

Table F4 **CSIRO prawn breeding project capabilities and activities**

Capability	Activity
Breeding system management	Established a captive breeding management system to enable selective breeding of domesticated *P. monodon.*
Software development	Developed sophisticated databases and software systems to enable accurate tracking of prawn pedigree, mate allocation, controlling inbreeding and selection for desirable genetic traits.
Molecular virology	Identified and characterised prawn viruses and their interaction with selectively bred prawns, enabling selective breeding for disease resistance. This was achieved through the development of simple virus testing kits that can be used on-farm to test each individual prawn for its breeding suitability.
Molecular genetics	Developed genetic markers to monitor genetic diversity, control inbreeding, optimise mate allocation and locate genes that control traits of commercial interest.

Capability	Activity
Quantitative genetics	Analysed estimated breeding values (EBVs) to optimise selective breeding of economically important traits.
Media communications	CSIRO made media outreach a core part of its strategy to increase awareness among the prawn industry and boost adoption rates. CSIRO undertook a concerted media campaign in 2010, which saw coverage of domestication and breeding of the black tiger 'super prawn' in major Australian news outlets such as the ABC, the Sydney Morning Herald and Channel Nine, among others.

Source: ACIL Allen Consulting; CSIRO

These capabilities were first applied in CSIRO's work with Australian prawn farmers in the domestication and selective breeding of *P. monodon* black tiger prawns. In addition, CSIRO took the lessons learnt from its Australian black tiger prawn breeding project and applied that newly developed knowledge and the related technology skills to *Litopeaneus vannamei* (Pacific White Shrimp) breeding in Vietnam, in cooperation with a local Vietnamese industry partner.

Prawn feed

CSIRO's prawn feed is more sustainable than alternatives

The world has long been looking for a sustainable alternative to conventional fish based prawn feed. CSIRO researchers have developed a way to take any source of high-volume, low-cost agricultural product like rice-bran and then use marine microbial processes to turn it into a feed supplement that when harvested and dried can be given to prawns.

CSIRO brought together a range of core capabilities for its prawn feed project. These are shown in Table F5. It is worth noting that using CSIRO's media communications capabilities were an essential part of its strategy to increase awareness of the outcomes its R&D into novel prawn feed and prawn breeding and thus help drive more rapid adoption by industry.

Table F5 **CSIRO novel prawn feed project capabilities and activities**

Capability	Activity
Microbiology and nutrient dynamics	Modelling nutrient dynamics and controlling the production of marine microbial biomass
Organic chemistry	Characterisation of bioactive compounds
Crustacean nutrition	Determining the dietary requirements of crustaceans and formulation of feeds containing Novacq™
Feed technology	Optimising the production, harvesting and processing of Novacq™
Media communications	CSIRO made media outreach a core part of its strategy to increase awareness among the prawn industry about the benefits of Novacq™. CSIRO undertook a concerted media campaign over the second half of 2013 and into 2014, which saw coverage of Novacq™ in major Australian news outlets.

Source: ACIL Allen Consulting; CSIRO

Current strategy period

CSIRO is engaged in ongoing research designed to extend the benefit of its prawn breeding and novel feeds research project.

F.3 Project outputs

F.3.1 Key outputs of the project

Prawn breeding

CSIRO has bred a healthier and faster growing prawn

The main focus of CSIRO's research is to help prawn farmers meet their commercial requirements for a prawn breed that delivers better yields. Consequently, CSIRO's selective breeding efforts have primarily been aimed at breeding a prawn that has faster growth rates and a more consistent size.

A further benefit of the breeding project has been the breeding of prawns that have greater resistance to common viruses. As part of the breeding project every potential parent prawn has a small piece of tissue snipped off for DNA fingerprinting and determining the viral load. If the prawn has an above average viral load it is judged to be less resistant to viruses and removed from the breeding project. Over time this selective breeding leads to prawn stocks that are more resistant to endemic prawn viruses.

It is important to understand that CSIRO does not provide prawn stock to prawn farmers but rather applies the breeding technologies and practices that it has developed to that farm's existing prawn stock. The key outputs of CSIRO's breeding project are:

- A detailed manual that provides prawn farmers with a standard operating procedure to help guide domestication and selective breeding projects on each prawn farm.
- A software package, including a detailed database program that allows prawn farmers to track prawn pedigree, select optimal mating, control inbreeding, and optimise selection of improved growth rates, feed conversion efficiency and tolerance to disease.
- Specialised training provided by CSIRO for prawn farm staff in new breeding practices and CSIRO's breeding project. This includes manuals, in-person instruction from CSIRO staff and other training aids.
- Ongoing analytical services. The prawn farmers regularly provide prawn breeding data to CSIRO who analyse that data and advise them on the best selection decisions to help guide each prawn farm's breeding choices.
  - Importantly, ongoing selective breeding will continue to provide benefits and those benefits are cumulative. However, if a company ceases to use the CSIRO process then its brood stock could rapidly decline in quality through poor selection, inbreeding, etc.
- Virus testing kits. The testing kit tests a piece of a prawn's body tissue to determine the viral load (a measure of the severity of viral infection). The testing serves two purposes. One is to enable early detection of viruses so that appropriate mitigation strategies can be taken to prevent the spread of disease throughout the entire prawn stock. The second is to enable more effective selective breeding for disease resistant prawns as information.

Novel prawn feed

The major output of CSIRO's research and collaboration with industry is the prawn feed additive Novacq™. The bio-active additive acts on a prawn's metabolic pathways to improve nutrient absorption from the prawn feed that Novacq™ is added to.

Novacq™ is made from agricultural waste – a world-first achievement

Novacq™ is made from what might normally be regarded as agricultural waste. Marine organisms are used to bio-convert the carbon in the agricultural waste into material that is then harvested, dried and used as a food additive for prawns. The marine microbes used in

the process are found in every pond in the world. What CSIRO have managed to do is learn how to manage that microbe and use its natural ability to convert the carbon in agricultural waste into a valuable product. The process is an entirely natural one and the only inputs are a source of carbon, sunlight and energy.

Novacq™ has been licensed to several firms

CSIRO's novel feeds research has generated two patents and an application for a third patent has been lodged. CSIRO has also established a licence for use of Novacq™ by prawn food mills. This licence comprises a standard operating procedure including instruction detailing how to produce Novacq™ and incorporate the additive into regular prawn food. Licences are regional and exclusive, meaning that only one vendor can sell Novacq™ in any given geographic region. The exception to this approach is that the licence granted to the Australian firm Ridley allows it to market and sell Novacq™ anywhere in the world.

Prawns fed Novacq™ grow 30-40 per cent faster

Novacq™ is the result of over ten years of CSIRO research. Farmed prawns that are fed the additive grow 30-40 per cent faster, are healthier and can be produced without the need for any products from wild fishery resources. This means that feed formulators/manufacturers can produce prawn feed that can be sourced from sustainable and terrestrial production.

Novacq™ is transformative, using no fish oil or meal

This is a transformative technology that removes dependency on wild-harvest fishmeal/oil for the global prawn farming industry. Greater uptake of Novacq™ will reduce demand for wild and farmed fish from the prawn industry. There is also the significant potential to increase the value of waste agricultural materials such as rice-bran.

The benefits of the additive have further strengthened Australian prawn aquaculture, which is already a global leader in sustainability and environmental management, by enabling prawn aquaculture farmers to entirely move away from wild-caught fishery products and instead use a more sustainable source of feed to meet increasing demand for food (CSIRO, 2013c).

F.3.2 Key publications

Examples of publications that flowed from the research on prawn breeding and prawn feed done by CSIRO include:

- Preston, N.P., Coman, G.J., Sellars, M.J., Cowley, J.A., Dixon, T.J., Yutao, L., Murphy, B.S. 2009. Advances in *Penaeus Monodon* breeding and genetics, pp 1-11 in Browdy, C.L. & Jory, D.E., editors. The Rising Tide, Proceedings of the Special Session on Sustainable Shrimp Farming, World Aquaculture 2009. The World Aquaculture Society, Baton Rouge, USA.
- Glencross, B.D., Irvin, S., Arnold, S., Blythe, Bourne, N., Preston, N.P. (2014). *Effective use of microbial biomass products to facilitate the complete replacement of fishery resources in diets for the black tiger shrimp*, Penaeus monodon. doi10.1016/j Aquaculture 2014.02.033
- Glencross, B.D., Tabrett, S.J., Irvin, S., Wade, N., Anderson, M., Blyth, D., Smith, D.M., Coman, G.E., Preston, N.P. (2013). *An analysis of the effect of diet and genotype on protein and energy utilization by the black tiger shrimp, Penaeus monodon. – why do genetically selected shrimp grow faster?* Aquaculture Nutrition 19: 128-138

F.3.3 Awards and public recognition

The quality and benefits of CSIRO's research has been recognised in the following awards:

- Australian Prawn Farmer's Association, Award for services to the prawn farming industry 2010 – Nigel Preston

- The Australian Innovation Challenge 2013, Winner of the Environment, Agriculture and Food Category: For the development of Novacq™ – the CSIRO Novacq™ team
- CSIRO Medal for Impact from Science 2014 – The Novacq™ Team (led by Dr Nigel Preston, Dr Brett Glencross and Mr Andrew Chalmers)

F.4 Status of Outcomes and Impacts

F.4.1 Nature of Outcomes and Impacts

Prawn breeding

The domestication and selective breeding of *P. monodon* has had a very significant impact on the prawn farming industry. Below we discuss how the benefits generated are distributed across different categories of beneficiaries.

The breeding project helped prawn farmers significantly increase their yields

Australian prawn farmers. The benefits have been particularly significant for this group. For example, in 2010, Gold Coast Marine, one of Australia's leading prawn farming companies were able, for the first time, to stock their whole farm with the progeny of domesticated, selectively bred broodstock. The results were that the average yields from the improved stocks was 17.5 tonnes per hectare (see Box 2) compared to the industry average for the same year of 7.8 tonnes per hectare (see APSQ, 2012).

A recent analysis of the productivity benefits of using domestic Black Tiger shrimp found that ponds stocked with domesticated *P. monodon* significantly shifted the production frontier by 39% compared to ponds stocked with wild stock (Norman-Lopez *et al*., 2014). In particular, the CSIRO prawn breeding project has helped improve the market competitiveness of *P. monodon* compared to the Pacific White shrimp (*Litopeaneus vannamei*), which has progressively replaced *P. monodon* as the most common breed in farmed prawn and shrimp production. By increasing the productivity of *P. monodon* aquaculture, prawn farmers are able to capture larger profits due to the price premium that the larger *P. monodon* commands over *L. vannamei* on the market (Norman-López *et al*., 2014).

Box F1 **Gold Coast Marine productivity gains**

The following is an excerpt from a letter from Nick Moore, General Manager of Gold Coast Marine Aquaculture Pty. Ltd. to the team leader for CSIRO's prawn breeding project.

> Some time ago I wrote to you [CSIRO's Dr. Nigel Preston] to thank you for your invaluable contribution to the monodon domestication program that allowed GCMA [Gold Coast Marine Aquaculture] to stock all 50 hectares of production ponds with domesticated stock.
>
> Last Friday we finished a season that could only be described as staggering.
>
> From those 50 hectares we produced 875 tonnes [of prawns], giving us an average of 17.5 tonnes per hectare. 14 ponds exceeded 20 tonnes per hectare with the new record now standing at 24.2. Given that this was also achieved with an FCR [feed conversion ratio, a measure of how efficient and animal is in converting feed into body mass] of 1.44 and an average weight of 37 grams, these figures are quite remarkable and far outweighed our expectations. Our results are not only records nationally, but globally too.
>
> It is our intention this coming year to aim towards the Christmas market, a target never in reach with wild progeny. The 8th generation broodstock within our maturation complex look exceptional and we are hoping to improve our ability to supply the market during historically difficult periods.
>
> Please accept not only our thanks but also our congratulations to all at CSIRO.

Source: Nick Moore, 2010, pers. comm., 26 May 2014

Overseas communities that are reliant on aquaculture. Breeding for disease resistance has been another important outcome of CSIRO's prawn breeding research as well as being the primary focus of CSIRO's work in Asia with Viet-UC, Vietnam's largest supplier of shrimp

The overseas breeding project has also produced more disease resistant prawns

seed. Asian populations of domesticated Pacific White Shrimp have historically been highly vulnerable to repeated waves of disease. The latest wave of early mortality syndrome, a bacterial disease has resulted in stock loss in the tens of billions to disease in farmed Pacific White Shrimp stocks across Asia, with some major companies recording decreased yields by as much as 50 per cent over the past year. This highlights the benefits of CSIRO's approach to selectively breeding farmed prawns for tolerance or resistance to local pathogens.

Lessons CSIRO has gained from its collaboration in Vietnam may serve as an important guide for dealing with serious disease outbreaks in Australian prawn populations in the future. Working with South-east Asian shrimp farmers also has the added benefit of monitoring and addressing disease outbreaks in the region before they have the opportunity to infect Australian prawn stocks. In the past, diseases in Asian shrimp populations have entered Australia via frozen shrimp imports, there is also potential for disease to spread via wild prawn populations.

The breeding project is generating royalties and licencing fees

CSIRO. CSIRO has also benefitted from royalties and licencing fees paid by companies licenced to utilise CSIRO's prawn domestication and breeding project. The total value of these licences and royalties will be approximately $1 million per year by 2017.

Novel prawn feed

A range of benefits have been delivered as a result of the CSIRO's research into novel prawn feed. They include: improved productivity and increased yields from prawn farms; more sustainable prawn feed; patents and royalty flows; and the creation of a market for what was previously agricultural waste. Below we discuss how benefits are distributed across different categories of beneficiaries.

Three firms have licences to produce and sell Novacq™

Prawn feed mills. Licenced prawn feed producers benefit through their ability to sell a new product with high nutrient value that eliminated feed producers' reliance on fish-meal or oil as a prawn feed additive. An important outcome of this project has been the allocation of licenses to produce and distribute Novacq™ in Australia and various countries in South-East Asia. The following three firms have to date licensed Novacq™:

- Ridley AgriProducts (sales in Australia, Indonesia, Malaysia and the Philippines)
- Viet-UC (sales in Vietnam)
- Maritech (sales in China)

The novel feed produces larger and healthier prawns

Prawn farmers. Prawn farmers benefit from access to new prawn feed that provides the capability to produce larger and healthier prawns. One on-farm trial of Novacq™ has demonstrated increased yields of 22 per cent. However, CSIRO judges this to be a conservative estimate of potential productivity gains as a result of the use of Novacq™ given much larger yield increases in research trials in controlled environment tanks (Glencross *et al*., 2013). The total productivity gains in terms of increased yields to be had when CSIRO's prawn breeding project and Novacq™ are used together are would be expected to be far higher.

Prawn farmers also have an opportunity to market their prawns as a more environmentally sustainable option compared to prawns that have been fed on fish-based feed. This may aid prawn farmers who wish to apply for established sustainability branding, which is certified and provided by organisations such as the World Wildlife Fund and Global Aquaculture. Eliminating the need to tap into wild fish stocks in order to produce prawn feed may also increase community acceptance of prawn farms on environmental grounds.

The novel prawn feed will also generate royalties

CSIRO. The CSIRO has benefited from the research by gaining potential future royalty streams from the licensing of Novacq™ as part of its novel feeds project. CSIRO is expecting royalties of roughly $250,000 in 2014, plus additional income from expansion into new geographic sales regions. By 2018, CSIRO is expecting total royalties to rise to $7.47 million, plus some additional revenue from sales in new markets.

In addition, CSIRO has strengthened its reputation for research in Australia and globally and expanded its partnerships in the global prawn and shrimp industry.

Overseas communities that are reliant on aquaculture. Use of Novacq™ and/or CSIRO's prawn breeding project may significantly increase the incomes of aquaculture communities, particularly in places where income security can be precarious, such as in Vietnam's Mekong Delta and emerging economies in other parts of Asia and in Africa.

Other beneficiaries. The community and the wild fish catching industry will benefit from a reduction in the pressure on wild fish stocks by the development and use of a prawn feed that does not use fish meal or oil. Another potential group of beneficiaries are farmers who could potentially supply what was previously regarded as agricultural waste to prawn feed manufacturers and thus realise a source of additional income.

CSIRO market and non-market impacts

Table F6 summarises the outcomes and impacts to date of CSIRO's prawn breeding and novel feeds research projects. In line with CSIRO's triple bottom line (TBL) benefit classification approach the outcomes and impacts have been categorised as environmental, social or economic.

Table F6 **Outcomes and impacts from CSIRO's prawn related research**

Outcome / Impact	Detail
Environmental impact	
Protecting existing fish stocks *Category: oceans and marine environment,* *Reach: Industry*	Decreased reliance on fish-meal and fish-oil as inputs for production in Australian Prawn Farms helping to preserve global fish stocks.
Development of a more sustainable prawn industry *Category: oceans and marine environment,* *Reach: National, Industry*	▪ Use of Novacq™ reduces feed costs in the production of farmed prawns. Development of Novacq™ decreases need to purchase fish-meal and fish-oil, thereby helping to preserve global fish stocks. Domestication of black tiger prawns also removes the need to trawl for wild broodstock for each generation of breeding. Over the long-term, these two breakthroughs promise to completely isolate black tiger prawn farming from wild fish and prawn stocks. ▪ Improved yields means that more prawns can be grown in a smaller space, potentially reducing the overall environmental footprint of black tiger prawn aquaculture.
Reduction in agricultural waste *Category: Sustainable industry development* *Reach: National*	Reduction in waste through utilisation of agricultural by-products to produce Novacq™.
Economic impact	
Improved productivity *Category: Management and productivity, New products or services,* *Reach: National*	▪ Use of Novacq™ increases Australian farmed prawn industry's production, thereby adding significant value to the industry. Proven on-farm increases in yields currently stand at 22 per cent when using high quality feeds. However, CSIRO testing suggests actual average productivity gains may prove to be much higher than this. ▪ CSIRO's black tiger prawn breeding project has led to increased production. Proven on-farm increases in black tiger prawn yields currently stand at 39 per cent compared to ponds stocked with wild prawn stocks. ▪ Use of Novacq™ increases production efficiency of farmed prawns through increased growth rates of up to 40 per cent.

Outcome / Impact	Detail
Improved competitiveness of Australian black tiger prawns *Category: Management and productivity, New products or services,* *Reach: National, Global*	▪ CSIRO's black tiger prawn breeding project has improved the competitiveness of Australian-produced prawns against imported shrimp, particularly Pacific White Shrimp produced in Asia. ▪ By increasing the productivity of black tiger prawn farming, Australian prawn farmers stand to capture a larger share of profits due to the price premium that larger, higher quality black tiger prawns command on the market.
Access to improved prawn feed *Category: New products or services,* *Reach: National, Global*	Development of Novacq™ improves the health and increases the size of black tiger prawns in particular by between 20 and 40 per cent depending on the overall quality of the diets used.
Access to virus detection kits *Category: New products or services,* *Reach: National, Global*	Virus detection kits enable early detection of diseases in prawn stocks and selective breeding for disease resistance. This has led to substantially lower loss of stock due to disease, particularly in Vietnam, where exposure of prawn stocks to disease is particularly severe.
Access to improved prawn breeds *Category: New products or services,* *Reach: National, Global*	Domesticated and selectively bred black tiger prawns are larger, have faster growth rates and are more disease resistant. CSIRO has been able to achieve similar improvements in selective breeding of White Pacific Shrimp in Vietnam, particularly in terms of improved disease resistance.
Increased employment *Category: The micro economy* *Reach: Firm*	The licencing of Novacq™ has delivered increased employment opportunities in Australia with one Australian supplier, Ridley AgriProducts, hiring an additional 7 staff for the pilot production site.
Social impact	
Access to better quality, cheaper prawns *Category: Equity and equality, Standard of living* *Reach: National*	Australian consumers will have access to competitively priced, higher quality prawns as a result of the superior size and health of farmed prawns and prawn production productivity gains as a result of CSIRO prawn breeding projects and use of Novacq™.
More reliable income streams *Category: Resilience* *Reach: National, Global*	Using prawns with improved disease resistance reduces the risk of catastrophic stock losses and subsequent loss of income. This may become particularly important for communities which are vulnerable to income loss from aquaculture, such as aquaculture and fishing communities in Vietnam's Mekong Delta.

Source: ACIL Allen Consulting; and CSIRO 2013a, 'Advancing aquaculture feed and prawn breeding', <http://www.csiro.au/Portals/About-CSIRO/What-we-do/Impact-case-studies/Aquaculture.aspx> , accessed 7 August 2014; and Norman-Lopez et al., *forthcoming*, 'Productivity benefits of using domestic Black Tiger shrimp'

F.4.2 Counterfactual

Prawn breeding

CSIRO's breeding research is 15 years ahead of others'

The domestication and selective breeding of black tiger prawns would have encountered a lengthy delay absent CSIRO's research project. Major Asian prawn producing countries including Malaysia, Vietnam and China all embarked upon research programs in an effort to domesticate *P. monodon* black tiger prawns, which are native to Asia and Oceania. However, these research programs were not successful and as a result these major Asian producers imported *L. vannamei* Pacific White Shrimp from Mexico, and made this species the foundation for Asian shrimp aquaculture. Other black tiger prawn breeding programs in Hawaii were also unsuccessful. Therefore, ACIL Allen estimates that the domestication and selective breeding of black tiger prawns would have been delayed by at least 15 years absent CSIRO's research project.

Novel prawn feed

Interviews with CSIRO team members who worked on the Novacq™ project suggested that the additive is unlikely to have been developed in the absence of CSIRO's ability to undertake long term multidisciplinary research. ACIL Allen will assume that in the absence of CSIRO's research, the Australian prawn farming industry would have continued with their existing practices by relying on fish-meal and fish-oil as an input to their production. Furthermore they would have faced much more severe competition from cheaper imports if the new improved prawn breeds had not been developed.

Development of the prawn feed would have been delayed by at least 15 years in the absence of CSIRO

As in the case of the prawn breeding, ACIL Allen estimates that development of novel prawn feed with the same characteristics and benefits as Novacq™ would have been delayed by at least 15 years in the absence of CSIRO's research project.

F.4.3 Attribution

Prawn breeding

The core research of CSIRO's black tiger prawn breeding project was undertaken by CSIRO. However, in kind support from prawn breeders was vital to the success of the project. In particular, partner prawn breeders made considerable investments in new farm infrastructure and provided the stock for CSIRO's on-farm experimentation. ACIL Allen would therefore argue that 75 per cent of the impacts of black tiger prawn domestication and selective breeding should be attributed to CSIRO, with the remaining 25 per cent of the impacts attributable to CSIRO's prawn farm partners.

Novel prawn feed

Interviews with CSIRO team members who worked on the Novacq™ project suggested that all benefits generated from the research should be attributed to CSIRO as CSIRO staff were responsible for all of the research associated with the product.

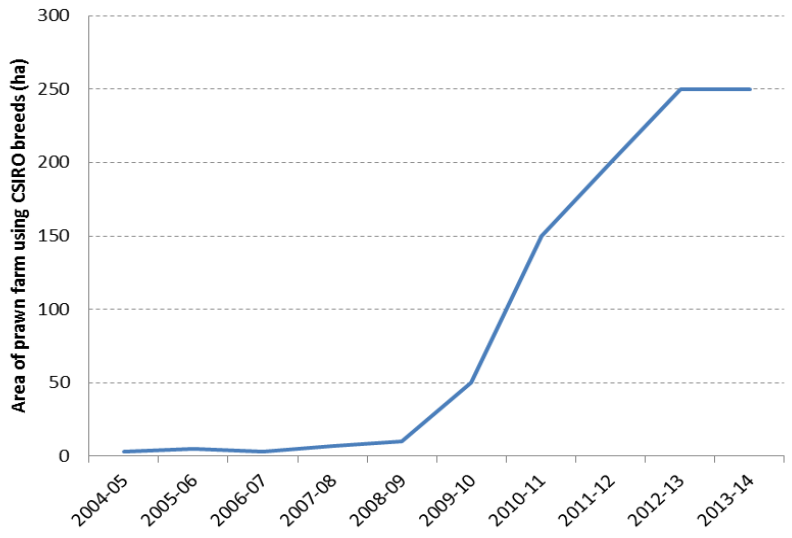
F.4.4 Adoption

Prawn breeding

Uptake of new prawn breeds has been very rapid

The uptake of new prawn breeds developed by CSIRO in Australia is shown in Figure F2. Uptake was very rapid between 2008/09 and 2012/13.

Figure F2 **Australian uptake of CSIRO prawn breeds**



Note: The total ponded area on prawn farms was 610 hectares at the end of 2010–11
Source: CSIRO and (APSQ 2012)

The reason for the current plateau of 250 ha (out of the current total of around 700 ha), is that some in the industry have been slower to make the up-front investment in the infrastructure required for on-farm domestication and selective breeding. CSIRO is currently working with the largest prawn farmer (Seafarms) to start a domestication project. This will add a further 150 ha to the area of ponds stocked with domesticated stocks by 2015-16. CSIRO are working with industry to develop the capability to supply the rest of the industry with domesticated stock by 2017-18. CSIRO expects that all Australian farms will be using domesticated stocks by 2020.

According to the director of CSIRO's prawn breeding project, Dr Nigel Preston, the area farmed is expected to double to 1,500 ha by 2024 and it is likely that CSIRO developed prawns will be used to stock all these additional ponds as well.[12]

Novel prawn feed

Marketing of Novacq™ has just begun …

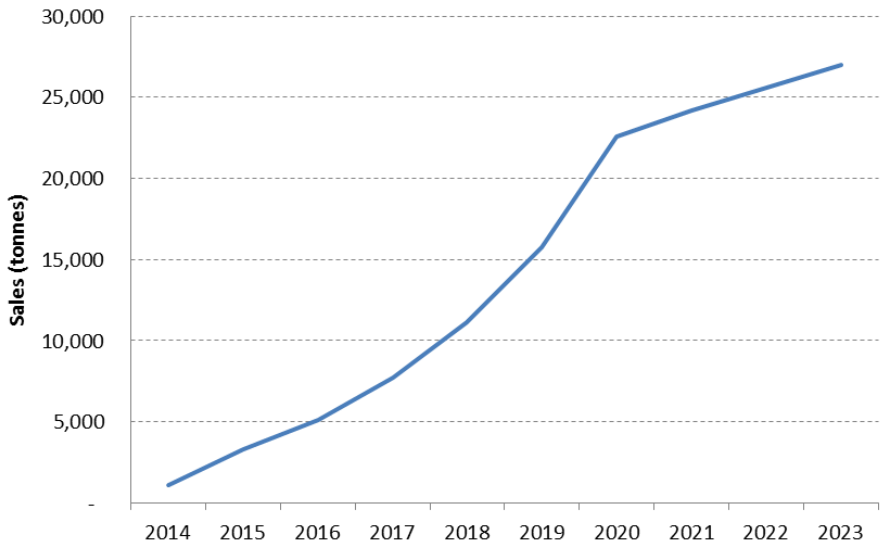
CSIRO-developed novel prawn food was only recently commercialised, so the level of uptake is relatively low at present. However, there are already three firms licensed to manufacture and sell Novacq™ which are based in Australia, China, and Vietnam. Their projected sales of Novacq™ in those countries is expected to grow rapidly, as shown in Figure F3. Each of these firms is licensed to market the prawn feed in their home country. The Australian firm is also licensed to market worldwide.

… but growth rates are projected to be substantial

Annual growth rates in sales of the CSIRO developed prawn feed in existing markets are projected to exceed 40% out to 2020.

[12] It is thought that much of the new prawn farming areas will be in Northern Australia.

Figure F3 **Projected sales of Novacq™**



Note: Sales of Novacq™ only began in 2013/14
Source: CSIRO

In addition, CSIRO is projecting that sales of Novacq™ in new or emerging markets such as Thailand and Ecuador could reach 45,000 tonnes by 2025.

Box F2 **Impact of CSIRO's media strategy on adoption rates**

Strong current and expected adoption rates of both CSIRO's domesticated black tiger prawns (and the associated breeding programme) and Novacq™ have been boosted by CSIRO's media campaign. CSIRO prepared its media messaging and engaged in concerted media outreach first in 2010, when the success of the black tiger prawn domestication and breeding project became apparent, and then in 2013/14, when Novacq™ was commercialised. Extensive media coverage of these breakthroughs was very effective in alerting the prawn industry to CSIRO's prawn aquaculture research, with the result that a number of prawn farming companies and prawn food mills to approach CSIRO to buy a licence to the breeding project or use Novacq™ in feed production.

This aided CSIRO in extending adoption of its prawn breeding project and Novacq™ into several key international markets, as well as increasing adoption rates in Australia. Recent media coverage of Novacq™ has directly led to sales and sales enquiries from new major prawn and shrimp producing markets, such as the Philippines, Indonesia, Malaysia, Ecuador, Thailand, India, Saudi Arabia, Oman, Mozambique and Madagascar.

CSIRO's media campaign has also led to new research and development partners. For example, media coverage in 2010 prompted Vietnam's Viet-UC, a company that today holds roughly 30 per cent of Vietnam's prawn production market, to approach CSIRO over a prawn breeding project for its *L. vannamei* Pacific White Shrimp stock. This was the start of several years of ongoing collaboration between CSIRO and Viet-UC.

Source: ACIL Allen; CSIRO 2013d, 'July 2013: Novacq™ prawn feed additive Media campaign associated with the industry launch and licensing agreement announcement – Evaluation Report', Canberra.

F.5 Assessment of impacts

F.5.1 Impacts to date

Economic impacts

Productivity gains will flow from CSIRO's research

Use of both Novacq™ and CSIRO's prawn domestication and breeding project delivers significant productivity gains.

Improved productivity: Latest on-farm evidence points to increased yields of at least 22 pre cent from the use of a premium prawn feed ($2.20/kg) with Novacq™ as an additive compared to prawns fed the same premium diet without Novacq™. However, on-farm and controlled environment trials using industry standard prawn feed ($1.80/kg) with or without Novacq™ have shown that prawns fed the standard feed containing Novacq™ grew 30-40 per cent faster.

On-farm evidence points to increased yields of at least 39 per cent as a result of the application of CSIRO's black tiger prawn domestication and breeding project. Finally, small scale tanks trails have demonstrated that the combined effects of selective breeding and the use of Novacq are highly synergistic (Glencross *et al*., 2013)

With the continued application of CSIRO's prawn breeding project, yields will continue to increase vis-à-vis the base case. If all of Australian prawn farms were stocked with domesticated and selectively bred black tiger prawns, CSIRO estimates that increases in yields would be 7,000 tonnes more than the current prawn farms production of roughly 5,850 tonnes. This would add approximately $120 million to the farm gate value of the industry.[13]

Efficiency and competitiveness will increase

Improved competitiveness: CSIRO's prawn breeding and novel feeds projects promise to improve production efficiencies for prawn farmers, although there will be some upfront capital expenditure associated with the prawn breeding project, due to the need for prawn farmers to invest in additional infrastructure. Domestication and selective breeding of black tiger prawns removes the need for prawn farmers to trawl wild prawns to collect broodstock for each new generation of prawns. Use of Novacq™ provides feeds that deliver faster growth rates. Farmers have the option of harvesting their crops earlier (to meet market demands when prices are highest) or to achieve larger size prawns in the same growing season and to take advantage of the higher prices paid for larger prawns.

Prawn farmers utilising Novacq™ and/or CSIRO's prawn breeding project can sell larger, healthier prawns that command a price premium on the market. At the same time, lower production costs will give prawn producers leeway to lower final selling price of their prawns, potentially taking greater market share and making Australian produced prawns more competitive with imported frozen shrimp.

In addition to economic benefits to Australia, a large part of the total economic benefits from CSIRO's prawn breeding project accrue overseas. In particular, Vietnam's prawn industry has benefitted from the partnership between CSIRO and Viet-UC, in which CSIRO has supplied the selective breeding techniques used on Australian black tiger prawns to Vietnamese Pacific White Shrimp. The collaboration with Viet-UC has resulted in faster growing prawns. Viet-UC is one of Vietnam's leading seed stock producers and anticipates significant future growth and associated benefits from using CSIRO's breeding technology.

[13] Calculation based on industry advice to CSIRO on recent farm-gate prices. Note that farm gate prices exceed $20 a kg around Christmas and Easter.

While the direct economic benefits of CSIRO's partnership with Viet-UC accrue to Vietnam, Australia also gains indirect economic benefits through this partnership. In particular, this partnership has enabled CSIRO to develop its breeding techniques specifically to combat high levels of disease in prawn stocks. The lessons gained from CSIRO's work in Vietnam will be applied to the Australian prawn industry if a wave of disease strikes Australian prawn stocks, potentially narrowing the time between the outbreak of disease and the application of effective mitigation strategies.

Employment: The commercialisation of Novacq™ has provided extra employment opportunities at Ridley AgriProducts, which is licenced to sell the feed additive. There are seven full time equivalent (FTE) staff at Ridley directly associated with the sale of Novacq™.

Environmental impacts

CSIRO's R&D has significant environmental benefits

Protecting existing wild fish stocks: The most important environmental impact of CSIRO's prawn breeding and novel feeds projects is the independence of black tiger prawn aquaculture from wild fish and prawn populations. Novacq™ provides adequate nutrition to prawns when added to quality plant-based prawn feed, so there is no need to harvest wild fish in order to add fish meal and fish oil to prawn feed.

Improved sustainability: In addition, CSIRO's black tiger prawn domestication project has removed the need for prawn farmers to harvest wild prawns in order to provide broodstock for the next generation of prawns. Moreover, increased prawn yields per hectare means a smaller environmental footprint in terms of the size of prawn farms.

Social impacts

Access to better, cheaper prawns: The development of Novacq™ and CSIRO's prawn breeding project will make larger, healthier prawns available to Australian customers at a price that is more competitive compared to alternatives, such as imported shrimp.

More reliable income streams: Greater consistency of prawn production as a result of CSIRO's breeding project – in terms of consistency of prawn sizes, yield sizes, and lower levels of stock loss due to disease – may also help to increase food security and income security for vulnerable communities overseas, such as fishing and aquaculture communities in the Mekong Delta.

F.5.2 Potential future impacts

Ongoing research will extend the gains already delivered

CSIRO is undertaking ongoing research designed to extend the gains arising from its black tiger prawn breeding and novel feeds research projects. A major focus of this ongoing research is the development of vaccines against common prawn diseases. CSIRO has been successful in injecting double stranded RNA to prevent viral infections and is currently working on developing a coating for this RNA so that it can be co-delivered in Novacq™.(Sellars *et al*., 2011) CSIRO is confident that a breakthrough on this coating technology will occur, meaning that Novacq™ will be enhanced in the future with vaccination properties.

CSIRO has incorporated an environmental management system into its prawn breeding project in order to manage the emission of waste products from prawn farms. This could have a large impact on the siting of prawns, particularly in areas that are environmentally sensitive but highly suited to prawn aquaculture, such as near the Great Barrier Reef.

F.5.3 Cost Benefit Analysis

ACIL Allen has estimated that the total accrued benefits from this project over the period will be around $882.2 million (including royalties revenues) 2004/05 to 2023/24 that is attributable to CSIRO. More information on the breakdown of that benefit is provided in the sections that follow.

Prawn breeding

The rate of return from prawn breeding is almost 250 per cent

CSIRO's prawn breeding project has delivered total benefits of $73.5 million to Australia between 2004/05 and 2013/14 compared to total input costs of $16 million over the same period. Given that 75 per cent of the impacts of CSIRO's prawn breeding project are attributable to CSIRO (see Section F.4.3) the net benefits attributable to CSIRO are approximately $39.1 million. This suggests a return of 245 per cent over total input costs for CSIRO-attributable benefits.

ACIL Allen estimates that CSIRO's prawn breeding project will accrue additional benefits equal to $452.5 million over the period 2014/15 to 2023/24 under a 5 per cent discount rate, of which 75 per cent, or $339 million, are attributable to CSIRO.

Data used for the prawn breeding cost-benefit analysis is presented in Table F7 and Table F8.

ACIL Allen has drawn on CSIRO historical data and projections of total hectares under black tiger prawn aquaculture production, combined with average yields (in terms of tonnes per hectare) for wild-caught broodstock black tiger prawns (which is the counterfactual) versus domesticated black tiger prawns subject to CSIRO's breeding project.

According to CSIRO, prawn production area using the domesticated broodstock is expected to increase from 250 ha in 2013/14 to 700 ha in 2018/19 as adoption of such broodstock increases to 100 per cent of domestic prawn production. In the following five years (from 2018/19 to 2023/24), prawn production is expected to double from 700 ha to 1,400 ha with new prawn farming areas being established in Northern Australia. CSIRO anticipates that its domesticated broodstock will be used in all the additional prawn farms.

For the cost-benefit projection out to 2023/24, ACIL Allen has assumed no increase in yield productivity for either wild or domesticated black tiger prawns after 2013/14 (the latest year for which production data is available). ACIL Allen has based projections of increasing hectares of aquaculture under black tiger prawn production based on forecasts provided by CSIRO.

ACIL Allen has used historic farm-gate prawn prices (in dollars per tonne) in inform calculations of the total value of wild and domesticated prawn production and net benefits. For projections out to 2023/24 farm-gates prices have been frozen at $17,500/tonne in 2014/15 dollars, the farm-gate price in 2013/14, which is the latest year for which data is available.

Table F7 **Prawn breeding benefits**

Year	Area under production (domesticated)	Average yield wild	**Average yield domesticated**	Price	Value – wild	Value – domesticated	Increased production costs	Net benefit
	(ha)	(t/ha)	(t/ha)	($/t)	($)	($)	($)	($)
2004-05	3	4	5.5	15,000	180,000	247,500	32,130	**35,370**
2005-06	5	4	5.6	16,000	320,000	448,000	57,120	**70,880**
2006-07	3	4.2	5.9	16,000	201,600	283,200	36,414	**45,186**
2007-08	7	5.1	7.1	16,000	571,200	795,200	99,960	**124,040**
2008-09	10	6.2	10.5	17,000	1,054,000	1,785,000	307,020	**423,980**
2009-10	50	7.8	17.5	17,500	6,825,000	15,312,500	3,462,900	**5,024,600**
2010-11	150	7.8	15.5	17,500	20,475,000	40,687,500	8,246,700	**11,965,800**
2011-12	200	7.8	15.5	17,500	27,300,000	54,250,000	10,995,600	**15,954,400**
2012-13	250	7.8	15.5	17,500	34,125,000	67,812,500	13,744,500	**19,943,000**
2013-14	250	7.8	15.5	17,500	34,125,000	67,812,500	13,744,500	**19,943,000**
2014-15	307	7.8	15.5	17,500	41,928,012	83,318,484	16,887,313	**24,503,160**
2015-16	377	7.8	15.5	17,500	51,515,257	102,370,062	20,748,761	**30,106,045**
2016-17	464	7.8	15.5	17,500	63,294,719	125,777,968	25,493,165	**36,990,083**
2017-18	570	7.8	15.5	17,500	77,767,670	154,538,318	31,322,424	**45,448,224**
2018-19	700	7.8	15.5	17,500	95,550,000	189,875,000	38,484,600	**55,840,400**
2019-20	804	7.8	15.5	17,500	109,758,128	218,109,100	44,207,197	**64,143,776**
2020-21	924	7.8	15.5	17,500	126,078,981	250,541,565	50,780,734	**73,681,850**
2021-22	1061	7.8	15.5	17,500	144,826,718	287,796,683	58,331,746	**84,638,219**
2022/23	1,219	7.8	15.5	17,500	166,362,213	330,591,576	67,005,580	**97,223,783**
2023/24	1,400	7.8	15.5	17,500	191,100,000	379,750,000	76,969,200	**111,680,800**

Source: ACIL Allen Consulting, CSIRO

Total costs for the prawn breeding project (comprising CSIRO support, external cash co-invested support and external in-kind support) are equal to $16 million, as outlined in Table F8.

Table F8 **Prawn breeding costs**

Year	CSIRO support	External cash co-invested support	External in-kind support
	$ million	$ million	$ million
2004-05	1.20	.26	.09
2005-06	1.23	.25	.08
2006-07	1.22	.20	.07
2007-08	1.23	.35	.12
2008-09	1.25	.27	.09
2009-10	1.00	.16	.05
2010-11	1.20	.24	.08
2011-12	1.30	.37	.12
2012-13	1.20	.54	.18
2013-14	1.10	.40	.13
Total	**11.93**	**3.04**	**1.03**

Source: CSIRO

Prawn breeding + novel prawn feed

Novacq™ will deliver significant future benefits …

Novacq™ has not yet delivered additional value because it has only very recently been released onto the market. This means that total benefits from the combination of prawn breeding and novel prawn feeds (Novacq™) are between 2004/5 and 2013/14 are $73.5 million, all of which comes from prawn breeding. Given that 75 per cent of the impacts of CSIRO's prawn breeding project are attributable to CSIRO, the total benefits net of input costs that attributable to CSIRO are approximately $55.1 million. When the total cost of CSIRO's prawn breeding and novel feeds project are taken into account ($16 million plus $12.3 million), net benefits fall to $26.8 million in the period 2004/5 to 2013/14.

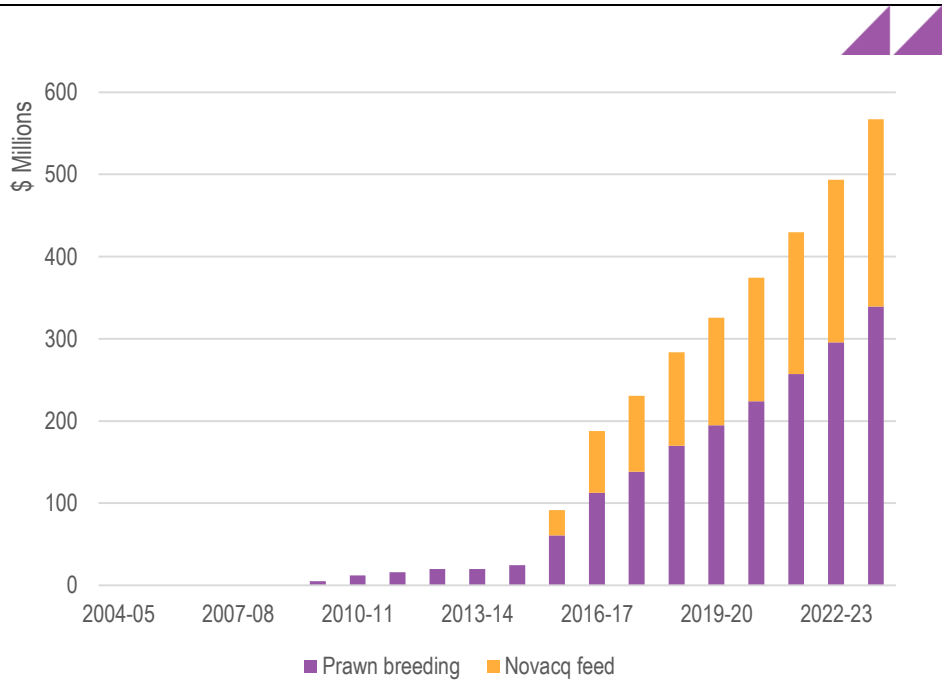
Novacq™ is expected to produce significant benefits in the 2014/15 to 2023/24 period. ACIL Allen forecasts suggest that incremental benefits from the use of novel prawn feed will be equal to $368.3 million over and above benefits gained from the use of CSIRO's breeding project over the same period, using a 5 per cent discount rate. In addition, CSIRO will earn roughly $101 million in royalties from the domestic and overseas sale of Novacq™.

… including around $100 million in royalties

Data underlying the prawn breeding cost-benefit analysis is presented in Tables F7 and F8, below.

For this analysis, area under black tiger prawn aquaculture production, wild broodstock average yield (in tonnes per hectare), farm-gate prices and total value of wild prawn production are consistent with Table F7, as these factors are not necessarily impacted by the use of Novacq™.

Figure F4 **Net benefits of prawn breeding versus prawn breeding + novel prawn feed**



Source: ACIL Allen Consulting; CSIRO

From 2015/16 to the end of the forecast period (2023/24), average yield of domesticated prawns (tonnes per hectare) increases based on information supplied to ACIL Allen by CSIRO. In particular, yields with Novacq™ (in conjunction with the use of domesticated broodstock) are expected to reach 22 t/ha. It is expected that full adoption of Novacq™ in all Australian prawn farms will be achieved by 2016-17. The average yield is therefore assumed to be 18.8 t/ha in 2014-15, 23.4 t/ha in 2025-16 and 22.0 t/ha from 2016/17 onwards.

According to CSIRO, Novacq™ will have a negligible impact on input costs per tonne which include the cost of feed, utilities and labour. It is assumed that input costs per tonne in real terms remain at $7,140 per tonne in 2014/15 dollars. Of course, total input costs will be higher than in the counterfactual because of the expected increase in yield (and hence production).

In Table F9, data on wild prawn yield (tonnes/ha) and farm-gate prices have been omitted, in order to ensure that the table is readable. This information, which has fed into the total benefits calculation in the final column, can be found in Table F7. The projected royalties

from Novacq™ shown in Table F9 are the combined royalties from both Australian and international licensees. The bulk of the royalties are expected to be from the latter.

Table F9 **Benefits of prawn breeding and novel feed**

Year	Area under production domesticated	**Average yield domesticated**	Value – wild	Value – domesticated	Increased production costs	Net benefit	Royalties from Novacq™	Total benefits
	ha	t/ha	$	$	$	$	$	$
2004-05	3	5.5	180,000	247,500	32,130	35,370	0	**35,370**
2005-06	5	5.6	320,000	448,000	57,120	70,880	0	**70,880**
2006-07	3	5.9	201,600	283,200	36,414	45,186	0	**45,186**
2007-08	7	7.1	571,200	795,200	99,960	124,040	0	**124,040**
2008-09	10	10.5	1,054,000	1,785,000	307,020	423,980	0	**423,980**
2009-10	50	17.5	6,825,000	15,312,500	3,462,900	5,024,600	0	**5,024,600**
2010-11	150	15.5	20,475,000	40,687,500	8,246,700	11,965,800	0	**11,965,800**
2011-12	200	15.5	27,300,000	54,250,000	10,995,600	15,954,400	0	**15,954,400**
2012-13	250	15.5	34,125,000	67,812,500	13,744,500	19,943,000	0	**19,943,000**
2013-14	250	15.5	34,125,000	67,812,500	13,744,500	19,943,000	0	**19,943,000**
2014-15	307	15.5	41,928,012	83,318,484	16,887,313	24,503,160	714,200	**25,217,360**
2015-16	377	18.8	51,515,257	123,834,753	29,506,354	42,813,141	1,151,800	**43,964,941**
2016-17	464	22.0	63,294,719	178,523,568	47,013,370	68,215,478	3,080,200	**71,295,678**
2017-18	570	22.0	77,767,670	219,344,709	57,763,432	83,813,607	6,011,700	**89,825,307**
2018-19	700	22.0	95,550,000	269,500,000	70,971,600	102,978,400	8,520,940	**111,499,340**
2019-20	804	22.0	109,758,128	309,574,207	81,524,960	118,291,119	11,844,622	**130,135,741**
2020-21	924	22.0	126,078,981	355,607,382	93,647,588	135,880,813	14,959,091	**150,839,905**
2021-22	1,061	22.0	144,826,718	408,485,615	107,572,830	156,086,067	17,458,069	**173,544,135**
2022-23	1,219	22.0	166,362,213	469,226,754	123,568,733	179,295,808	18,257,086	**197,552,895**
2023-24	1,400	22.0	191,100,000	539,000,000	141,943,200	205,956,800	19,225,829	**225,182,629**

Source: ACIL Allen Consulting; CSIRO

Total input costs for conducting the novel prawn feed project were $12.3 million, as shown in Table F10.

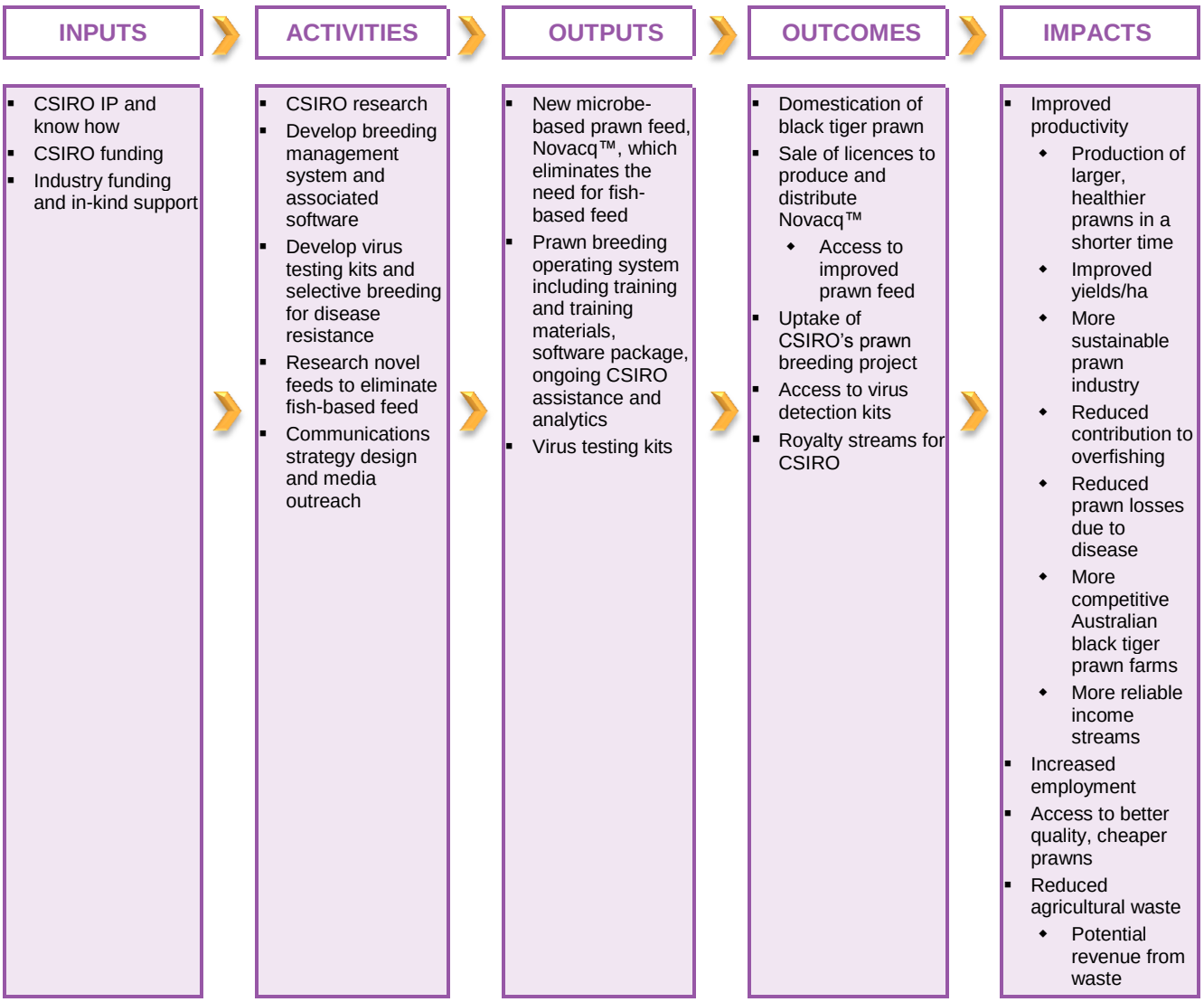
Table F10 **Novel prawn feeds costs**

Year	CSIRO support	External cash co-invested support	External in-kind support
	$ million	$ million	$ million
2004-05	0.85	0	0
2005-06	1.20	0	0
2006-07	1.35	0	0
2007-08	1.27	.2	.1
2008-09	1.40	.15	.07
2009-10	1.01	0	0
2010-11	0.80	0	0
2011-12	0.83	.4	.2
2012-13	0.99	.26	.13
2013-14	0.39	.50	.18
Total	**10.10**	**1.51**	**.69**

Source: CSIRO

Figure F5 presents CSIRO's impact evaluation framework diagram for its work on prawn breeding and feed.

Figure F5 **Aquaculture feed and prawn breeding – Impact evaluation diagram**



Source: ACIL Allen Consulting

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Appendix G Case study: Textor Technologies

SUMMARY OF KEY FINDINGS

- This case study provides a good example of how CSIRO assists small and medium sized enterprises (SMEs).
- The expertise provided by CSIRO played a critical role in the successful development of a new technology-based product at Textor Technologies.
- The new product will generate benefits for the parents of newborn babies in Australia and around the world.
- The 3D fabric technology has underpinned the successful expansion of the Textor business and helped it to grow its exports.
- While it is too early to determine the precise economic impact of the project, we have a high degree of confidence that the benefits of the project are at least an order of magnitude greater than its costs.

G.1 Introduction

G.1.1 Purpose and audience

This independent case study evaluation has been undertaken to assess the economic, social and environmental impact of CSIRO research into 3D nappy fabric undertaken with Textor Technologies. This case study may be used as a standalone report and also aggregated with other case studies to substantiate the impact and value of CSIRO's activities relative to the funds invested in those activities.

The report is provided for accountability, reporting, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, CSIRO and the general public.

G.1.2 Background

Approximately 300,000 babies are born in Australia each year. Around 40 per cent of these are born to first-time mothers. Research with first time mothers has indicated that one of their strongest challenges involves managing their young baby's very liquid bowel movements (Kimberly-Clark 2013). The market for disposable nappies for young babies in Australia is around $500 million per annum.

The modern disposable nappy is a complex and sophisticated product with breathable outer covers, highly absorbent material on the inside, and shape designed to suit gender. IBISWorld Australia estimated that, in 2009, 5.6 million disposable nappies were used every day in Australia.

Nappies have traditionally maintained the same flat shape over time. Children who are fed mainly liquids in their first six months are prone to very liquid bowel movements that would normally leave residues on their skin. Kimberly-Clark, a global household brands company that has manufactured nappies for many years, recognised that traditional nappies were not always able to sufficiently protect a child's skin.

This recognition coincided nicely with the development of a new 3D fabric developed by CSIRO in partnership with Textor Technologies. Textor's alliance with Kimberly-Clark enabled it to demonstrate relatively easily that by using this new fabric it was possible to

create a new nappy that better protected the health of a young child's skin.[14] Kimberly-Clark has now extended the use of the Textor liner to its nappy products for older babies.

G.1.3 Approach

The approach taken in this case study aligns with the nine-step process described in the CSIRO's impact evaluation guide namely:

1. Initial framing of the purpose and audience of the impact evaluation.
2. Identify nature of impacts (*what is the impact pathway, what are the costs and benefits*)
3. Define a realistic counterfactual (*what would have occurred in the absence of CSIRO*)
4. Attribution of research (*CSIRO vs. others' contribution*)
5. Adoption (*to date and in future*)
6. Impact (*timing, valuation, distributional effects among users, effects on non-users*)
7. Aggregation of research impacts (*within program of work*)
8. Aggregation of impacts (*across program of work*)
9. Sensitivity analysis and reporting.

Note that steps 7 and 8 above are less relevant for this individual case study as the Textor project is being considered in isolation. Of course, the aggregation of the impacts of all the case studies will occur in order to help estimate a lower bound for the value of CSIRO research activities.

G.1.4 Project origins and inputs

One of CSIRO's strategies is to apply its world-class knowledge and facilities to business in order to grow and maintain a strong Australian industry. A key component of CSIRO's plan to do this is to use its Small and Medium Enterprises (SME) Engagement Centre to facilitate connections between businesses and research organisations so that SMEs can develop and implement new ideas (CSIRO 2014). The goal of the SME Engagement Centre is:

> Assist small to medium Australian enterprises by identifying and connecting companies to technical expertise and resources, defining technical issues, developing research projects for industry and providing guidance around access to funding for research.[15]

The Government's *Researchers in Business* Program has supported this project

The SME Engagement Centre has aided over 100 projects via the Department of Industry's *Researchers in Business* (RIB) program (now *Research Connections*). The RIB program utilised resources from within CSIRO and other research organisations to enable the transfer of useful knowledge from researchers to companies participating in the program (CSIRO 2014).

This project has drawn on the expertise of the Future Manufacturing Flagship, whose goal is:

> To create $2 billion of additional annual value for Australia's manufacturing industry by 2025 through the development and application of resource efficient, clean and transformational technologies.

Textor Technologies has made significant investments in new technologies and plant

Textor Technologies, a Melbourne-based SME, was formed though a management buyout of an English textile company. It designs and manufactures highly specialised non-woven textiles that are engineered for specific purposes. These are low margin products which

[14] Textor Technologies has had an alliance with Kimberly-Clark since 2002.

[15] Portfolio Budget Statements 2014-15. Budget related paper no 1.12. Industry portfolio, page 196.

Textor manufactures in high volume (more than 100 million square metres per year) at a modern factory that operates 24 hours per day, seven days per week (Roberts, 2014).

The Textor factory is highly automated, with computers monitoring 4,000 separate points in the production process. Textor is reported to have invested $17 million in its plant in recent years (Roberts, 2014). Textor is a highly efficient company, with products made to order and shipped out the day they are made. Bales of the Textor product used by Kimberly-Clark are loaded directly into shipping containers.

Kimberly-Clark is a well-known global brand that is available in more than 175 countries. Every day, nearly a quarter of the world's population use one or more Kimberly-Clark products. Kimberly-Clark is first or second in terms of market share of its products in more than 80 countries. It has 57,000 employees around the globe. In Australia Kimberly-Clark is known for its leading consumer brands such as Kleenex and Huggies.

Project inputs

In 2010 a CSIRO scientist, Dr Niall Finn, started work in Textor's plant under the *Researchers in Business* (RIB) program. The funds provided to Textor under the RIB program were used to help meet the costs of the placement (primarily the researcher's time). Following the success of the first researchers in business program grant for FY 2009-10 a second researchers in business program grant was provided for FY 2010-11.

Table G1 outlines the financial contributions to the Textor project in the period 2009-14. Textor also paid for CSIRO's workshop to manufacture the special rotating drums Textor use to make the new product. CSIRO's workshop made the drums used in both the pilot plant and the full scale plant currently being used at the Textor factory. The total cost of the CSIRO workshop's contribution to the technology is around $38,000 to date.

Textor Technologies also invested its own funds to develop this innovation. This included the time of Textor personnel and the cost of test runs on the Textor production line. In addition, the production line was modified and its speed increased.

Table G1 **Textor project — financial contributions 2009–14**

Financial year	CSIRO expenditure (science, testing and machining)	Revenue from RIB	Textor payments to CSIRO	CSIRO funds
2009-10	$210,000	$50,000	$50,029	$109,971
2010-11	$220,000	$50,000	$57,000	$113,000
2011-12	$249,000		$87,394	$161,606
2012-13	$256,000		$130,029	$125,971
2013-14	$259,000		$126,385	$132,615
Total	*$1,194,000*	*$100,000*	*$450,837*	*$643,163*

Source: ACIL Allen Consulting and CSIRO

In this project, the CSIRO team drew on expertise and facilities at its Geelong site

This project made use of the non-woven textiles pilot facilities at CSIRO Materials Science and Engineering at Geelong, in particular the hydro-entanglement line which was purchased by CSIRO in 2002 for about $500,000. This equipment is "close to manufacturing scale", which saved Textor having to divert its production line equipment to do early stage investigation in the development of the new product (Balinski, 2013).

CSIRO also used its pilot scale nonwoven carding equipment and various textile finishing machines for applying chemical treatments curing and drying etc. None of this equipment was purchased specifically for the project.

Textor paid for various components so that the CSIRO system could be upgraded for higher speeds and also for modifications needed in the development of the new process. These modifications were used to provide the engineering knowledge needed to increase the production speeds on Textor's production machines.

Other CSIRO equipment and capabilities used included Dynamic Mechanical Thermal analysis for material properties analysis, infra-red spectroscopy, differential scanning calorimeter and various other materials analysis tools. Also various Textile Testing Laboratory tests were carried out, some of which were paid for by Textor.

G.2 Project activities

Textor had a well-established relationship with CSIRO prior to the start of this project. CSIRO staff in Geelong had experience in working with textiles and had equipment which was used to pilot the production of the new Textor product. This helped to de-risk the project (Balinski, 2013).

In 2010 Textor Technologies learnt of the *Researchers in Bus*iness Program while attending an Industry Association function. CSIRO's SME Engagement Centre helped to develop the funding application, grant agreement and researcher placement agreement which defined the project and funding arrangements. Shortly afterwards Dr Niall Finn from CSIRO began working at Textor technologies' premises in Tullamarine for three days a week. The fact that Textor had worked with Dr Finn previously was an additional factor that helped facilitate the establishment of this arrangement (Textor Technologies, 2014).

Having a committed and motivated researcher is important to the success of these projects

Dr Finn's expertise enabled him to help Textor to develop fabrics with specifically tailored properties. In this case, his expertise was specifically applied to developing a fabric product which, when used in nappies, could make them softer and keep the wearer drier for longer periods. In addition, Dr Finn's expertise enabled him to help ensure that these fabrics could be manufactured using the high throughput manufacturing processes required to make the use of the technology commercially viable (CSIRO 2012).

CSIRO's Dr Finn was fully integrated into Textor's business

Textor adopts an open book management policy that allows all employees access to information in relation to the company's finances, including its profits. Textor applied the same policies to Dr Finn who became fully integrated into the business.

Textor continued their relationship with Dr Finn on conclusion of the *Researchers in Business Program* on a commercial basis. The relationship generated useful research and development (R&D) that led to significantly more absorbent textiles that were relatively more comfortable for consumers who use them. The R&D also allowed for the large-scale commercial production of the new textiles (Textor Technologies, 2014).

Textor and Dr Finn's research was focused on developing a composite 3D fabric. The initial textile prototypes were visually similar to the surface appearance of an egg-carton, due to their distinct and multiple peaks and troughs. Trials with the prototype showed that by using the 3D structure in a child's nappy it would help speed the absorption of fluid bowel movements into the body of the nappy and keep them away from the child's skin.

G.3 Project outputs

G.3.1 Key outputs of the project

The eventual output of the R&D on this project was a technology for creating a three dimensional (3D) fabric that allowed Kimberly-Clark to launch a proprietary innovation in nappies.

The 3D liner will have benefits for the parents of newborn babies in Australia and around the world

Irene Anast, Marketing Sector Leader - Baby & Child Care, Kimberly-Clark Australia, has stated that of all the innovative consumer led features that have been developed for Huggies Newborn Nappies, the 3D UltraAbsorb layer is particularly exciting as it helps parents overcome the challenge of managing the liquid bowel movements associated with newborn and infant babies before they start having solid foods.

> This is an innovation so unique that we truly believe it will change the game of what a nappy can deliver. We've experienced fantastic results from mums who tested the new nappy, which tells us just how much this innovation will mean to them and their babies.
>
> We're particularly proud of how this innovation has been born locally in Australia through a very successful collaboration between Kimberly-Clark, our long time supplier Textor and the CSIRO (Kimberly Clark, 2014, pers. comm.).

With Kimberly-Clark's world-wide market reach, the scope for Textor to increase its production of the innovative fabric is considerable.

G.3.2 Awards and public recognition

In 2011 Textor was recognised by Kimberly-Clark as its Global Supplier of the Year, due to the success of the Textor product in the 3D UltraAbsorb Huggies Nappy.

Both Textor and Dr Finn have been recognised for their innovative work

In August 2014 Textor Technologies was awarded a medal at the annual Australasian Industrial Research Group (AIRG) awards. The medal acknowledged the innovative methods used to produce the 3D fabric, which CSIRO co-developed with Textor Technologies.

In October 2014 Niall Finn was awarded the CSIRO Ian McLennan Achievement for Industry Award for his leadership of the Textor Technologies and the CSIRO 3D Nappy Liner Team. This Award is made every two years, recognising outstanding contributions by CSIRO scientists and engineers to national development.

G.4 Status of Outcomes and Impacts

G.4.1 Nature of Outcomes and Impacts

CSIRO's partnership with Textor via the *Researchers in Business* Program and secondment of Dr Finn has generated a range of outcomes and impacts. These are summarised in Table G2. In line with the CSIRO's triple bottom line approach to classifying benefits, the Table categorises the outcomes and impacts as social, environmental or economic.

Table G2 **CSIRO Textor project outcomes and impacts**

Impact	Detail
Social impact	
Happier parents and babies *Reach: National, Global* *Impact: Life & Health, Standard of Living*	Parents have access to a nappy that can better deal with their baby's fluid bowel movements and protect the health of their baby's skin. This lead to reduced liquid bowel movement cleaning for parents and calmer babies
Health benefits *Reach: National, Global* *Impact: Life & Health*	The unique 3D UltraAbsorb layer absorbs and contains baby's runny bowel movements and minimises the spread within the nappy, leaving the baby's skin noticeably cleaner, more protected and more comfortable.
Employment *Reach: Industry* *Impact: The micro economy*	Textor currently employ some 50 staff. It is probable that many of these jobs would not have existed without the new 3D fabric developed in partnership with CSIRO. Textor has needed to upgrade the skills of its operators and has shifted its hiring policy generally to focus on STEM capability. Textor is less likely to be viable without the technology developed as part of this project. The implementation of the technology has encouraged Textor to upskill jobs and increase the number of graduates from the STEM disciplines.
Economic impact	
Product innovation *Reach: National, Global* *Impact: New products or services*	The development of the 3D fabric has enabled Kimberly-Clark to bring a new world-class product innovation to market, which will benefit sales and market share, as well as further differentiate Huggies as the market leader
Increased Profitability *Reach: National, Global* *Impact: Management and productivity*	The partnership with CSIRO enhanced Textor's production processes and will result in a doubling of business turnover. The focus of the business has changed from servicing the local markets in a range of general applications to being the best in the world in fluid transfer materials.
Export opportunities *Reach: National, Global* *Impact: international trade*	Textor is currently exporting around 70 per cent of its output from the Tullamarine site to most countries throughout the world. Kimberly-Clark has facilitated these supply contracts for their various nappy production facilities. Kimberly-Clark is exporting this Australian developed innovation into six other markets at this stage.
Environmental impact	
Waste disposal *Reach: National, Global* *Impact: Land quality and management*	While the relative environmental impact of using disposable nappies has been the subject of some argument, a recent study indicates that the view among some that disposable nappies are less environmentally friendly than reusable nappies may be incorrect. A major Government sponsored and independently reviewed study in the United Kingdom in 2005 (Aumônier and Collins 2005), which was updated in (Aumônier *et al* 2008) assessed a wide range of activities associated with manufacture, use and disposal of disposable and reusable nappies which can affect the environment. The 2008 report concluded that: *The environmental impacts of using shaped reusable nappies can be higher or lower than using disposables, depending on how they are laundered. The report shows that, in contrast to the use of disposable nappies, it is consumers' behaviour after purchase that determines most of the impacts from reusable nappies.*

Source: ACIL Allen Consulting, Australian Financial Review 2012, Aumônier and Collins 2005, Aumônier *et al* 2008.

The main result of this project has been the expansion of Textor's capabilities to develop textiles that are considerably more absorbent and comfortable for the consumer and can be produced efficiently in large quantities. In addition, the improvements to Textor's production process in creating higher quality fabrics have enabled it to expand production and improved its competitive advantage over its rivals (CSIRO, 2013). Textor currently employs around fifty personnel (Balinski, 2014).

There are six patents covering the new 3D fabric technology, all of which are held by Kimberly-Clark.

The main beneficiaries of this project are Textor Technologies, Kimberly-Clark, babies using the nappies and the parents of those babies. CSIRO and the *Researchers in Business* program have also benefited from the project.

Textor Technologies have benefitted from the partnership with CSIRO through improvements to their production processes. The fabric technology is being progressively incorporated into the millions of nappies Kimberly-Clark produces annually in Sydney. In addition, 70 per cent of Textor's product is exported to Kimberly-Clark plants in the region (Roberts, 2014). This has helped Textor to double its turnover and improve its profits.

Kimberly-Clark's market presence around the world will ensure wide uptake of this new technology

Kimberly-Clark has benefitted from their alliance with Textor by obtaining new and innovative intellectual property, which they are able to market globally. In Kimberly-Clark's testing, the new product received never-seen-before preference scores – 73 per cent of Huggies users preferred the new product over their current Huggies nappy. The consumer preference continued once launched into market, with the innovation driving strong business results.

This project is a good example of how engagement with CSIRO can be advantageous to SMEs

Finally, the *Researchers in Business* Program has benefitted from this project as it provides an excellent example of what can be achieved through the placement of a CSIRO researcher in an SME. CSIRO's reputation has also benefitted through the conduct of a very successful project with an SME. CSIRO has, through this project, demonstrated its ability to assist an SME with capabilities that often do not exist in such firms.

G.4.2 Counterfactual

If CSIRO and Textor had not undertaken this project, Textor would not have achieved the growth in its business and users of disposable nappies would be continuing to use a less satisfactory product. It will be difficult for Kimberly-Clark's competitors to match the success of the 3D UltraAbsorb product given that a strong intellectual property position has been established.

In the absence of the new technology there is a real possibility that Textor's business would have contracted to the point where its ongoing financial viability could have been threatened.

G.4.3 Attribution

The expertise provided by CSIRO was critical to the development of the 3D fabric

Textor's partnership with CSIRO significantly improved the former's production processes, turnover and notably led to the development of the new lining used by Kimberly-Clark in their latest range of nappies. CSIRO, through Dr Finn, provided critical inputs and innovation to the success of the project.

The development of the technology used in the new nappies provides an excellent example of how CSIRO works effectively with different levels of industry in order to deliver innovation and improve competitiveness. In this case, each of the three parties brought crucial elements to the table to help ensure the successful development and deployment of the technology. Contributions from each of these parties included:

- *CSIRO* brought their scientific expertise in textile technology, pilot-scale processing facilities, and their high end mechanical fabrication capability to bear on the project.
- *Textor* made major investments (in time and equipment) and provided the capability to rapidly scale up and test the technology at high levels of production.
- *Kimberly-Clark* invested in a strong promotional and marketing program to promote the 3D technology in the nappies. This investment enabled the rapid deployment of the

technology in the market place, and expanded the Australian innovation into other Kimberly-Clark markets around the world.

Based on the above, ACIL Allen proposes that the attribution of identified benefits for this case study should be split evenly between CSIRO, Textor Technologies and Kimberly-Clark.

G.4.4 Adoption

Adoption of the technology has been very rapid

Adoption rates have been high. The fact that the market testing was quick to reveal strong consumer preferences for the product would of course have helped drive that rapid adoption rate.

Kimberly-Clark has already launched the new nappy in other countries, including in the US and Russia. One source reports that total sales of disposable nappies in Australia grew by $8 million in 2013 and Kimberly-Clark was the biggest contributor to this growth. The strongest value growth of 2 per cent was reported to be in the product for newborn babies. However, this could be attributed, at least in part, to a growth in Australia's birth rate (Euromonitor, 2014). Because the new Huggies product has only recently been rolled out across the globe, it is too early to report the results.

Exports account for 70% of Textor's production

Textor is already exporting around 70 per cent of its production of their 3D nappy liner fabric to Kimberly-Clark plants overseas. Textor is actively considering expanding production to accommodate the growing global demand for the material.

G.5 Assessment of impacts

G.5.1 Impacts to date

It is too early to assess the economic impact of the new product

The economic impact of the creation of a new product has largely occurred since March 2013, when the new Huggies nappy range came on the market. Improvements in management and productivity at Textor occurred soon after Dr Finn's placement from CSIRO.

G.5.2 Potential future impacts

As Textor increases its production and Kimberly-Clark starts to produce product with the 3D layer in other markets, the economic impacts can be expected to grow. Current production of 3D fabric is expected to double over the next two years when the capacity of the current equipment will be limited. The business is actively looking to expansion options depending on future global demand.[16]

Textor is continuing to work with CSIRO and further innovations can be anticipated, as Balinski from Manufacturers' Monthly noted:

> Textor is already thinking about generation two and three (Balinski, 2014)

G.5.3 Cost Benefit Analysis

The data needed for a CBA is commercially confidential

ACIL Allen was unable to prepare a formal cost benefit analysis for the Textor case study. The main reason for this is that it is still too early to be able to judge what the financial returns to the companies from the technology are. However, even if that were not the case, we understand that both firms regard the figures on commercial returns as highly commercially confidential are not prepared to make them available.

[16] Personal communication with Textor.

However the benefits of this project are likely to be orders of magnitude more than its costs

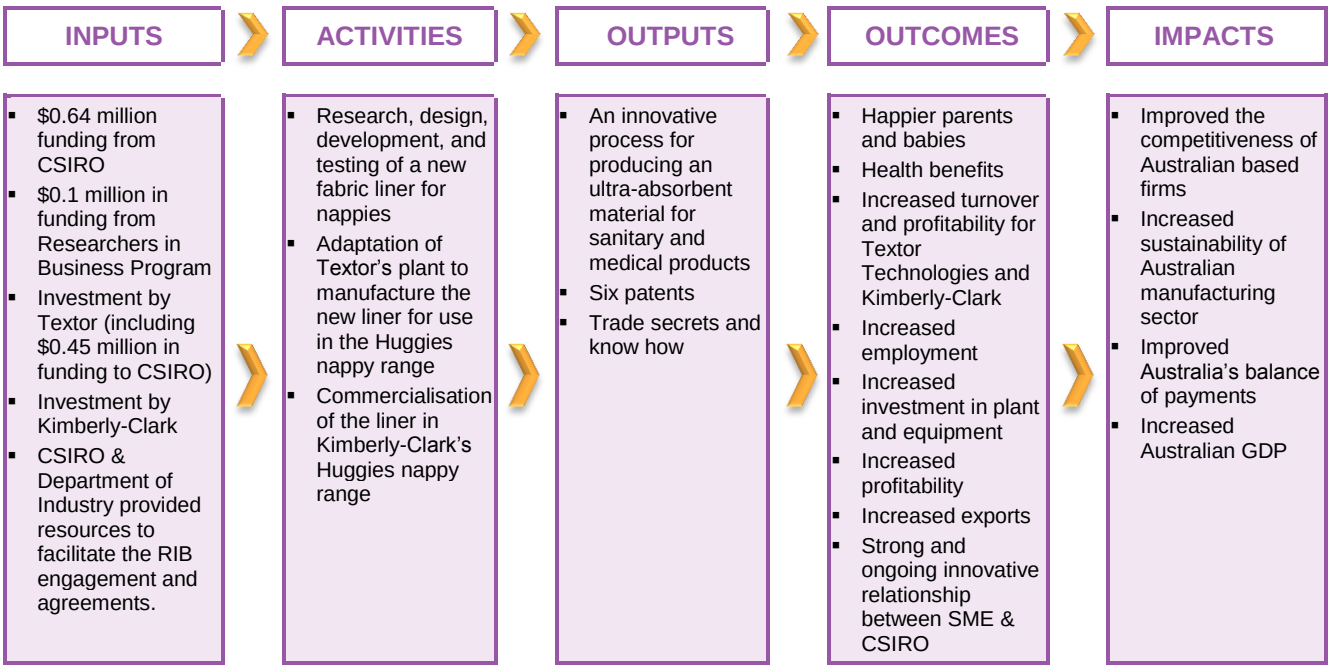
The costs to CSIRO were approximately around $643,000. The Australian Financial Review reported in February 2012 (before the expansion resulting from this project) that Textor's turnover was reported to be $22 million (AFR 2012). As noted earlier, it is possible that in the absence of this CSIRO developed technology Textor's financial viability could have been threatened. Because Textor is not a public company, its turnover and profits are not publicly disclosed. However, the benefits achieved by Textor from this project are likely to be at least of the order of the firm's turnover, i.e. in the tens of millions of dollars.

Kimberly-Clark is a large multi-national corporation with an extensive product range. Kimberly-Clark does not report its performance by product range. The corporation's most recent annual report referred to the new Huggies nappy as one of the highlights for 2013.

G.5.4 Impact pathway diagram

Figure 6 presents the impact framework diagram for CSIRO's work on 3D fabrics in collaboration with Textor Technologies.

Figure G1 **Textor project – impact**



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Appendix H Case study: Integrated water resource assessments

SUMMARY OF KEY FINDINGS

- For the first time, Australia has systematically developed and applied a nationally consistent framework for assessing water resources and water availability under changing climatic conditions, covering roughly 72 per cent of total water for agricultural use.
- The key findings, tools and methodologies developed under CSIRO's integrated water resource assessments (WRAs) provide a basis for responsible water resource management by allowing water managers to make better informed decisions about current and future trade-offs between different water users (both human users and water for environmental use). This generates more efficient water usage over the long-term and it helps water managers avoid investments with large unexpected future economic and environmental costs.
- The assessments have delivered significant economic and environmental value. We conservatively estimate that CSIRO has likely delivered benefits of around $685-795 million in present value terms, although our analysis also shows that benefits from these two decisions may be as high as $1.24 billion present value. These estimates are based upon our analysis of just two major water management decisions (sustainable diversion limits in the Murray-Darling Basin and the construction of irrigation schemes across Tasmania) that arose as a result of two water resource assessments that together formed only 30 per cent of the total research budget.
  - In reality, CSIRO's WRAs have been incorporated into many other water management and investment decisions across Australia, not just the two decision for which benefits have been costed in this case study. As a result, total environmental and economic benefits are likely to be significantly higher than $685-795 million at a conservative estimate, and potentially in excess $1.24 billion.
- This suggests a return on research ($54.2 million) of roughly 12 to 1, if the lower estimate of $625-735 million in benefits is used, and a return on research costs of almost 30 to 1, if the higher estimate of $1.24 billion in benefits is used..

H.1 Introduction

H.1.1 Purpose and audience

This independent case study evaluation has been undertaken to assess the economic, social and environmental impacts of CSIRO's integrated water resource assessments (WRAs). This case study has been prepared so it can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of CSIRO's activities.

The report is provided for accountability, reporting, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, CSIRO and the general public.

H.1.2 Background

Water demand continues to rise in Australia due to population growth and the expansion of industries such as agriculture and mining. Australia's aridity and the high variability of water runoff from year to year means that large dams, river regulation and water distribution systems are required to ensure reliable water supplies. In some areas, water resources

have been over-allocated and high levels of water use have caused unacceptable levels of environmental degradation and, in some cases, severe water rationing.

Australia faces rising water supply insecurity, and a pressing need to better understand current and future water supply

Water resources were severely strained during the 1997-2009 drought in south-eastern Australia – the source of Australia's largest proportion of food production and the area of greatest population density – resulting in drastic rationing of water use and extensive environmental degradation. Given that most of Australia's water use is concentrated in south-eastern Australia, the drought had a substantial economic, environmental and social impact. While the drought was broken by two summers of flooding in eastern Australia, dry conditions in other parts of the year have persisted and drought has returned to some areas. In Australia's south-west, the drought was just one episode in a larger 35-year trend of declining rainfall levels (CSIRO, 2008).

Going forward, Australia's water resources are expected to face the additional burden of expanding agricultural and minerals production combined with drier overall climatic conditions across the continent due to climate change. The means that Australia will need to develop more resilient water management systems underpinned by robust water resource assessments, in order to withstand the recurrence of shocks such as the millennium drought.

H.1.3 Approach

This approach taken in this case study is based on CSIRO's impact framework and aligns with the nine-step process described in the CSIRO's impact evaluation guide, namely:

1. Initial framing of the purpose and audience of the impact evaluation.
2. Identify nature of impacts (*what is the impact pathway, what are the costs and benefits*)
3. Define a realistic counterfactual (*what would have occurred in the absence of CSIRO*)
4. Attribution of research (*CSIRO vs. others' contribution*)
5. Adoption (*to date and in future*)
6. Impact (*timing, valuation, distributional effects among users, effects on non-users*)
7. Aggregation of research impacts (*within program of work*)
8. Aggregation of impacts (*across program of work*)
9. Sensitivity analysis and reporting.

Note that steps 7 and 8 above are less relevant for this individual case study as the integrated water resources assessment program is being considered in isolation. However, the results of this individual case study have fed into the synthesis report in order to estimate a lower bound of the total value of CSIRO.

H.1.4 Program origins and inputs

The objective of CSIRO's Water for a Healthy Country Flagship, under which the water resources assessments analysed in this case study took place, is as follows:

> Consistent with Australia's national interest, the Flagship will develop science and technologies that improve the social, economic and environmental outcomes from water, and deliver $3 billion per year in net benefits for Australia by 2030 (CSIRO, 2013b).

CSIRO's WRAs have been a key component of achieving this overall Flagship goal. Water resource assessments are studies undertaken by CSIRO in a number of Australia's major river and underground water basins, which seek to assess current and future water supply under changing climate conditions. The assessments aim to provide the knowledge, tools and information necessary to make water management decisions that can take current and

future regional water balances into account. By enabling water managers to make decisions based on a stronger information base, the WRAs contribute to water management and investment decisions that can deliver higher and more reliable economic returns and better outcomes for the environment over the long-term. This is possible because the tools and information contained within the WRAs provide a basis for water managers to more effectively manage the trade-offs between short-term and long-term economic gains, protecting environmental flows and ecological habitats, and protecting water resources that have cultural and aesthetic value.

History of the program

CSIRO has a long history of scientific research aimed at understanding and better managing Australia's water resources. Research that currently falls under the Land and Water Flagship was previously under the Water for a Healthy Country Flagship, and other parts of the organisation before that. The water resources assessments surveyed in this case study took place between 2006 and 2013.

WRAs began as part of the Howard government's response to a water supply crisis during the millennium drought

CSIRO's water resource assessments began in 2006, when the then-Prime Minister John Howard called on CSIRO to conduct a sustainable yields assessment of the Murray Darling Basin at a time when Australia's food bowl was in the grips of the millennium drought. As the severity and length of the drought deepened, conflict over water resources in the Murray-Darling Basin intensified and water sharing arrangements ceased. Prime Minister John Howard called upon CSIRO to carry out an independent, scientific and transparent study of current and future water supply in the Murray-Darling Basin to underpin the creation of a new water management plan – the Murray-Darling Basin Plan.

The Murray-Darling Basin Sustainable Yields (MDBSY) Project began in 2006. The tools, methodologies and capabilities developed in the course of MDBSY and a related project, the South-Eastern Australian Climate Initiative, were then adapted and applied to sustainable yields projects in three other areas of Australia (northern Australia, south-west Western Australia and Tasmania), after the Council of Australian Government (COAG) highlighted the need to better understand water resources and water development constraints and opportunities in key regions around Australia. Following this, the techniques and experience gained as a result of four sustainable yields assessments were extended and applied to the Great Artesian Basin, and the Flinders River and Gilbert River catchments in north Queensland. Together, these seven projects form the focus of our analysis in this case study.

Over the course of these seven water resource assessments, CSIRO gradually built up a core set of capabilities that enabled it to conduct thorough and robust assessments of current and future water availability across many regions of Australia. In some of these project, such as the Flinders and Gilbert Agricultural Resources Assessment, this core set of capabilities was extended so that CSIRO was able to assess water supply and water infrastructure development.

While ensuring long-term balance between water supply and demand is a well-established principle, Australia was until recently a sparsely monitored area and the ability to quantify key terms in the water balance and provide reliable estimates over time was lacking. This lack of basic data and analysis was previously a major hurdle for water managers and government policy makers as they sought to make equitable decisions about water infrastructure, allocation and use that would yield sustainable water supplies over the long-term. In some areas, such as the Murray-Darling Basin, lack of information also contributed to friction and disagreement over water management between different users. This lack of current and future water resource data and information in many key areas of regional

Australia – and the large barrier this has created to effective, well-informed water management decision-making – is the gap that CSIRO's WRAs have sought to fill.

Project inputs

Total funding for the six assessments covered in this case study was:

- CSIRO funding equal to $6.5 million over eight years
- External funding equal to $47.7 million over eight years

Funding for the projects covered in this case study provided by external partners is highlighted below:

Table H1 **Significant contributions by external partners**

Project	Sources of revenue	Revenue
Australian and state governments	South Eastern Australian Climate Initiative	$7.9 million
Australian Government	Murray Darling Sustainable Yields Project	$12 million
Australian Government	Great Artesian Basin Water Resource Assessment	$6.3 million
Australian and state governments	Northern Australia Sustainable Yields Project	$5.9 million
Australian and state governments	South-West Western Australia Sustainable Yields Project	$5.2 million
Australian and state governments	Tasmania Sustainable Yields	$4.2 million
Australian and state governments	Flinders and Gilbert Agricultural Resource Assessment	$6.2 million

Source: CSIRO

H.2 Program activities

In the period 2006 to 2013, CSIRO undertook six water resources assessments focusing on different parts of regional Australia, as well as the South Eastern Australian Climate Initiative.

CSIRO has built up capabilities needed to develop and apply a nationally consistent water resource assessment framework

As a result of the cumulative capabilities built up through these projects, Australia has systematically developed and applied a nationally consistent framework for assessing water resources and water availability under changing climatic conditions to serve as a basis for responsible water resource management.

Each of these projects has seen techniques and methodologies originally applied to the Murray-Darling Basin Sustainable Yields Project, the first of CSIRO's water resource assessments, adapted for regional conditions and varying levels of data availability. Each project has also yielded new techniques and methodologies that have both improved CSIRO's integrated water resource assessment capabilities, and allowed the WRAs to be applied to a greater range of areas.

In the following summary of each of the water resource assessments undertaken and completed between 2006 and 2013, sub-sections labelled 'the issues' outlines what problems necessitated an integrated water resource assessment, 'project focus' outlines what each assessment consisted of and what activities were undertaken, and 'significance' outlines how each project contributed new tools and methodologies to CSIRO's integrated water resource assessment and analysis capabilities.

H.2.1 South Eastern Australian Climate Initiative (SEACI) – generating foundation knowledge

The issues: From 1997 to 2009 south-eastern Australia was gripped by one of the most extreme and long-lived droughts on record, which inflicted large damage to the region in terms of agricultural production and ecological degradation. While there was significant speculation at the time about the relationship between the millennium drought and climate change, and whether droughts of this kind would become a recurring feature of south-eastern Australia's climate, there was a need for a comprehensive study to address these questions in a scientifically rigorous way.

Project focus: The South Eastern Australian Climate Initiative (SEACI) was a six-year research program that ran from 2006 to 2012 and aimed to better understand the impacts and drivers of climate change and climate variability on water resources in south-eastern Australia. SEACI sought to achieve this by placing extreme events into historical context, and developing improved seasonal and long term projections of future climate and water availability.

Significance: SEACI produced foundation knowledge and a number of methodological breakthroughs that were critical to the development of subsequent integrated water resource assessments.

SEACI demonstrated that robust water availability forecasts are impossible absent climate change modelling

SEACI established climate change scenarios (based upon broader Intergovernmental Panel on Climate Change [IPCC] global climate scenarios) and water supply forecasting methodologies that would be refined, tailored and applied to other water resource assessments and sustainable yields assessments. SEACI also made significant improvements to existing models such as the Predictive Ocean Atmosphere Model for Australia (POAMA) (CSIRO, 2012).

SEACI delivered greater confidence and understanding as to the anthropogenic causes of climate events in the region (CSIRO, 2013b). Importantly, SEACI demonstrated that historical water supply data can no longer be considered to be a reliable basis for forecasting future water supplies and water flow patterns. The experience of the millennium drought underlined the findings of SEACI: that a robust forecast of water supply is impossible absent detailed climate change scenarios and modelling (SEACI, n.d.).

H.2.2 Murray-Darling Basin Sustainable Yields (MDBSY) – the nation's first integrated, basin-wide water resource assessment

The issues: Former Prime Minister John Howard called on CSIRO to undertake its first 'sustainable yields' assessment in response to a water scarcity crisis in Australia's food bowl. The Murray-Darling Basin generates roughly 40 per cent of the gross value of Australia's agricultural production (CSIRO 2008b). However during the 1997-2009 millennium drought, water availability fell significantly and water sharing plans were suspended as upstream irrigators came into conflict with downstream irrigators. The millennium drought also exacerbated a longer-term decline in the ecological health of the basin, reflecting the fact that a very high proportion of water resources have been extracted for consumptive use over many decades. In 2008, only one of the 23 river valleys in the basin was in 'good' ecological condition, and the basin was characterised by a long-term decline in waterbird population health, floodplain vegetation and native fish (CSIRO, 2012b).

By the time that Howard initiated CSIRO's assessment of the Murray-Darling Basin in 2006, it was clear that water resources management plans in place at the time had failed to successfully adapt to the extreme dry conditions of the millennium drought, and that a

thorough, scientific assessment of current and future water availability, carried out by an independent and trusted scientific research body, was needed to underpin a new water management plan in the Murray-Darling Basin.

Project focus: MDBSY project ran from 2006 to 2008 and involved the development of methodologies for determining the extent of current and future water resources available in the basin. The assessment of water availability and demand in the area factored in scenarios for future catchment development, groundwater extraction and climatic conditions to 2030. This was achieved using four scenarios of future development based upon:

- historic climate and current water development (i.e. human water consumption associated with the development of water usage infrastructure such as farm dams, plantations, groundwater systems and proposed irrigation development);
- historic climate for the last ten years and current water development;
- climate change forecasts to 2030 and current development, and;
- climate change forecasts to 2030 and projections of water development to 2030.

For each scenario, the MDBSY project provided an assessment of the impact and current and future predicted water resource development of key environmental assets.

The project involved development, integration and application of new hydrological models, water data collection and involved the building of effective teams across disciplines and organisations, including partnerships between CSIRO and industry.

Significance: The MDBSY project was the first of CSIRO's water resource assessments, involving the development of water resource assessment tools, methodologies and capabilities that underpinned all subsequent water resource assessments.

MDBSY tools and methodologies formed the foundation for subsequent WRAs

This was the first time that CSIRO had engaged in research that assessed how rainfall is linked to runoff, headwater region river flows, extraction of water for irrigation or other uses, and watering of wetlands and downstream flows, all the way to the river mouth. As such, it was the most comprehensive Basin-wide assessment of water availability ever undertaken. Due to the richness of existing water data in the area, CSIRO was able to provide detailed basin-wide information on current and future water balances by linking climate, groundwater, surface water and surface water-groundwater interaction models, and adapting new and existing models to have the same time-steps and time-periods (CSIRO, 2013b).

The MDBSY also triggered several new innovations that have proven important for measuring and analysing surface water-groundwater interactions and flows. These innovations included:

- Defining a criterion for rivers that have become disconnected from groundwater sources that previously recharged those rivers;
- Providing guidelines to improve the identification and modelling of rivers that are recharging groundwater (rather than the other way around);
- Developing field research approaches to determine the state of connectivity between groundwater sources and rivers (CSIRO 2013b).

CSIRO also demonstrated that climate change is already having a strong impact on water supply and water flow in the Murray Darling Basin, reinforcing the conclusions of SEACI, that climate modelling is needed in conjunction with analysis of historic trends to produce robust climate and water supply forecasts. In particular, the project demonstrated that the millennium drought was worse than previous droughts, and that the traditional autumn and winter 'filling season' (i.e. the traditional season of greater rainfall and filling of dams) saw far

less rainfall and higher temperatures. Changes in runoff amplified this, resulting in lower overall water supply (CSIRO, 2013b).

H.2.3 Northern Australia Sustainable Yields (NASY) – busting the myth of "excess water"

The issues: Northern Australia is characterised by high overall rainfall unevenly spread over very wet monsoon months and very dry winter months, tropical environments and relatively low levels of development. Less than 1 per cent of the total area of the North-East Sea, Gulf of Carpentaria and Timor Sea Drainage Divisions has been cleared and used intensively, with the rest of the area dedicated to pastoralism, nature conservation, indigenous land use, mining and forestry (CSIRO, 2009b). While high rainfall levels would seem to suggest that there are opportunities for greater development of the region's agricultural potential, a lack of information about current and future water supply patterns in northern Australia has made assessing the region's development potential very difficult, particularly in terms of the possible expansion of irrigated agriculture.

Moreover, there is a perception that has been reflected in the popular press in the past (and particularly during the millennium drought) that the north of Australia has a water surplus, and that some of this water should be delivered to the southern states, who suffered large water shortages in the period 1997-2009 (CSIRO, 2009a). In the absence of a scientific understanding of Northern Australia's water balance, the viability of such water diversion proposals could not be properly assessed.

Project focus: The NASY project was initiated by COAG in March 2008 and ended in 2009. It assessed past, present and possible future water resources for each of the 13 regions across three drainage divisions in northern Australia. The NASY was part of the larger Northern Australia Water Futures Assessment, which was managed by northern state governments. The project assessed current and future water supply under the four scenarios (outlined above the description of the MDBSY) for three drainage divisions: the Gulf of Carpentaria Drainage Division, the Timor Sea Drainage Division and the Northern North-East Coast Drainage Division, which together encompass the north coasts of Queensland, the Northern Territory and Western Australia (CSIRO 2013d). While no new data was collected for the project, as the NASY was largely a desktop study, new data was generated through numerical modelling using existing data as a base, and new interpretations of existing data were undertaken (CSIRO, 2009b).

The NASY project provided a water *resource* assessment (which indicates how much water there is at any given time and location) for the whole region and a water *availability* assessment (which indicates how much water can be diverted or extracted from each source at any given time and location) for some parts of the region where there was a greater wealth of data to allow more detailed availability analysis (CSIRO, 2009b).

Significance: The NASY project was most comprehensive survey of northern Australia's water balance ever undertaken, and it was the first such study of the region to incorporate climate change projections. Lack of existing data on water resources and extraction rates across northern Australia posed a new challenge to the application of models that had been used in the MDBSY, where there was a wealth of existing water data and water models made providing detailed water balances easier. To address this, the NASY developed new models specific to the region and the NASY identified key data gaps that prevented more detailed water availability assessments in many areas, indicating areas of further study.

NASY developed innovative new ways to deal with lack of pre-existing water data and identified areas of further study

Importantly, NASY also found that there are significant constraints on the development of water storage and irrigated agriculture across many areas of the north. This conclusion was partly a function of data issues: due to lack of data it was difficult to estimate future changes in environmental flows due to development in many areas. However, this conclusion was also supported by findings that there is a high level of year-to-year and season-to-season water flow variability, few perennial rivers, low levels of soil suitability for irrigation across many areas, and a strong need for seasonal flooding to ensure the viability of local ecosystems. These findings effectively busted the myth that the entire north of Australia would be suitable for irrigated agriculture to a scale that the north could become a 'food bowl of Asia', although, as will be seen in the case of the Flinders and Gilbert Catchment Assessment, subsequent studies showed potential for more intensive irrigated agriculture on a smaller scale in some discrete areas of the north (CSIRO, 2013j).

H.2.4 Tasmania Sustainable Yields – supporting responsible water resource development

The issues: While agriculture has long been an important part of Tasmania's economy, lack of water infrastructure and uncertainty about feasible options for alternative cropping in many areas of the country have acted as a hindrance to increased investment. Unlike mainland Australia, Tasmania has abundant water supplies and was largely unaffected by the millennium drought.

Project focus: The Tasmania Sustainable Yields project was initiated by COAG in March 2008 and ended in 2009. The objective of the project was to undertake an assessment of current and future water supply and supply variability in Tasmania under four climate change and development scenarios (the same scenarios as those outlined in the MDBSY project, above, with the exception that Tasmania SY included development of forest plantations in its analysis).

The project aimed to provide the necessary information to ensure that the Commonwealth government co-invested only in those scheme which were robust under the most extreme climate change projections. The study covered Tasmania's five major agricultural regions: Derwent-South East, South Esk, Pipers-Ringarooma, Mersey-Forth and Arthur-Inglis-Cam. Together, these areas constitute almost 50,000 square kilometres, or 72 per cent of Tasmania's land area (CSIRO, 2009d).

Significance: As neither surface water nor groundwater extractions are metered in a consistent way in Tasmania, CSIRO developed and applied a comprehensive suite of river models, as well as three groundwater models for different groundwater areas. In order to assess the ecological impacts of irrigation and other water developments, CSIRO used flow stress ranking to determine ecological impacts of changes to streamflow at key ecological sites and sub-catchments.

TasSY incorporated plantation forests into WRA methodologies and developed models to cope with lack of pre-existing data

This was the first time that the impacts of Tasmanian catchment development (commercial plantation forests and future irrigation development), changing groundwater extraction rates, climate variability and anticipated climate change on water resources at a whole-of-region scale were quantified. This was achieved through the most comprehensive hydrological modelling ever attempted in the region, using rainfall-runoff models, groundwater recharge models, river models and groundwater models (CSIRO, 2009c).

The Tasmania SY was also significant in its focus on assessing the impact of plantation forests on overall water availability, demonstrating that plantation forests can reduce streamflow to a greater extent than climate change (CSIRO, 2013b).

H.2.5 South-West Western Australia Sustainable Yields (SWWASY) – groundwater is significant for water supply

The issues: The south-west is one of Australia's most water-challenged areas, due to rapid population growth and associated development, decreasing rainfall, and a high level of vulnerability to further decreases in water supply due to climate change. Between 1975 and 2008, runoff to metropolitan dams decreased by more than 75 per cent, while groundwater storages in the Gnangara Mound decreased by over 45 GL each year (CSIRO, 2008). As a major agricultural area, food production has also been affected by the 35 year trend of dry conditions. While a need for diversification of water sources and better water management has been recognised, lack of integrated understanding about south-west WA's water current and future water supply had hindered decision making.

Project focus: The South-West Western Australia Sustainable Yields project was initiated by COAG in March 2008 and ended in 2009. It assessed current and future water yield for the entire south-west of Western Australia over an areas extending from Geraldton in the north, to Albany in the south. The assessment estimated future water balance in the region using four climate change and water resource scenarios (outlined in the section on the MDBSY project, above). The study focused in particular on modelling groundwater resources and mapping the interconnectivity of aquifers. Activities undertaken in the project included the formation of climate scenarios and modelling of climate change effects on catchment runoff, aquifer recharge and rainfall levels, modelling of surface-groundwater exchanges, and assessment and reporting of the implications of these factors for water yield.

Significance: The SWWASY project was one of the first detailed studies of the impacts of climate change of the recent past on existing water supplies in the region. The project demonstrated that there have been changes in the rainfall-runoff relationship in the region over the past decades, and that lower groundwater levels are due to a drier overall climate. This has led to reduced surface-groundwater interactions and hence reduced streamflows (CSIRO, 2013b).

SWWASY developed new techniques to measure surface-groundwater interactions

SWWASY also utilised a number of modelling techniques to measure surface water-groundwater interactions and groundwater characteristics. Many of the techniques for measuring and analysing groundwater flows utilised in SWWASY formed a basis for the subsequent Great Artesian Basin Water Resources Assessment (CSIRO, 2013b).

H.2.6 Great Artesian Basin Water Resources Assessment (GAB WRA) – supporting the management of a globally significant resource

The issues: The Great Artesian Basin (GAB) is one of Australia's most important water resources and is the largest and deepest underground water reservoir in the world. It lies under an area of 1.7 million square kilometers covering Queensland, New South Wales, South Australia and the Northern Territory, or approximately 22 per cent of the continent. However, there has been growing concern about the sustainability of GAB water use, with increasing extraction rates and a history of inefficient extraction causing dropping water levels and pressure decline in the basin (although pressures have started to recover over the past decade or so).

Project focus: The GAB WRA was commissioned by the then-Commonwealth Department of Sustainability, Environment, Water, Population and Communities and the National Water Commission in July 2010 and ran until 2013. CSIRO partnered with Geoscience Australia to provide an analytical framework to assist water managers across the four main sub-basins that comprise the GAB (West Eromanga, Central Eromanga, Surat, and Carpentaria). The

GAB WRA represented a continuation of the sustainable yields projects and drew upon many of the core tools and methodologies developed in the course of the Murray-Darling Basin and south-west Western Australia Sustainable Yields projects. CSIRO's assessment involved a basin-scale investigation of water resources and the potential impacts of climate change and groundwater development to 2070. The study revealed that the complex geological features such as faults and ridges govern groundwater movement in the GAB and identified areas where underlying geological basins and overlying shallow groundwater are potentially connected with aquifers of the GAB.

Significance: A key contribution of the Great Artesian Basin WRA was the development and application of isotope hydrology – a process that measures the specific isotopic fingerprint of water molecules to trace water flows and water age. While CSIRO has maintained an isotopic hydrology laboratory for over 40 years, the GAB WRA was significant due to the incorporation of a noble gas laboratory for the project in 2009. This laboratory was primarily established to measure helium-4 in order to aid tracing old groundwater discharge to rivers in the Great Artesian Basin. By incorporating noble gas analysis into historic water level and quality monitoring data, hydraulic testing, environmental tracers and geophysical techniques, the GAB WRA improved the techniques used to assess the connectivity of aquifers (CSIRO, 2013b).

GAB WRA developed sophisticated groundwater tracking tools

The GAB WRA brought together knowledge of geological and hydrological conditions in a consistent way for the entire basin for the first time, drawing together and harmonising existing research and data on the GAB, as well as adding new CSIRO-developed and collected models and data.

The GAB WRA identified the complex geological features such as faults and ridges that govern groundwater movement in the basin and where deep geological basins and overlying shallow groundwater are connected to aquifers in the GAB. It demonstrated that many more reservoirs and basins have connected water flows than was previously thought. This involved the creation of a series of maps of reservoirs and basins that gauged the potential for connected water flows (CSIRO, 2013e). The assessment also demonstrated that groundwater has a greater potential to move vertically across GAB formations than previously thought.

H.2.7 Flinders and Gilbert Agricultural Resource Assessment (FGARA)

The issues: High levels of annual rainfall had prompted speculation about the viability of intensive irrigated agricultural in the areas of north-east Queensland surrounding the Flinders and Gilbert River for many years. However, until CSIRO carried out the Flinders and Gilbert Resource Assessment (FGARA), lack of consistent information on current and future water supplies in the region created high levels of risk for potential agricultural investors and inhibited informed discussion on changes to land usage regulations. While previous studies of the area had highlighted the potential for intensified irrigated agricultural production, these studies either assessed irrigation proposals at the local level only, without assessing how such developments may fit into a sustainable catchment and regional development framework, or they identified constraints to greater agricultural activity in over larger areas of north Queensland, without assessing how these constraints could be addressed in a sustainable way (Rudwick and Miller, 2014). Water resources and development potential was broadly mapped in the NASY project, but detailed information on where and when surface water could be taken, how much water could be reliably and sustainably removed, and where and how it might best be stored was still lacking (Dickson, 2014).

Project focus: CSIRO's Flinders and Gilbert Agricultural Resource Assessment (FGARA) was one component of the larger North Queensland Irrigated Agriculture Strategy (NQAIS), which began in January 2012 under the leadership of the Queensland Government, James Cook University and CSIRO and ended in December 2013. Building on the reconnaissance-scale Northern Australia SY data and methods, the FGARA involved comprehensive analyses of water resources in the Flinders and Gilbert river catchments, in order to identify and test the commercial viability of irrigated agricultural opportunities and assess the potential environmental, social and economic impacts and risks of such development. The FGARA sought to: 1. identify and evaluate water capture and storage options; 2. identify and test the commercial viability of agricultural opportunities, and; 3. assess the potential environmental, social and economic impacts and risks of water capture/storage and irrigation development.

The project's activities included:

- Fieldwork to collect data, establish the value, costs and risks of irrigated agricultural production or other water developments, and benchmarking of new production methods.
- Region-scale geochemical and geophysical surveys to map salinity risks and connectivity and surface and groundwater.
- Mapping land and soil agricultural suitability and production risks (such as salinity and floods) across agricultural, horticultural and pastoral systems.
- Topographic mapping and automated terrain analysis to identify and evaluate water storage and development options.
- Hydrodynamic and river modelling to assess the extent, magnitude and duration of floods, land suitability, and connectivity between surface water and groundwater.
- Assessments of potential environmental impacts under a range of climate and development scenarios and identify Indigenous water values.
- Socio-economic cost–benefit analyses, including demands placed on key resources under a range of development scenarios.
- Information and data distribution through web-based information products, reports and regular community-based information sessions (CSIRO, 2014c).

Significance: Where previous assessments focused on single development activities or assets – without analysing the interactions between them – FGARA considered the opportunities presented by the simultaneous pursuit of multiple development activities and assets. By this means, the Assessment used a whole-of-region (rather than an asset-by-asset) approach to consider development. As such, FGARA provided a blueprint and a set of methodologies for rapidly assessing future land and water developments in other parts of northern Australia (Rudwick and Miller, 2014).

FGARA was also significant because it analysed the commercial viability of water development and infrastructure choices, with reference to current and future water supply and supply reliability. Where other WRAs aimed to inform government decision-making and provide information to agriculturalists, the FGARA provided information that can be tailored to meet the due diligence requirements of private investors and lenders, by addressing questions of profitability and income reliability of agricultural and other developments.

FGARA linked WRAs directly to a range of water infrastructure and agricultural development opportunities

CSIRO applied new digital soil mapping techniques to better understand soil properties and create land suitability maps for a variety of crops across the region. This involved integrating the use of airborne electromagnetic surveys, to measure soil salinity and quality, with noble gas tracer analysis applied to the GAB WRA. This allowed CSIRO to conduct run-of-river tracer studies, in order to better understand the geological conditions surrounding surface water-groundwater interactions. This was the first time that multiple tracers had been used

to quantitatively measure local and groundwater discharges (CSIRO, 2013b; Jolly *et al.*, 2013).

FGARA saw the first operational application of the 'DamSite' model, developed by CSIRO researchers, which enables researchers to automatically identify potential dam locations. DamSite involved the creation of high-resolution digital elevation models for dam sites, assessing streamflow uncertainty and assessing the risk of water table rise, even in areas with little pre-existing water data. (CSIRO, 2013b).

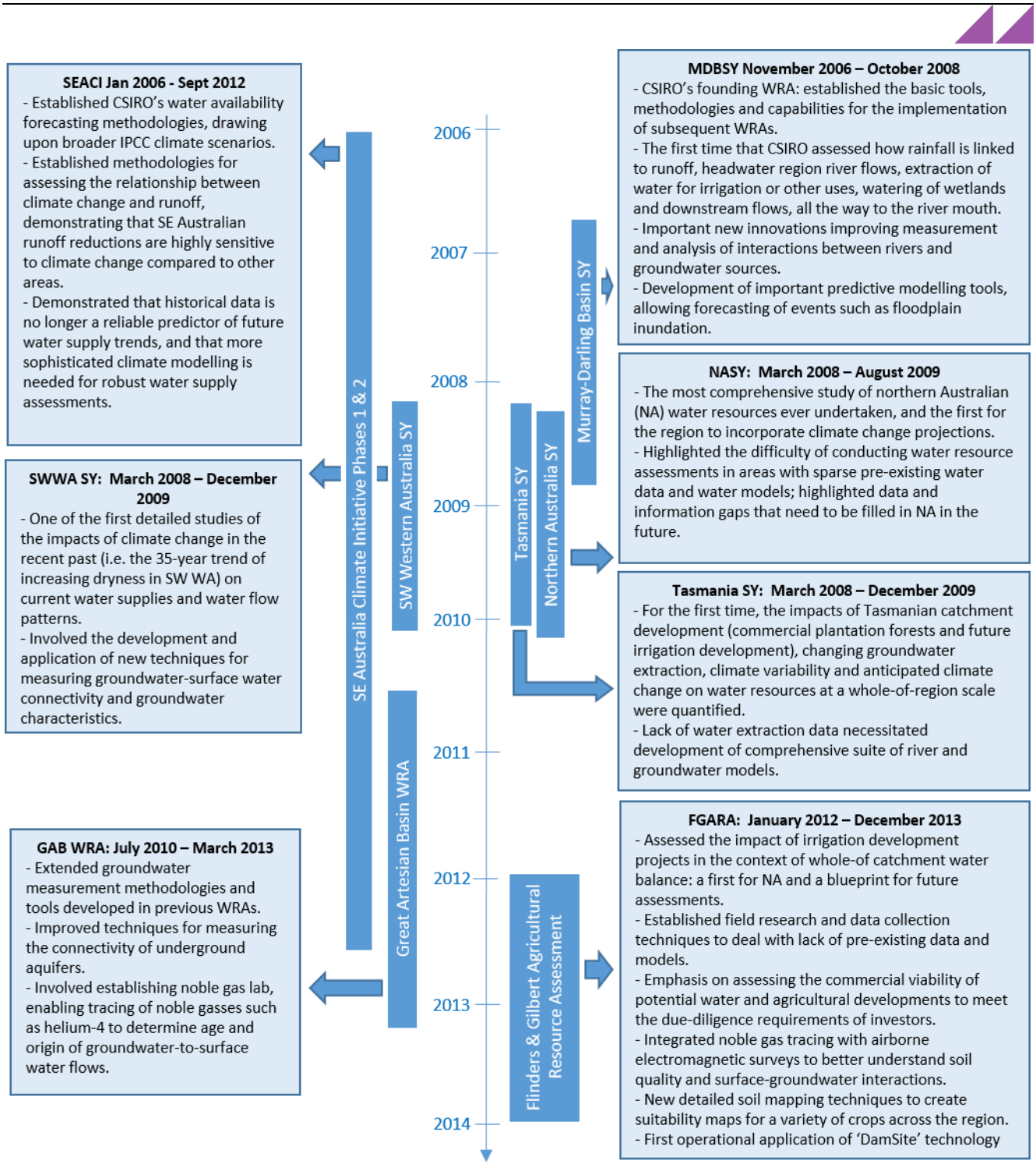
In addition, FGARA built on previous WRA work in data-poor regions, such as Tasmania and northern Australia, to create a new model to assess the risk of groundwater rise under irrigation in data sparse areas (CSIRO 2014c).

H.2.8 Cumulative capabilities built over the course of the WRAs

The cumulative experience of these water resource assessments and the SEACI enabled CSIRO to build its capabilities to assess current and future water balances to a high level of geographic detail, across large basins and water systems. The implementation of WRAs in highly diverse water system and climate areas of Australia have also enabled CSIRO to develop flexible tools and methodologies for conducting water resource assessments both in areas that are rich in existing water supply and consumption data, and in areas where pre-existing data is relatively sparse.

The timeline below presents a visual summary of each of CSIRO's water resources assessments (as well as SEACI), highlighting how each subsequent project built upon and extended the tools, methodologies and capabilities developed in the preceding projects.

Figure H1 **Timeline of cumulative water resource assessment capabilities**



Source: ACIL Allen Consulting

H.2.9 Summary of common activities across all WRAs

A number of activities are common across all of the water resources assessments, are summarised in the table below:

CSIRO's WRAs incorporated a diverse and cross-disciplinary set of capabilities and activities

Table H2 **Common activities across all sustainable yields assessments**

Activity	Detail/example
Integration of pre-existing data and models to provide a consistent picture over time of water resources	This involved the collection of existing models for different water sources in the region, critical assessment of the models, harmonisation of time periods and units across the models, and integration with newly developed CSIRO models for each WRA and the SEACI.
Characterising and quantifying climate and hydrologic variability	This involved: ▪ analysing hydroclimate variability over annual, decadal and longer time scales; ▪ long-term trends in climate and streamflow series, and; ▪ large-scale ocean–atmosphere drivers of regional climate and changes to these drivers.
Estimating climate change impacts on water	This involved: ▪ assessing and weighting global and regional climate models; ▪ climate–water modelling to predict future water availability and river flow characteristics; ▪ providing recharge estimates over large land areas and water systems.
Hydrological modelling	This involved: ▪ attributing past and future changes in water availability to changes in climate inputs and changes in dominant hydrological processes; ▪ quantifying biosphere influence on water availability through catchment vegetation; ▪ modelling of individual catchment-scale hydrological processes (land use change, high and low flows, surface water – groundwater interactions, and floodplain processes); ▪ estimating changes in water balance components under future scenarios of land use change; ▪ developing a floodplain inundation model to predict the size, depth and volume of floodplain inundation.
Developing measurement and modelling techniques to assess surface-groundwater interactions	This involved ▪ comparing methods of estimating groundwater contributions to surface water flows and developing new methods where necessary; ▪ developing modelling methodologies; ▪ developing field-based approaches to determine the state of connectivity in losing rivers
Tailoring water resource assessments to water planning needs	This involved: ▪ communicating water availability projections to important stakeholders; ▪ developing risk-based methods that can better utilise climate–water prediction to consider alternative water planning and adaptation options; ▪ working with catchment, state and Australian Government agencies to incorporate climate–water prediction in basin and regional water sharing plans and climate adaptation options.
Developing techniques to estimate and quantify uncertainty and probability in water resource models	This involved: • providing a methodology to account for uncertainty in forecasts of groundwater flows; • exploring different options to deal with uncertainty in hypothetical future water allocations; • developing a range of benchmark techniques and methodology for recognising and estimating uncertainty in water supply forecasts.

Source: ACIL Allen Consulting; CSIRO 2013b

H.3 Program outputs

H.3.1 Key outputs of the program

The outputs of each WRA were a series of reports and datasets on regional water resources

Outputs from the WRA projects have varied depending upon the region of study, but a number of outputs have been common throughout the five regional studies. These include:

- Publicly accessible modelling and databases that detailing water resources in each region: in all of the areas covered by the assessments CSIRO's WRAs provided the first consistent, robust and transparent assessment of current and likely future water resources for each region, including an assessment of possible future climate implications.
- Region-specific water resource assessment reports. These include a range of summary reports and technical report to inform policy making, investment decisions, stakeholders and the general public.
- Benchmarking of standard water resource assessment models and methodologies. CSIRO benchmarked standard methodologies for measuring rainfall and surface water evaporation.

In addition, each project has yielded a number of outputs that are particular to each project.

South Eastern Australian Climate Initiative

The primary outputs of SEACI were a series of scientific journal papers, reports, and datasets, which included:

- Synthesis reports for phases 1 and 2 of SEACI, covering major research findings on climate and water availability in south-east Australia.
- Program annual reports for the years 2009/10 to 2011/12, detailing project activities, publications and major findings in phase 2 of the project per year.
- A series of final reports covering major research findings on issues including rainfall and evaporation patterns, climatic and weather patterns, runoff and drainage, model assessments and forecast data.
- A series of accessible factsheets covering the SEACI project itself, major research findings on issues such as the millennium drought, prediction of seasonal climate and streamflow, future climate and streamflow, and a summary of all of SEACI's major research findings.
- 75 peer reviewed academic journal articles
- Downloadable data on projected changes in climate and water runoff under 1ºC of warming and 2ºC of warming (South Eastern Australian Climate Initiative, n.d.).

Murray-Darling Basin Sustainable Yields

The primary outputs of the MDBSY were a series of reports and datasets, which included:

- Whole-of-basin water resource assessment reports, including detailed and summary reports.
- Detailed and summary reports outlining project methodologies and the terms of reference for the project.
- Water resource assessment reports for 18 regions within the Murray-Darling Basin, with a detailed report, a summary factsheet and snapshot and summary presentations/reports of main research findings for each region.

— 17 technical reports covering issues and topics including: water resources in the parts of the Great Artesian Basin that underlie the Murray-Darling Basin; climate data and hydrological scenario modelling; data management and methodologies; groundwater and recharge modelling and groundwater management; water evaporation modelling; surface-groundwater interactions modelling, rainfall and runoff modelling, historical reports and data of relevance; surface-groundwater connectivity assessment; region-specific modelling reports, and; use of satellite observations for water balance estimates (CSIRO, 2013j).

Northern Australia Sustainable Yields

The primary outputs of the NASY were a series of reports and datasets, which included:

— Summary reports of current and future water balances covering both the entire area of northern Australia, as well as the three individual drainage basins (the north-east coast, Gulf of Carpentaria and Timor Sea drainage basins).

— Detailed reports and summary factsheets containing current and future water balances in localised drainage sub-divisions within the broader North-East Coast, Carpentaria and Timor Sea drainage divisions.

Six technical reports outlining groundwater recharge modelling, streamflow simulation, northern Australian climate data, and detailed summaries of high and low flow regime changes under different climate scenarios, river modelling, and rainfall runoff modelling (CSIRO, 2013i).

Tasmania Sustainable Yields

The primary outputs of the Tasmania SY were a series of reports and datasets, which included:

— Two summary reports covering the whole of northern and eastern Tasmania: one examining water availability in Tasmania, another outlining climate change projections and impacts of water runoff levels in Tasmania.

— Six technical reports

— One of these technical reports is a large five volume publication containing detailed water availability reports for the five surveyed regions: the Arthur-Inglis-Cam region, the Mersey-Forth region, the Pipers-Ringarooma region, the South Esk region, and the Derwent-South East region.

— The remaining five technical reports and datasets include: climate scenario, rainfall-runoff modelling, groundwater assessments and modelling, detailed river modelling for each of the five surveyed regions, a report on the ecological impacts of water availability, and a glossary of water-related terminology.

In addition to these reports, the Tasmania SY project involved the creation of a comprehensive suite of river models to measure movement and use of water within a project area, to compensate for the lack of existing data and water metering infrastructure in many areas of Tasmania (CSIRO, 2013g).

South-West Western Australia Sustainable Yields

The primary outputs of the SWWASY were a series of reports and datasets, which included:

— Three detailed reports covering surface water yields, groundwater yields, and water yields and demand in south-west Western Australia, including water supply projections under climate change scenarios out to 2030.

— Summary reports and factsheets covering the detailed reports.

— Two technical reports describing project methodologies and climate analyses for south-west Western Australia (CSIRO, 2013h).

Great Artesian Basin Water Resources Assessment

The primary outputs of the GAB WRA were a series of reports and datasets, which included:

— Water Resource Assessment reports for the whole of the Great Artesian Basin

— Water Resource Assessment reports for each of the main sub-basins (the West Eromanga, Central Eromanga, Surat and Carpentaria sub-basins)

— Five technical reports outlining groundwater models and modelling methodologies, assessments of future climate and groundwater development on springs, hydrostatigraphy, hydrogeology and system conceptualisation, outline of main lexicon, and models of climate and groundwater development.

— Datasets available through Geoscience Australia, including a 3-D visualisation of the GAB, and data reports (CSIRO, 2013c)

Flinders and Gilbert Agricultural Resource Assessment

The primary outputs of the FGARA were a series of reports and datasets, which included:

— Two detailed reports covering the Flinders and Gilbert catchments respectively, providing comprehensive analysis of the feasibility, economic viability and sustainability of agricultural development in each catchment.

— Summary reports, FAQs and factsheets covering FGARA project management, key findings, two separate agricultural resource assessments of the Flinders River Catchment and the Gilbert River Catchment, socio-economic impacts, Indigenous values surrounding water and agricultural development in the region and airborne electromagnetic mapping (AEM, a techniques used to map soil salinity and groundwater quality).

— 17 technical reports covering methodology and research findings for issues such as: river system, streamflow and surface-groundwater modelling; climate data and hydrological and agricultural scenario modelling; dam and sediment modelling; flood and floodplain mapping and modelling; Indigenous water values, rights and interests; irrigation costs and benefits; socio-economic impact evaluations; land suitability assessments and agricultural production.

— Soil datasets accessible through CSIRO's Data Access Portal covering soil properties and modelled irrigation land uses (i.e. crop and irrigation combinations), with more detailed information on location-specific soil sample results available upon request.

In addition to these reports and datasets, CSIRO applied a new digital soil mapping approach to create land suitability maps for a variety of crops across the region.

H.3.2 Awards and public recognition

CSIRO's has received a number of awards for its water resources assessments.

Table H3 **Awards related to water resources assessments (2009-2014)**

Year	Award
2013	Eureka Prize for Research and Innovation finalist: The South Eastern Australian Climate Initiative led by Dr. David Post and Dr. Francis Chiew (CSIRO), Dr. Bertrand Timbal and Dr. Harry Hendon (BOM) for enabling better management of Australia's precious water resources in the face of future climate challenges.
2012	CSIRO Land and Water Division award: Excellence in Research Award to Dr. David Post and team for the South Eastern Australian Climate Initiative.
2010	Dr Tom Hatton awarded Public Service Medal.
2010	Finalist: The South-West Western Australia Sustainable Yields Project in the Australian Water Association (Western Australia) Water Awards ('Program Innovation' category).
2008	CSIRO Chairman's Medal for Murray Darling Basin Sustainable Yields Assessment team.
2008 & 2009	Finalist: Australian Museum Eureka Awards – Water Resource and Innovation for Murray Darling Basin Sustainable Yields Assessment Team.
2009	2009 Team of the Year by the eWater CRC: to Dr Alice Brown and Dr Wendy Welsh for their exceptional efforts in research and stakeholder engagement in support of the new River Manager modelling tool.

Source: CSIRO 2013b

H.4 Status of Outcomes and Impacts

H.4.1 Nature of Outcomes and Impacts

Water resource assessment outcomes

Improved understanding of water balance in Australia

CSIRO's water resource assessments have strengthened understanding of the current and future water balance in a number of key regions that together comprise roughly 72 per cent Australia's water resources. CSIRO has achieved this in the following ways:

CSIRO's WRAs yielded significant improvements in scientific understanding of water supply, though …

Provision of comprehensive information that is consistent across large areas, but also detailed and area-specific.

One of the main tasks of the water resource assessments involved the collation of existing data, models and research on water supply and demand in each region of study, critically assessing these pre-existing research resources, and harmonising pre-existing research so that underlying methodologies, units, time-steps and other features could be analysed on consistent terms. For projects that were chiefly desktop studies, such as NASY, harmonising existing research and data and applying CSIRO's own new modelling and analysis to this data was the main task. For other studies involving intensive data collection, new data and models were meshed with pre-existing data.

…provision of consistent and detailed scientific information on regional water resources …

By incorporating and harmonising pre-existing research, CSIRO was able to produce a picture of the current and future water balance in each region that represented the result of cumulative research not just of CSIRO, but of the broader scientific community. This was important not only for the provision of comprehensive and consistent information for the broader public, but also to strengthen CSIRO's image as a trusted and impartial provider of information in an area (water consumption and water trade-offs) that is often highly contested (the value of public trust in CSIRO's research findings is discussed further below).

Moreover, the WRAs provided rigorous, whole-of-basin assessments side-by-side with detailed assessments of smaller regions within each basin. In all cases where CSIRO undertook WRAs, this was the first time that a whole-of-basin water resources assessment, which was consistent across the entire basin and incorporated future projections based on climate change analysis, had been undertaken. At the same time, smaller region-specific studies provided the ability to drill down to specific areas within this same broader analytic framework, providing new understanding of the links between water supply and consumption in the larger basin and local areas.

Information of this level of consistency, detail and scale had never been provided to this extent in the Murray-Darling Basin, northern Australia, north and east Tasmania, south-west Western Australia, the Great Artesian Basin, and the Flinders and Gilbert Catchments before.

Improvement of climate change projections and incorporation into large water resource assessments.

All of CSIRO's water resources assessments included climate change projections under a range of scenarios. All of the sustainable yields projects included climate change projections out to 2030, while the GAB WRA included climate change projections out to 2070, in recognition of the fact that flow processes are slow in large regional groundwater systems. For all of the regions covered by CSIRO's WRAs, this was the first time that projections of future water supply on a whole-of-basin level were undertaken based on a combination of historical data and sophisticated climate modelling.

…incorporation of robust climate change projections in water availability forecasts …

This involved the creation and improvement of climate change models, starting with SEACI. SEACI saw the adaptation and improvement of many key models that describe current climate patterns and their future development under IPCC scenarios of higher atmospheric greenhouse gas concentrations. These improvements underpinned new and important research findings in the Murray Darling Basin in relation to the role of the millennium drought and changes in water flow patterns that have already taken place, and projections of how weather and water flow patterns will evolve out to 2030. Improvements to climate models in other parts of Australia were similarly key to the credibility of future water balance and water flow projections in other WRAs.

Improvements to climate models, particularly the coupled atmosphere–ocean–land climate model (POAMA) has also significantly increased the accuracy of shorter-term seasonal climate and weather forecasting in Australia (CSIRO, 2013b).

Improved understanding of key water flow characteristics.

…improved methodologies for measuring and understanding water flows …

CSIRO's WRAs saw progressive improvements to modelling and understanding of key characteristics of water flows across basins. A few examples of these are:

- *Improved understanding of aquifers and groundwater*. For example, the GAB WRA saw the development of models and research techniques that gave a much more comprehensive picture of where underground connections exist between the Great Artesian Basin and other aquifers and basins, showing that the Great Artesian Basin is more interconnected than was originally thought.
- *Improved understanding and forecasting of floods*. One of the major breakthroughs in flooding forecasting was the development of the River Murray Floodplain Inundation Model (RiM-FIM) which was applied in the course of the MDBSY project. The RiM-FIM allows water resource managers to predict the timing and extent of flooding on any given floodplain.

— *Improved forecasting of rainfall and understanding of seasonal rainfall variability*. All WRAs resulted in significant improvements in seasonal streamflow forecasting in each region of study. Streamflow forecasting methodologies developed in the course of SEACI and MDBSY, which were then extended to NASY and FGARA, have formed the basis of an ongoing Bureau of Meteorology streamflow forecasting service.

— *Improved understanding of the water runoff levels*. CSIRO's WRAs involved refining and improving established methodologies for assessing the relationship between climate change and water runoff levels. In this way, projects such as SEACI and SWWASY were able to demonstrate that in many areas of Australia, runoff levels are very sensitive to rainfall levels, with reduced rainfall as a result of drier overall conditions leading to disproportionate declines in runoff levels.

— *Improved streamflow forecasts*. Building on work to improve streamflow forecasts developed under SEACI, CSIRO and the Bureau of Meteorology (BOM) researchers developed a seasonal streamflow forecasting tool, which is now used by the BOM in its routine forecasts (CSIRO, 2013b). Streamflow forecasting methodologies have been adapted and applied in other WRAs to predict the future viability of water infrastructure projects such as dams and irrigation systems.

— *Improved understanding of soil characteristics and crop suitability*. CSIRO developed new ways to gauge soil qualities such as salinity and crop suitability, producing detailed crop suitability data and maps as part of the TasSY and FGARA water resource assessments.

— *Novel water data collection techniques*. While the first sustainable yields assessment, the MDBSY, was characterised by a wealth of existing water extraction data as a result of extensive water metering and measurement infrastructure, many subsequent water resources assessments took place in areas with sparse water supply and consumption data. CSIRO developed novel techniques to tackle lack of pre-existing data, including through the developed of new region-specific models, and through new and efficient data collection techniques, such as noble gas tracing for groundwater measurements in the Great Artesian Basin and the use of airborne electromagnetic surveys in FGARA.

Quantification of water supply uncertainty. As well as providing unprecedented levels of information on current and future water balances in each area, the WRAs also developed novel techniques folr highlighting and quantifying future uncertainty of water supply. In many cases, new awareness of future water supply uncertainty came about as a result of the research findings themselves. For example, one of the most important research findings of SEACI was that the movement southward of tropical weather patterns means that the traditional 'filling season' (i.e. times of high rainfall when water storage infrastructure such as farm dams is filled) in the autumn and winter will no longer be as reliable as it has been previously, and that more rain may come in the summer months in some years. Key research findings such as these can help water managers better factor uncertainties into their decision-making.

…defining uncertainties and quantifying the degree of uncertainty associated with future water flows …

CSIRO's WRAs also developed a novel method of quantifying streamflow uncertainty to produce streamflow probability forecasts. This was applies in the Tasmania SY and FGARA projects, allowing users to pinpoint specific large water infrastructure and access an expected rate of future streamflow. Analysis and quantification of streamflow uncertainty gives water managers an important new tool in assessing the long-term viability of major water infrastructure investments.

Effective communication to ensure that research findings and new water planning resources reach a wide and diverse audience

A key part of improving understanding of Australia's current and future water balance has

been the effectiveness with which CSIRO has communicated its research. Enabling CSIRO's research findings and new methodologies to be understood by the diverse set of stakeholders involved in water management decisions means that they are more likely to be incorporated into water resource decision-making.

…improving public understanding of Australia's water supply constraints and opportunities …

An important avenue through which this has been achieved is through the reports themselves, which cater to a wide variety of stakeholders through a combination of highly detailed, technical reports, which can be used by government water regulators, departments and agencies, corporations and banks and a range of other users, and easy-to-access, plain English summary reports and factsheets, which make WRAs accessible to the broader public and other non-experts.

The combination of accessibility, breadth and detail in the WRAs has been key to ensuring that the main messages of each WRA spread more effectively to CSIRO's diverse target audience, enabling each WRA's key findings, tools and methodologies to be incorporated in a greater number of high-impact water management decisions and decision-making processes. Moreover, transparency of methodologies and accessibility of WRA findings have been important for the success of the projects, particularly in cases where some major stakeholders, such as farmers, were at times doubtful of the benefits of such assessments (Woodhouse, 2014).

…maintaining and enhancing CSIRO's reputation as a source of trusted advice and information on water resource management, and …

Provision of trusted and authoritative research. CSIRO has been able to establish itself as an authoritative voice in Australia's public discussion about water supply and management. This is important because greater levels of trust in CSIRO's research findings from more stakeholders mean that the research and methodologies developed in the course of WRAs are more likely to be incorporated into water decision-making on the part of governments, companies, lenders/investors, environmental groups and private individuals such as farmers. CSIRO has employed a number of strategies that have contributed to higher levels of public confidence in the WRAs, including:

- Publishing extensively in peer-reviewed scientific journals
- Incorporating pre-existing research and data into WRAs
- Building Australia's largest water resources research group with a wide breadth of cross-disciplinary skills and expertise
- Partnering with key organisations to supplement in-house skills and capabilities and build confidence with these organisations
- Transferring technology and skills to these partner organisations
- Engaging with a diverse array of stakeholders in the course of WRA research project.

…providing a benchmark for future WRAs

Formation of a benchmark for further water resource assessments. Beginning with SEACI and MDBSY, CSIRO's WRAs have established a set of methodologies, tools and research that forms a benchmark for rigorous and detailed basin-scale water resource assessments in other areas. This set of research, tools and methodologies is now being extended and applied to other areas and water management issues in Australia. This framework is also being extended to further projects in Australia and internationally (see Section H.H.5).

Incorporation of WRA findings into regional water management plans and decision-making processes

CSIRO's success in improving understanding of current and future water balances in key areas of Australia has led to the widespread adoption of WRA methodologies and research in a number of water management plans, regulatory processes and investment decisions across the country. While it is difficult to precisely characterise all of the ways in which

WRAs have been adopted by water managers, the following highlights the most significant examples of uptake of each WRA.

South Eastern Australian Climate Initiative

CSIRO's WRAs have been incorporated into key water decision-making processes by a wide range of water managers

Adoption by Victorian government. SEACI research findings have been incorporated into state and local water planning, trading, management, and investment decisions in Victoria since 2006. Specifically, the Victorian government has instituted 'Sustainable Water Strategies' for each of four regions in the state. Previously, water supply planning had been based on the assumption that historic rainfall and streamflow records provided a reliable basis for forecasting future resources availability. The new regional Sustainable Water Strategies draw on SEACI analysis to provide a holistic review of water resource management, considering surface water and groundwater resources and environmental and consumptive needs, and incorporating future flow scenarios from SEACI under different degrees of global warming. Victoria's Central Region was the first to release a Sustainable Water Strategy incorporating SEACI climate scenarios in 2006, followed by the Northern Regional Sustainable Water Strategy released in 2009, and the Gippsland and South West Strategies released in 2011 (Fitzpatrick, 2013).

The Victorian government has also mandated that the state's 17 water corporations responsible for supplying water to cities and towns produce 'Integrated Water Cycle Strategies'. These Strategies involve forecasting future water supply and demand in order to underpin business cases for investments in new large scale water infrastructure such as dams. The Integrated Water Cycle Strategies are reviewed every five years. Victoria's water corporations are required to consider a range of future water supply and water flow scenarios that are underpinned by SEACI data and forecasting methodologies (Fitzpatrick, 2013).

Adoption by the Bureau of Meteorology. The Bureau of Meteorology (BoM), which was a major partner of CSIRO in SEACI, has adapted and adopted the improved POAMA seasonal climate model to produce the official seasonal climate outlook (CSIRO, 2013a). SEACI also provided the initial foundation for a BoM new seasonal streamflow forecasting service covering the east and north-east regions of Australia.

Adoption by ACTEW Water: The ACT's water and sewerage operator, ACTEW Water, has incorporated SEACI's research in the planning of the Cotter Dam extension, which involves the construction of a new 80 metre high dam to help secure the ACT's water supply over 2009 to 2013 (CSIRO, 2013b).

Murray-Darling Basin Sustainable Yields

Adoption by the Murray-Darling Basin Authority: As a result of the MDBSY project, CSIRO has become an ongoing provider of scientific research to the Murray-Darling Basin Authority (MDBA). The MDBSY project was established by former Prime Minister John Howard under the 2007 Water Act to create and enforce the Murray-Darling Basin Plan for the management of water resources in the basin. Following the end of the MSDBSY project in 2009, CSIRO used the techniques and research developed in the course of that project to undertake further research projects on contract for the MDBA, in order to answer specific research questions related to the development of the Murray-Darling Basin Plan.

In particular, CSIRO used research from the MDBSY as a basis for the River System Modelling Project and the Groundwater Assessment Project, which was implemented over 2009 and 2010. The methods, systems and input data were used by the MDBA in the development of sustainable diversion limits (SDLs), set under the Plan. SDLs set annual volumes of water to be recovered from irrigators and returned to the environment as environmental flows, with specific SDL for each catchment and aquifer, and an SDL for the

Murray-Darling Basin as a whole. SDLs seek to cap total water consumption across the basin at 10,873 GL/year by 2019, a target which entails the reclamation of 2,750 GL/year of water for environmental flows from human consumption, to be achieved by a combination of water buybacks and investment in greater water infrastructure efficiency. The MDBA also uses the River Murray Floodplain Inundation Model (RiM-FIM) tool applied in the MDBSY project, to determine floodplain areas impacted by various management scenarios (CSIRO, 2013b).

CSIRO extended research done under the MDBSY and SEACI to provide advice to the MDBA on defining climate scenarios for Basin Plan modelling and modelling of climate impacts on groundwater. CSIRO also provided training for the purpose of best research practices and knowledge transfer to the MDBA, including through the secondment of staff.

Northern Australia Sustainable Yields

The NASY have been incorporated into a number of submissions to the Joint Selection Committee on Northern Australia for the Northern Australia White Paper that is currently being drafted by the Commonwealth Government. One submission from the Australian Academy of Science used the NASY to demonstrate the importance of including scientific knowledge in the drafting of the White Paper, highlighting the many data and knowledge gaps that were uncovered by the NASY relating to northern Australia's water resources and agricultural potential (Australian Academy of Science 2014).

NASY methodologies and research also provided an important foundation for CSIRO's review of sustainable development in northern Australia, which was commissioned by the Northern Australia Land and Water Taskforce (CSIRO, 2011). This review formed the scientific foundation for the Taskforce's final report, which urged caution in the developed of large-scale irrigation and water storage infrastructure in northern Australia, highlighting the ecological limitations on water diversions in many areas of the north and supporting the conclusion of the Taskforce that "the potential for northern Australia to become a 'food bowl' is not supported by evidence" (Northern Australia Land and Water Taskforce, 2009).

Tasmania Sustainable Yields

Adoption by Tasmanian government: In 2009, the then-Tasmanian Premier David Bartlett announced a plan for The Tasmanian government of Premier name used the findings and tools developed under the Tasmania SY project to underpin a plan to significantly expand the area of Tasmania under irrigated agriculture and bring an additional 188,900 mega litres of irrigation water to Tasmanian farmers (The Australian, 2009). The information underpinning this decision was directly based on the findings of the Tasmania Sustainable Yields project as well as ongoing partnership research between CSIRO, the Tasmanian Department of Primary Industries and the Tasmanian Institute of Agricultural Research (David Bartlett, quoted in The Australian, 2009).

Tasmania Irrigation, a state-owned company established in 2011 to develop and operate government-subsidised irrigation schemes, uses the modelling and data developed by CSIRO in the Tasmania SY project in its due diligence investigations for investment decisions. According to Tasmania Irrigation, all of its irrigation and dam-building schemes must demonstrate 95 per cent reliability of water provision over 100 years. Tasmania Irrigation quantifies water supply reliability on a project-by-project basis with reference to a combination of historical hydrology data, and the climate change projections out to 2030 developed by CSIRO, which incorporate wet, median and extreme dry scenarios (Tasmania Irrigation, n.d.).

Adoption by Federal Government: In 2009 the Australian Federal Government has made use of the Tasmania SY project to guide its co-investment under a National Partnership

Agreement in nine new irrigation projects in Tasmania, involving Federal Government investment of up to $140 million, to ensure that all co-invested projects are economically and environmentally sustainable out to 2030 (Department of the Environment).

Great Artesian Basin Water Resources Assessment

As the GAB WRA drew to a close relatively recently (March 2013), it is somewhat early to assess the adoption of its research findings and methodologies. However, the Great Artesian Basin Sustainability Initiative (GABSI), which seeks to improve water use efficiency across the basin, is scheduled to draw to a close this year. It is likely a that government efforts to put a new Great Artesian Basin management framework in place will involving consulting the research findings and methodologies of GAB WRA, given that the GAB WRA is the most comprehensive and up-to-date study of the Great Artesian Basin available.

Advances in understanding of the Great Artesian Basin as a result of CSIRO's WRA are also underpinning a new CSIRO research program examining the impacts of coal mining and coal seam gas developments on groundwater. Given the high level of public disagreement over the impacts of unconventional gas exploration and production on shared groundwater resources, the impacts of this current set of studies on policy-making and regulation is expected to be significant.

Flinders and Gilbert Agricultural Resource Assessment

As this project finished relatively recently (December 2013), it is too early to review the uptake of FGARA. However, as a result of the key findings of FGARA – that farm dams could support between 10,000 and 20,000 ha of irrigation in 70-80 per cent of years in the Flinders catchments, and that large dams could support 20,000 to 30,000 ha of irrigation in 85 per cent of years in the Gilbert catchment – there has been growing momentum to increase the area of irrigated agriculture from roughly 1,000 ha at present (CSIRO 2013f; CSIRO, 2014a). FGARA findings are being incorporated into the revision of the Queensland Government's Water Resources (Gulf) Plan and FGARA has provided the information to underpin two separate water infrastructure development proposals, each entailing development of over 15,000 ha of irrigation (CSIRO, 2014a).

FGARA may also provide the information needed to underpin changes to many of the restrictive statutory rules in place in the region at present, which limit the areas in which intensive agriculture is allowed to take place. Changes to these regulations could help to open up greater finance and lending opportunities for agricultural developers in the region (Woodhouse, 2014).

CSIRO market and non-market impacts

The uptake of CSIRO's WRAs by water managers and decision-makers has yielded a range of economic, environmental and social impacts.

WRAs have delivered a wide range of economic, environmental and social impacts

Table H4 **Summary of impacts**

Impact	Detail
Economic impacts	
Allocation of water resources to highest value users	CSIRO's water resource assessments provide water managers and water markets with information needed to direct water resources to water uses that can be expected to deliver higher long-term benefits compared to decisions that would have been made absent this rigorous information base. In many cases this means that incorporating WRAs into water decision-making can underpin better economic outcomes, for example by enabling investments that are more likely to produce returns under future climate change. In many cases this means that incorporating WRAs into water decision-making will also underpin better environmental outcomes. Improvements in both of these areas can be expected to deliver greater overall value in the long-term.
'Insurance value' of avoiding high-cost or highly damaging investments	Better understanding of future water supply scenarios reduces the likelihood that water managers will invest in agricultural or water projects that will become loss-making or unviable in the future as a result of changes in climate or water supply patterns. This likelihood can be expected to become lower as WRAs are increasingly incorporated into regular water investment planning. At the same time, better information on future water supply risk can help investors avoid higher risk investments, while at the same time freeing up capital in agricultural regions that are more water secure going forward.
Optimisation of cropping decisions and higher agricultural productivity	Cropping suitability maps and seasonal water flow forecasts from the WRAs allow farmers to optimise cropping choices and manage crop production uncertainty more effectively than previously. This can reduce risk of misallocation of farming land to sub-optimal uses and risk of loss from water supply stress.
Reduced economic cost of flooding and drought	More accurate and effective forecasting of weather and water supply events, such as flooding and drought, facilitates timely preparation for such events by water managers, potentially mitigating loss of property and production.
Greater resilience to climatic and water supply uncertainty	Improved understanding of key areas of future climate and water supply uncertainty and quantification of water annual supply probability for certain sites enables water managers to factor uncertainty into their water plans, allowing greater preparedness and flexibility in the face of extreme events.
Reduced water availability for some users	In areas where CSIRO's WRAs have shown a need to greater environmental flows, some water users potentially face reduced water access. An example of this is the Murray Darling Basin, where CSIRO's MDBSY and subsequent related research informed the setting of sustainable diversion limits (SDLs).
Environmental impacts	
Increased ecological health of river and groundwater systems	Information on current and future regional water balances enables water managers to be better informed about the impacts of different levels water extraction on the environment. In some cases, such as the Murray-Darling Basin, WRAs have demonstrated the need for increased environmental flows in order to restore damaged rivers and ecosystems. CSIRO has estimated the ecological and economic benefits to be gained from returning 2,800 GL/year of environmental flows (almost the same level as the 2,750 GL/year that is currently being implemented by the Murray Darling Basin Authority) to the Murray-Darling Basin at $3-8 billion (CSIRO, 2012b). In other cases, such as parts of Tasmania and the Flinders and Gilbert catchments, WRAs have demonstrated the local ecosystem's ability to absorb greater levels of water extraction, while at the same time setting upper limits on sustainable levels of water extraction.
Reduced likelihood of serious environmental damage	Better information on thresholds for sustainable water extraction levels lowers the likelihood that water managers will extract water far in excess of these thresholds. Apart from a desire to ensure sustainable levels of water use over the long-term, understanding of sustainable water extraction thresholds by the broader public, government policy makers, environmental groups and downstream water users has the potential to create pressure for other water users to extract within agreed sustainable levels.

Impact	Detail
Social impacts	
Increased sustainability of agricultural communities	CSIRO's integrated water resource assessments can help mitigate shocks from natural disasters, water supply and climate variability and longer-term water supply and climate change, potentially reducing losses and creating greater resilience for communities that are directly dependent upon local water supplies, such as agricultural communities and rural indigenous communities.

H.4.2 Counterfactual

Absent CSIRO's WRAs, water managers would have made decisions without the benefit of rigorous water supply information, increasing the probability of costly delay or error

In the absence of CSIRO, water management and investment decisions would still have been undertaken, but in coming to these decisions the various governments involved would have sought advice from other researchers in either universities or the private sector, most likely through an open tender process. However, an open tender process would not have yielded the diverse and multidisciplinary range of resources and capabilities such as already existed within CSIRO. The advantage CSIRO had was that it was able, on request, to mobilise a large research staff to work on the issues. This was particularly important in light of the difficult and contested questions facing governments in 2006 in relation to the Murray-Darling Basin. It is unlikely that as highly focused a research effort as that delivered by CSIRO could have been mounted through government tendering a range of projects to other researchers.

The experience prior to the initiation of this work suggests that:

- The level of community acceptance of the investment decisions, particularly in areas where there were significant differences of view about competing water use (for example, between environmental or irrigation uses) would have remained low – CSIRO's reputation for high quality scientific research, and consistent delivery of that in the case of water assessments, was an important factor in creating common agreement in the underlying science of water management.
- Information gathering for decision making would have been slower, resulting in loss of efficiency and value. In cases such as the formulation of the Murray Darling Basin Plan, it would have been much more challenging and technically demanding for the Murray-Darling Basin Authority to bring together a fragmented base of evidence, rather than the consistent evaluation framework delivered through the MDBSY and later associated CSIRO research projects.
- Risk of investment in water management systems and infrastructure that may not have proven viable in the face of future climate and water supply change would have been higher.
- Overall, water management and investment decisions in each of the regions covered by CSIRO's WRAs would have been less well-informed and therefore more prone to costly error.

H.4.3 Attribution

Attribution of research effort

70 per cent of the research outputs of the WRAs are attributable to CSIRO

Undertaking multidisciplinary, system-scale R&D is one of CSIRO's key strengths. CSIRO has considerable expertise in terms of quantifying the hydrological resource base, the physical processes, management rules and constraints that affect water balance in basin river systems. Bringing hydrological and climate scientists together was a unique and important part of CSIRO's success in its integrated water resource assessments. CSIRO is the only organisation that holds capability at this scale and breadth of operation in Australia, and probably the world – particularly with its specific focus on integrated river basin modelling (CSIRO, 2013b).

At the same time, CSIRO partnered with a range of organisations, including partners in government agencies and the private sector, in order to increase CSIRO's capacity and access to information. These partner organisations such as the Bureau of Meteorology, Sinclair Knight Merz (now Jacobs) and Geoscience Australia made important contributions to CSIRO's water resource assessments. However, CSIRO remains the largest water research organisation in terms of both its scale and the breadth of operations in Australia, housing a relatively comprehensive set of cross-disciplinary skills and expertise necessary to carry out ambitious water resources assessments. Moreover, while different partner organisations brought important research capabilities to individual WRAs, CSIRO remained the chief organising force. Therefore, ACIL Allen attributes 70 per cent of the research outcomes of the WRAs to CSIRO.

H.4.4 Adoption

CSIRO's water resource assessments have been commissioned by Australian Governments. As the discussion of project outcomes above indicates, incorporation of WRA tools, methodologies and research into water management and investment decisions making has been substantial, particularly in the case of the MDBSY, SEACI and the Tasmania SY.

CSIRO's WRAs have been brought to bear on water investment decisions worth billions of dollars

However, while it is possible to roughly estimate the value of investment decisions that have utilised WRA research, tools and methodologies so far, the primary function of the WRAs – to provide better information to underpin better and more efficient decision-making – makes ascribing an exact adoption rate difficult. As there has been no coordinated and comprehensive effort to track when, how and to what extent CSIRO's WRAs have been incorporated into government and private section decision-making, precisely quantifying the level of adoption of WRAs is challenging. Nonetheless the impacts of adoption so far can have been significant, considering the large value of just a few investment decisions that WRAs have influenced:

- In the Murray-Darling Basin, the government has committed to water buy-backs worth $3.2 billion and investment in new water-efficient infrastructure necessary to return 2,750 GL/year of environmental flows by 2019 (Department of the Environment [b]).
- SEACI modelling, methodologies and data have been integrated into 'Sustainable Water Strategies' for each region in Victoria over the period 2006-2011 as well as each of Victoria's 17 water corporations' 'Integrated Water Cycle Strategies'. As such, SEACI has the potential to influence the decision-making process for all major water investments in Victoria. Many of these water investments involve projects with capital costs of several billion dollars in government and private spending, such as Victoria's irrigation modernisation projects (Department of Environment and Primary Industries, 2014; see also Department of Sustainability and the Environment, 2011a and 2011b).

— The Tasmanian and Federal governments and private investors have committed a total of $310 million according to the construction of ten irrigation schemes in Tasmania, with investment decisions resting heavily on sustainability assessments derived from CSIRO's Tasmania SY project (Tasmanian Irrigation, 2012).

— ACTEW Water incorporated SEACI climate modelling into its water security assessments that underpinned the $363 million expansion of the Cotter Dam in the Australian Capital Territory (Independent Competition and Regulatory Commission, 2010).

This indicates that CSIROs WRAs have been integrated into water management decision making that has produced investment of at least $3.9 billion in water management systems and infrastructure. As ACIL Tasman noted in its previous review of the Water for Healthy Country Flagship, the domain in which CSIRO's WRAs operate has 'big dollar games' afoot, meaning that there are potentially very large values associated with early identification of the more cost effective approaches available and even marginal gains in efficiency (ACIL Tasman, 2006).

H.5 Assessment of impacts

H.5.1 Impacts to date

The WRAs have delivered benefits to Australia, due to …

By enabling better understanding of current and future water supply, CSIRO has delivered information that which allows water managers to make decisions about where water should be directed and how it should be used, with better understanding of what impacts and trade-offs those decisions will involve.

….increased economic and environmental water use efficiency, and …

This increases the probability that those decisions will deliver more efficient water use. In particular, the WRAs enable water managers to deliver two distinct types of efficiencies. One is greater economic efficiency: for example, as a result of the WRAs, water managers now have a better idea of what areas of Australia can sustain irrigated agriculture up to what level of water extraction. As a result, these water managers can make decisions that deliver lower long-term costs and higher returns. Another is greater environmental efficiency: for example, water managers now have a better idea of what areas of the environment are most vulnerable to environmental degradation, and where restoring certain volumes of environmental flows will produce the largest environmental benefits. This means that water managers' decisions on returning environmental flows can be better targeted to produce maximum environmental outcomes.

…lower probability of high-cost/loss-making water investments

In addition to delivering greater economic and environmental efficiency, the WRAs enable water managers to better avoid large costs. Again, these avoided costs are both economic and environmental. The WRAs can enable water managers to avoid large environmental costs by highlighting the environmental sustainability 'thresholds' above which further water extraction could lead to severe environmental damage. Because these 'thresholds' are now known and backed up by rigorous science, CSIRO's WRAs decrease the likelihood that water decisions that bring severe environmental loss will proceed. This is particularly relevant in the context of the original rationale for the WRAs themselves – providing information needed to underpin better water management in the Murray-Darling Basin at a time (2006) when a combination of severe drought and water mismanagement meant that some areas of the Lower Murray were threatened with irreversible environmental damage over a wide area. By the same token, the WRAs can enable water managers to avoid large economic costs. By highlighting the sustainable limits of water extraction in a given area, the WRAs can help guide investment decisions in water infrastructure, such as irrigation and dams, that will be underpinned by more consistent water supply into the future. This

minimises the danger that large water infrastructure investments will become stranded or loss-making, due to shortages of water supply.

Some of these benefits lie in future, but many have already been delivered due to strong uptake of WRAs

Given that WRAs have already been closely incorporated into water decision-making in Tasmania (in relation to irrigation), the Murray-Darling Basin (in relation to sustainable diversion limits), Victoria (in relation to regional and corporate water planning), and the Australian Capital Territory (in relation to ACTEW Water's water infrastructure investment planning), these benefits of greater efficiency and avoidance of large potential future losses have already been delivered, and will continue to be delivered with the extension of research from the WRAs and uptake by more water managers.

H.5.2 Potential future impacts

Future integrated water resource assessment projects

Pilbara water resource assessment – partnering with WA government and industry

WRAs are being adapted and extended to a range of new applications.

CSIRO is currently undertaking a further integrated water resources assessment in the Pilbara region of northern West Australia in partnership with the WA government and BHP, the findings from which will be delivered in March 2015. This WRA follows in the tradition of previous WRAs outlined in this report and builds upon previous WRA methodologies, tools and research findings. This has led to initial cooperation with a range of resource sector companies and government agencies interested in the Pilbara on the development of a cumulative impacts management framework for water management in the Pilbara, which is in early stages of development. Should CSIRO be asked to proceed with this work, the value to the iron ore mining industry in WA alone is expected to be significant (water is the single largest compliance issue for iron ore miners in WA in dollar terms).

National Water Accounts and Australian Water Resources Assessments – operational delivery by the Bureau of Meteorology

Underpinning the new National Water Accounts and Australian Water Resources Assessments (which are delivered through the BoM website) is the work of the Water Information Research and Development Alliance (WIRADA), a partnership between CSIRO and BoM. WIRADA has expanded innovations developed under SEACI and the MDBSY to improve the quality and range of BoM's water data reporting, making BoM water data consistent, integrated, and easy to use. BoM's National water accounts and Australian Water Resources Assessments provide information on climatic conditions and landscape characteristics, patterns and variability in water availability over time, surface water and groundwater status, floods, stream flow salinity and inflows to wetlands, and urban and agricultural water use. The Australian water resource assessments include an integrated landscape, groundwater, river routing and data assimilation modelling system that can produce water balance terms on a 5km grid covering the entire continent on a day-by-day basis. National water resource assessment reports have been published for 2010 and 2012 by the Bureau of Meteorology.

Bioregional assessments

Just as public concern over water management in the Murray Darling Basin launched the sustainable yields projects in 2006, growing public concern over the water trade-offs involved in coal seam gas (CSG) and large coal mine developments has prompted the Commonwealth Government to initiate a program of risk-based cumulative bioregional impact assessments to assess the impact of CSG exploration and production and coal mining on water resources and water-dependent assets. The bioregional assessments program builds upon the success of the Sustainable Yields projects and involves many of

the same core partners: CSIRO, the Bureau of Meteorology and Geoscience Australia. The mandate involves CSIRO and its partners carrying out 15 bioregional assessments for Australia's major coal basins, to be delivered by June 2016.

In particular, bioregional assessments will involve an extension of the Great Artesian Basin Water Resources Assessment study. The methodologies and capabilities developed in that study will be extended to assess deep groundwater, connectivity and impacts on ecological assets.

The new methodologies, tools and informatics capabilities developed in the course of the bioregional assessments will provide an information platform and capacity to transparently audit and repeat further future bioregional assessments.

Improved Bureau of Meteorology streamflow forecasting

CSIRO and the Bureau of Meteorology have formed a partnership, the Water Information and Research Development Alliance (WIRADA), which draws on past work developed under SEACI. In particular, WIRADA has extended SEACI research to produce a new seasonal streamflow forecasting service delivered by BOM, covering the east and north-east regions of Australia. This tool can also be used by farmers, irrigators and water managers to manage their water based on likely inflows into their catchments over the coming three months (CSIRO 2013a).

International water resource assessments

CSIRO is in the process of applying the suite of methodologies, tools and capabilities developed in undertaking Australian water resources assessments to water basins overseas. WRAs are currently being undertaken in Bangladesh by CSIRO in partnership with the Australian Department of Foreign Affairs and a number of local partners including the Bangladesh Water Development Board (CSIRO 2014b). CSIRO is also intending to expand its WRA work into other areas of South Asia characterised by difficult water use trade-offs and large reductions in environmental flows, including Nepal, India and Pakistan.

Greater monitoring of uptake

Going forward, CSIRO is seeking to develop methodologies to more accurately track the uptake and use of its integrated water resource assessments, in order to better understand the end-application of this work and inform future development of further water resources assessments.

H.5.3 Benefit Valuation Analysis

In this benefits valuation, ACIL Allen has assessed the economic and environmental benefits from two water management decisions – the imposition of sustainable diversion limits (SDLs) in the Murray-Darling Basin and Tasmania's irrigation building scheme – that have been directly influenced by CSIRO's WRAs. Valuation of the benefits derived from these two examples forms a lower-bound estimate of the impact of all the WRAs. This report does not seek to place a value on the total benefits delivered by all of the seven WRAs. Because the WRAs are primarily focused on delivering information that aims to change how water is allocated, quantification of benefits would require data on:

1. how water was allocated before WRAs were incorporated into decision-making,
2. what decisions were made and to what extent the WRAs influenced those decisions,
3. how water allocations changed as a result of those decisions, and,
4. what benefits were gained as a result of changes in these water allocations.

Satisfying this four-step process is not possible for all of the seven WRAs. In many of the regions where CSIRO has carried out WRAs, such as northern Australia and Tasmania, detailed water consumption data is difficult to obtain due to lack of data collection. Moreover, there has been no coordinated and consistent effort to track all of the water management and investment decisions in Australia that utilised WRAs information or methodologies, or to analyse the extent to which WRAs have influenced specific water management decisions. Finally, even where information exists on decisions that incorporated CSIRO's WRAs, many of these decisions have not been subject to a separate analysis of the economic, environmental and social benefits arising from changed water management. While the WRAs have collectively delivered significant benefits to Australia, these information constraints make quantifying the entire impact of all of the WRAs surveyed in this case study challenging.

We quantify benefits delivered by CSIRO's WRAs through two examples: environmental benefits in the Murray-Darling Basin, and economic benefits in Tasmania.

While examining only two examples of the impact of CSIRO's WRAs can only represent a slice of the overall benefits that CSIRO's WRAs have delivered, examining the impacts of SDLs in the Murray-Darling Basin and irrigation schemes in Tasmania, and analysing how much of those impacts can be attributed to CSIRO, enables us to pinpoint a lower-bound monetary value that can in turn suggest the magnitude of likely benefits that all of the WRAs together have delivered.

Environmental benefits delivered by the WRAs: returning environmental water to the Murray-Darling Basin

CSIRO's Murray-Darling Basin Sustainable Yields project has delivered substantial value through its influence on the imposition of sustainable diversion limits (SDLs) in the Murray-Darling Basin. ACIL Allen has chosen this example to illustrate the environmental benefits that the WRAs deliver, because it satisfies the four-step process described above:

1. We have information on how water allocations before SDLs were introduced. In 2009, which is the baseline year for the Murray-Darling Basin Authority's SDLs, an average 13,623 GL/year was diverted for human consumption.
2. We also have a specific decision that was made based upon CSIRO's WRAs: when the Murray Darling Basin Authority set sustainable diversion limits for each area of the basin, and for the basin overall, the scientific research underpinning those limits was largely provided by CSIRO and delivered through the River System Modelling Project and the Groundwater Assessment Project. These two projects were based heavily upon the research findings, tools and methodologies developed in the MDBSY.
3. We also have information on how water allocations have changed/will change as a result of this decision. The Murray Darling Basin Plan aims to return 2,750 GL of water per year to environmental flows by 2019, which means that by 2019, long-term human water consumption in the basin will have dropped to 10,873 GL/year.
4. As discussed below, studies commissioned by the MDBA have assessed the benefits and costs associated with returning 2,800 GL/year of water to the Murray Darling Basin (a figure only slightly above the SDL target that was eventually agreed upon, which is 2,750 GL/year).

Benefits of returning 2,800 GL/year to the environment

A CSIRO study identified $3-8 billion in environmental benefits from returning 2,800 GL/year of water to environmental flows in the Murray-Darling Basin

In 2011-12, CSIRO was commissioned by the Murray-Darling Basin Authority (MDBA) to identify and quantify the ecological and ecosystem services benefits that are likely to arise from recovering 2,800 GL/year of water for the environment in the Murray–Darling Basin and, where possible, to elicit the monetary value of those benefits. The baseline scenario for this analysis was water flow in the Murray-Darling Basin under June 2009 water

management arrangements (including dams, environmental works infrastructure and consumptive uses). CSIRO's study also incorporated the findings of a range of previous studies also commissioned by the MDBA. The benefits estimated from this study can be assumed to closely correlate with likely benefits from the sustainable diversion limits (SDLs) imposed by the MDBA.

The CSIRO study found that the additional Basin-wide value of enhanced habitat ecosystem services – arising from floodplain vegetation, waterbird breeding, native fish and the Coorong, Lower Lakes, and Murray Mouth – is worth between AU$3 billion and AU$8 billion in present value 2010 dollar terms under the 2,800 GL/year scenario relative to the baseline scenario.[17] This estimate of the value of ecosystem services rested primarily on benefits transfer analysis.

Other benefits due to improvements in other ecosystem services include:

- Additional carbon sequestration within river red gum and blackbox floodplain vegetation that is maintained in a healthy condition, which is worth between AU$120 million and AU$1 billion.
- Increased supply of aesthetic appreciation ecosystem services under the 2,800 GL scenario relative to the baseline scenario, potentially worth more than AU$330 million
- Avoided damage and treatment costs associated with the supply of fresh water, worth in the order of AU$30 million.
- Tourism benefits, estimated to worth up to AU$160 million annually.

However, CSIRO cautioned that, to avoid the risk of double counting, monetary values such as the above should not be summed to a single value because of possible overlaps. For example, the non-use values that underpin the habitat values might also capture some aspects of other ecosystem services such as recreation and mental health, or aesthetic appreciation and cultural inspiration (CSIRO, 2012b).

Attribution of benefits to CSIRO's MDBSY

How much of the estimated environmental benefits, $3-8 billion, are attributable to CSIRO, and specifically to the role CSIRO played in the MDBSY project? To establish a lower-bound estimate, ACIL Allen assumed that the MDBSY resulted in water management and usage that delivers a 10 per cent increase in overall environmental value compared to the counterfactual, i.e. the decision that would have been made absent the rigorous information base that the MDBSY provided. This level of attribution is in line with previous related studies: a 2009 review of the Water for a Healthy Country Flagship by Deloitte Access Economics attributed 5-10 per cent of the benefits linked with the Flagship's research to CSIRO, while a 2006 review of the Water for a Healthy Country Flagship by ACIL Tasman's ascribed 10 per cent of the benefits linked to the Flagship to CSIRO.

When this attribution rate is applied to CSIRO's lower-bound estimate of the benefits of returning 2,800 GL/year of environmental flows to the Murray-Darling Basin, the share of benefits attributable to the MDBSY would be equal to $300 million (i.e. 10 per cent of $3 billion in estimated benefits). Remembering that other organisations contributed to the research outputs of the MDBSY, and that this report ascribes an average 70 per cent of the research outputs of all WRAs to CSIRO, the share of roughly $3 billion in benefits

[17] Note that the CSIRO report does not provide information on the timing of the stream of benefits for the ecological indicators or water quality benefits that underpin the monetary values calculated in the report. However, the report uses pre-existing Centre for International Economics (CIE) methodology to estimate present value for values related to ecosystem service of habitat. CSIRO's report does not include a discount rate. Other estimates of value are estimated in annual 2010 dollars. More details of this methodology are available on p. 146 of CSIRO's report (CSIRO, 2012b).

attributable to CSIRO's work in the MDBSY would be equal to $210 million in present value 2010 dollar terms (i.e. 70 per cent of 10 per cent of $3 billion in estimated benefits).[18]

$210 million: our lower-bound estimate of the environmental value delivered by CSIRO's MDBSY through sustainable diversion limits

$210 million is an approximately lower-bound estimate of CSIRO's contribution to the expected benefits of restoring 2,750 GL/year of environmental flows to the Murray-Darling Basin under the MDB Plan, as delivered through the MDBSY. This is well in excess of $54.2 million in total costs for all seven of CSIRO's integrated water resources assessments (including SEACI), meaning that this figure alone – a lower bound estimate of the benefits attributable to only one decision based on only one of the seven WRAs – covers the costs of the entire research program.

However, we consider a 10 per cent attribution rate to be a highly conservative estimate of the impact of MDBSY on the imposition of sustainable diversion limits. Whereas previous Deloitte and ACIL Tasman reviews examined the highly diverse programs and impacts of the entire Water for a Healthy Country Flagship, in this case we are examining a situation in which there is a clear line of sight between the one project, MDBSY, and its influence on one decision, sustainable diversion limits:

- CSIRO provided the main modelling and research tools upon which the calculation of SDLs for each part of the basin rested. Moreover, the transfer of water systems modelling capability to MDBA provided the opportunity to extend the WRA as part of Basin Plan modelling.
- Absent CSIRO's input into defining and quantifying sustainable diversion limits, there would have been a less rigorous scientific based for establishing those limits, because there would have been no study that assesses water supply in a consistent way across the entire basin, including forecasts of future water supply based on climate change modelling.
- Even if other researchers had been called upon to conduct a water resources assessment in the Murray-Darling Basin in 2006, no other organisation in Australia has the range and depth of in-house capabilities that could be brought to bear on this sort of project that CSIRO has. Rather than the consistent, basin-wide framework delivered by the MDBSY, the outcome of an open tender process would likely have been a far more fragmented and ultimately less useful research output.
- The political process that lead to the Murray-Darling Basin Plan, and the aim to return 2,750 GL/year of water to environmental flows, would likely have been longer and more contested absent CSIRO's scientific assessment and trusted public image.

$1.12 billion: our upper estimate of the environmental value delivered by CSIRO's MDBSY through sustainable diversion limits

Therefore, to establish a more realistic estimate of benefits delivered by the MDBSY, we assume that 20 per cent of the impacts of returning 2,750 GL/year to environmental flows to the Murray-Darling Basin can be attributed to the MDBSY. Using CSIRO's upper-bound estimate of benefits ($8 billion) as a result of returning 2,800 GL/year to environmental flows, the total benefits attributable to the MDBSY are equal to $1.6 billion (i.e. 20 per cent of $8 billion). Remembering that 70 per cent of the research outputs of the MDBSY are

[18] Actual benefits may be slightly lower than this estimate given that returned environmental flows that the environmental flows assessed by CSIRO in its benefits estimate (2,800 GL/year) is roughly 1.8 per cent higher than the SDL target that was eventually agreed upon (2,750 GL/year). Benefits attributable to CSIRO's role in the MDBSY that are based on CSIRO's 2,800 GL/year benefits estimates have not been adjusted for this difference ($1.8 per cent) because the marginal benefits of higher or lower levels of environmental flows do not increase in a linear way. Modest increases in environmental flows may produce an increase in the value of total benefits that is far higher than the rate of increase in environmental flows when an ecosystem has suffered from very low levels of environmental flows historically. Conversely, for an ecosystem with historically healthy levels of environmental flows, large increases in environmental flows will not necessarily produce equally large benefits.

attributable to CSIRO, the total benefits attributable to CSIRO's work in the MDBSY are equal to $1.12 billion in present value 2010 dollar terms.[19]

$600-700 million: our mid-point estimate of the environmental value delivered by CSIRO's MDBSY through sustainable diversion limits

Given the large variation between these upper and lower bound estimates, and given the fact that the lower-bound estimate represents a highly conservative level of attribution, we argue that a mid-point figure, $600-700 million in present value 2010 dollar terms, represents a more reasonable estimate of the environmental benefits delivered by CSIRO's MDBSY as a result of its influence over sustainable diversion limits in the Murray-Darling Basin.

Costs of returning 2,800 GL/year to the Murray-Darling Basin

Returning 2,750 GL/year to environmental flows also entails costs, at least over the short-to-medium term, to irrigated agricultural production, as much of the 2,750 GL/year will be allocated away from irrigators. The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) has estimated at an annual cost of $542 million in gross lost agricultural production from 2,800 GL/year of water being returned to environmental flows (CSIRO, 2012b).

An ABARES study has identified costs to agricultural production as a result of SDLs, which we calculate to be $477 million

Given that this is an estimate of gross (rather than net) loss, ABARES' estimate does not take into account the cost of that agricultural production, which in 2013 was equal 78 per cent of the total value of grain production, meaning that average net returns were 22 per cent of total revenue from the sale of grain crops, according to ABARES (Valle, 2014). However, farmers that choose to sell water through the MDBA's water buyback scheme are more likely to do so if they value of the water they sell is higher than the agricultural production that they would yield from that water. This suggests that the most productive agricultural producers are unlikely to sell their water rights, because they will gain higher net returns on their agricultural production compared to selling water. In other words, the water buy-backs that underpin SDLs are likely to come from marginally profitable agricultural producers, for whom production costs are higher than the 2013 average of 78 per cent of total revenues from the sale of agricultural products. Assuming that marginal agricultural producers are earning half the returns of the nation-wide average, meaning that these marginal producers only earn an 11 per cent return on agricultural products sold, ABARES' estimate of $542 million in lost agricultural production net of production costs comes down to $59.6 million in net lost annual agricultural production. To convert this annual cost into net present value terms, in order to make it comparable with the benefits discussed in the section above, we apply a standard multiplier of 8 to arrive at roughly $477 million in lost agricultural production in present value terms, significantly lower than estimated environmental PV benefits equal to $3-8 billion.

$15-61 million: our lower and upper-bound estimates of the short-to-medium-term costs delivered by CSIRO's MDBSY through the imposition of sustainable diversion limits

As CSIRO's MDBSY has contributed to the benefits of returning 2,750 GL/year of environmental flows to the Murray Darling Basin through SDLs, it has also contributed to the costs in terms of lost agricultural production, at least over the short-to-medium term. Using the same attribution rates (70 per cent of 5 per cent for a lower bound, and 70 per cent of 20 per cent for a higher estimate), we estimate that CSIRO's work in the MDBSY is responsible for $15 million present value in lost agricultural production, as a lower bound estimate, and $61 million present value in lost agricultural production as a higher estimate.

In reality, the trade-offs between increasing environmental flows and losing agricultural production in the Murray-Darling Basin exist only in the short-to-medium term. Over the longer-term, higher water prices will drive innovation in agricultural production, forcing the

[19] Again, actual benefits may be slightly lower due to the 1.8 per cent discrepancy between the volume of returned environmental water underpinning CSIRO's benefits estimates and the eventual agreed SDL for the Murray-Darling Basin.

agricultural sector to become more water efficient. In addition, increased sustainability of water flows in the Murray-Darling Basin, healthier ecosystems and more resilient water supply will also bring long-term benefits to agricultural production in the form of greater water supply security. Incorporating improved understanding of the limits of water extraction, beyond which the risk of serious damage of ecosystems rises dramatically, decreases the likelihood that the Murray-Darling Basin will enter its next drought with an ecosystem that is already heavily damaged by long-term low environmental water flows. In turn, this will ensure that agricultural production in all parts of the Basin, particularly in the lower reaches of major rivers, will be more sustainable and profitable over the long-term, and less exposed to large losses as a result of catastrophic environmental damage.

The identified benefits more than cover the total program cost of all WRAs

Our lower-bound, mid-point and upper-bound benefits estimates of the environmental delivered by CSIRO's MDBSY through the imposition of SDLs more than cover total program costs for all seven WRAs in this case study of $54.2 million.

Implications for the broader environmental value of CSIRO's WRAs

Given that this evaluation has only examined the benefits associated with one WRA (MDBSY) and one decision (SDLs), it can be assumed that CSIRO's WRAs have delivered environmental benefits in excess of our mid-point estimate of $600-700 million because they have also delivered environmental benefits in other regions and through other water management decisions. This is based on three considerations.

In reality, environmental benefits delivered by all the seven WRAs are likely to be well in excess of $600-700 million

One consideration relates to the fact that uptake of WRAs delivers increased environmental efficiency. Many of CSIRO's WRAs have assessed areas with high levels of ecological degradation and reduced environmental flows. In the Murray-Darling Basin itself and in other areas of Victoria, both the MDBSY and SEACI have influenced a broad range of water management and investment decisions, not just the decision to impose SDLs. While these decision are not always associated with the return of environmental flows per se, they are associated with long-term water use that is less likely to exceed the sustainable limits of water extraction in each area. Given that the MDB and Victoria have been characterised by high levels of water extraction, the marginal benefits of more sustainable water management over the long-term for the environment can be expected to be large. Similarly, in areas such as south-west Western Australia, which has a 35 year declining trend in runoff and consequently decreased environmental flows, the marginal benefits of water management decisions that take account of the natural limits of sustainable water extraction can be expected to be significant.

A second consideration is the avoidance of large future environmental costs. In particular, both Tasmania and Northern Australia have in the past been subject to speculation as to how Australia can harness high levels of local water yield for increased agricultural production. In the case of Tasmania, this ambition has translated a large irrigation-building scheme. In the case of Northern Australia, there have been repeated calls to introduce large-scale irrigation in the region and turn it into a 'food bowl' to meet the growing food demand from Asia. In both of these cases, better understanding of the sustainable limits of water extraction provided by CSIRO's WRAs enables water managers to take sustainable environmental flows into account in their decision-making, potentially avoiding investments that carry large future environmental costs. In Tasmania, this meant proceeding only with irrigation schemes that were shown under CSIRO methods to have sustainable streamflow into the future. In northern Australia, CSIRO effectively busted the 'food bowl' myth, although it has highlighted the potential for smaller scale irrigation in some discrete areas of the north.

A third consideration is that the MDBSY accounted for only 22 per cent of the total input costs of the WRAs covered in this case study. This 22 per cent of total research expenditure

has delivered at least $600-700 million in environmental benefits (remember that only one decision arising out of the MDBSY has been costed), but many other areas covered by the WRAs face widespread environmental problems due to water over-extraction, while other areas have faced the prospect of large-scale water infrastructure development. The small share of the MDBSY in overall inputs compared to the large benefits it has delivered supports the conclusion that the environmental benefits delivered by CSIRO's WRAs are likely much higher than $600-700 million identified in this case study.

Economic benefits delivered by the WRAs: irrigation in Tasmania

ACIL Allen has chosen to use the expected economic benefits of irrigation schemes in Tasmania to illustrate the economic benefits that the WRAs deliver, because this is one of the few WRA-influenced investment decision for which a publicly available economic impact study has been conducted.

Estimate of economic impacts

Tasmanian Irrigation has identified economic benefits equal to $858 million for tranches one and two of Tasmania's irrigation schemes

Tasmania has embarked on a large expansion of irrigation infrastructure that has been co-funded by the federal and Tasmanian state governments, and private investment. In total, Tasmanian Irrigation, the state-owned company responsible for implementing the irrigation schemes, has estimated that the first tranche of ten irrigation schemes in Tasmania will deliver $192 million in direct farm-gate economic benefits and further additional economic value of $384 million, while the second tranche of an additional five irrigation schemes will deliver $282 million in national economic benefits, or $858 million in net present value economic benefits (Tasmanian Irrigation, 2012). All of these figures are net present value calculated over a projection period of 40 years, under a standard six per cent discount rate.

Attribution of benefits to CSIRO's Tasmania SY

How much of these estimated economic benefits are attributable to CSIRO, and specifically, to the role CSIRO played in the Tasmania Sustainable Yield project? ACIL Allen assumed that Tasmania SY resulted in water management and usage that delivers a 10-to-20 per cent increase in overall economic value compared to the counterfactual, i.e. the decision that would have been made absent the rigorous information base that the Tasmania SY provided. ACIL Allen believes that applying the same lower- and upper-bound attribution rate of 10-to-20 per cent that was applied to the Murray-Darling Basin example above is justified, because there is a clear and direct line of sight between Tasmania SY and how that study influenced the decision to invest in large irrigation schemes in Tasmania, and the siting of each individual scheme:

- Tasmania SY techniques, such as land suitability mapping and future water supply mapping, were crucial in demonstrating the economic and ecological sustainability of expanded irrigation in Tasmania, providing the scientific information needed to underpin the then-Premier David Bartlett's announcement of the first tranche of the irrigation scheme in 2010 (The Australian, 2010).
- It is a condition of both Federal government co-investment and investment by Tasmanian Irrigation that all irrigation schemes must demonstrate 95 per cent water supply reliability for 100 years. The research and methodologies underpinning this requirement were first developed and supplied by CSIRO through the Tasmania Sustainable Yields project and then subsequently further developed by CSIRO in partnership with the State government (Tasmanian Irrigation, n.d.; Department of the Environment, n.d.).

$60-120 million: our lower- and upper-bound estimates of the benefits attributable to CSIRO's Tasmania SY project

Based on Tasmanian Irrigation's identification of economic benefits, ACIL Allen estimates lower- and upper-bound benefits from Tasmania's irrigation schemes that are attributable to Tasmania SY of $85.8 million to $172 million in present value terms (i.e. 10 per cent and 20 per cent of total benefits of $858 million respectively). Remembering that this study attributed 70 per cent of the research outputs of the WRAs to CSIRO, the total economic benefits attributable to CSIRO's role in Tasmania SY are equal between $60 million and $120 million in present value terms.

Both this lower and upper bound estimate covers total program costs of $54.2 million for the seven WRAs.

Implications for the broader economic value of CSIRO's WRAs

In reality, the economic benefits of CSIRO's WRAs are likely to be well in excess of $60-120 million

CSIRO's WRAs can be expected to result in water investments that are more economically efficient compared to the counterfactual, in which investment decisions would be made without the rigorous information base the WRAs provide. The type of economic benefits derived from greenfield water infrastructure development, as seen in the example of Tasmania's irrigation schemes can be expected to also occur in other areas where CSIRO has conducted its WRAs. In particular, economic benefits of a similar order of magnitude to those identified in Tasmania could emerge as a result of CSIRO's study of the Flinders and Gilbert Catchment, which suggested that the two rivers can support up to 95,000 hectares or irrigated agriculture. While the recent release of the report in December 2013 means that CSIRO's FGARA has yet to lead to investments on the scale of those in Tasmania, the study has led to increased confidence in the ability of the area to support small-to-medium sized irrigated farms (Tapp, 2014). This can be expected to yield significant economic benefits, particularly for local communities.

In areas that have already seen significant development of water irrigation and storage infrastructure, and where the sustainable limits of water extraction have already been tested, these economic benefits will be dominated by avoidance of large future economic loss, and greater economic viability of future additional water infrastructure development. This is because these additional investment can take place with the benefit of a better understanding of natural limits of sustainable water extraction. The scale of avoided economic losses from investment decisions that later prove to be unprofitable or unfeasible due to changing water supply patterns could be considerable, given that water infrastructure investments can often run into hundreds of millions of dollars for only one project.

Tasmania Sustainable Yield accounted for only 7.7 per cent of total financial inputs into the seven WRAs surveyed in this case study. If 7.7 per cent of CSIRO's WRA budget yielded $60-120 million in economic benefits, it can be expected that the total economic benefits delivered by all seven of the WRAs are likely much higher than this. These economic benefits will continue to grow as WRAs are incorporated into a wider array of investment decisions, particularly in places that have been proven to have significant greenfield development potential, such as the Flinders and Gilbert Catchments.

Overall aggregation of benefits

As a lower estimate, CSIRO's WRAs have delivered approximately $685-795 million in economic and environmental benefits in present value terms. This is based upon the mid-point estimate of benefits delivered by SDLs in the Murray-Darling Basin that are attributable to CSIRO's MDBSY ($600-700 million) and a mid-point estimate of benefits delivered by Tasmania's Tranche 1 and 2 irrigation projects that are attributable to CSIRO's Tasmania SY (i.e. the mid-point between $60 million and $120 million in benefits, which is $85-$95 million). It should be emphasised that these are approximate estimates, due to methodological differences between CSIRO's estimation of benefits in its 2012 report on

returning environmental water to the Murray-Darling Basin and Tasmanian Irrigation's estimate of economic benefits from Tranche 1 and 2 irrigation schemes. Nonetheless these estimates provide an indication of the lower bound of benefits delivered by all of the WRAs. Moreover, the higher estimates of benefits from these two examples – $1.12 billion from SDLs in the Murray-Darling and $120 million from irrigation schemes in Tasmania – suggests that benefits from all seven of the WRAs could be much higher still. This is particularly the case given that Tasmania SY and MDBSY accounted for only 29.7 per cent of the total research budget of all seven WRAs.

The following table presents a summary of the costs and benefits of CSIRO's WRAs and the investment decisions that the WRAs have influenced so far:

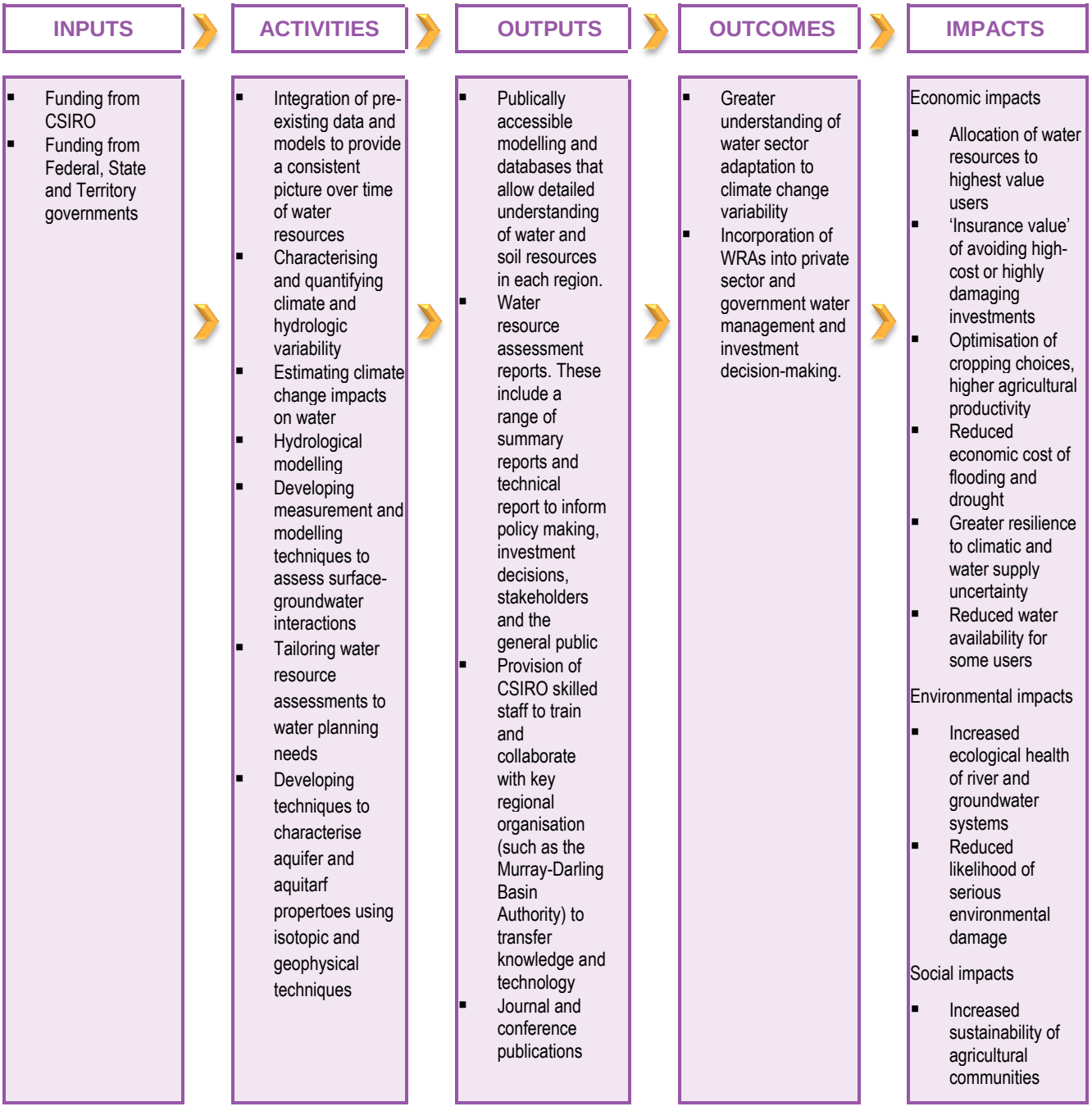
Table H5 **Costs and benefits of WRA impacts and activities**

Activity/impact	Benefit	Cost
CSIRO research	Nationally-consistent water resource assessment framework.	$54.2 million
Environmental impacts	$600-700 million (possibly as high as $1.12 million) from analysis of MDBSY influence on imposition of SDLs. — This represent the outputs of only 22 per cent of total research budget, and only one of many decisions influenced by WRAs. — Therefore environmental impacts of all WRAs is likely to be substantially higher than $600-700 million, and potentually above $1.12 billion.	$15-61 million in lost agricultural production as a result of MDBSY influence on imposition of SDLs. — This is a short-to-medium term cost that will dissipate over time due to positive economic influence of increased water supply security and increased incentive to improve the water efficiency of agricultural production.
Economic impacts	$60-120 million from analysis of Tasmania SY influence of Tasmanian irrigation schemes. — This represent the outputs of only 7.7 per cent of total research budget, and only one of many decisions influenced by WRAs. — Therefore economic impacts of all WRAs is likely to be substantially higher than $60-120 million.	
Capital expenditure on infrastructure construction	Additional economic benefits flowing from construction of improved water storage and consumption infrastructure.	$310 million – Tranche 1 Tasmanian irrigation schemes $363 million – Cotter Dam extension Additional capital spending in Victoria as a result of government and corporate water strategy planning.

Source: ACIL Allen Consulting

H.5.4 Impact pathway diagram

Figure H2 **CSIRO Integrated Water Assessments - impact**



Source: ACIL Allen Consulting

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