

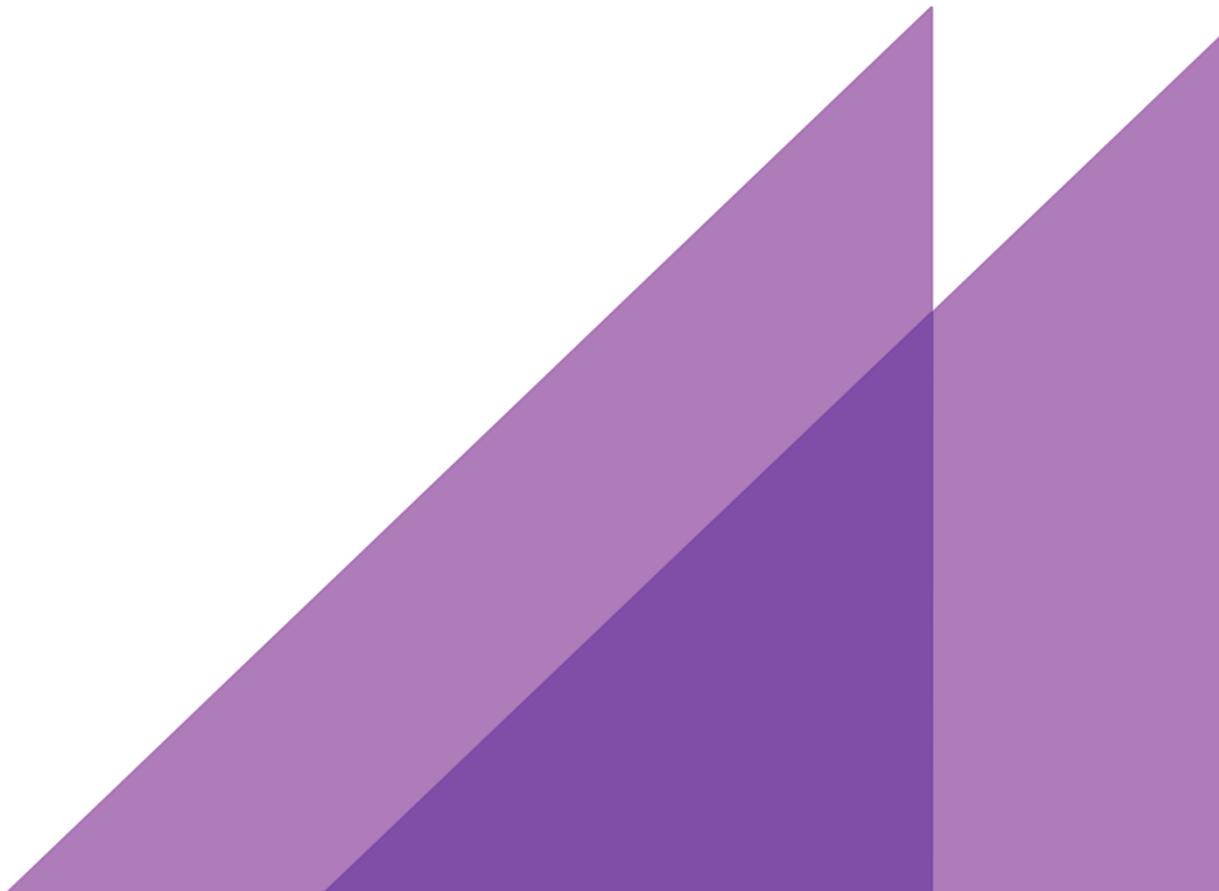
REPORT TO
CSIRO

DECEMBER 2014

CSIRO's IMPACT AND VALUE



AN INDEPENDENT
EVALUATION





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1 Introduction

1.1 Purpose of the report

This report has been prepared for the Commonwealth Scientific and Industrial Research Organisation (CSIRO) by ACIL Allen Consulting Pty Ltd (AAC). It provides an independent assessment of a select number of cases in which to measure the economic, social and environmental impact and value of CSIRO, and compares this to the level of investment it is obtaining from the Australian Government.

This report assesses CSIRO's impact and value

The report focuses on the current CSIRO strategy period – 2011-2015. However, it necessarily takes into account the fact that the value and impact of CSIRO's activities across this period have drawn heavily on earlier work and capability established before 2011, while many of the impacts relevant to assessing the value of the work during the current strategy period can be expected to arise beyond 2015.

This delivery of value and impact over time is inherent in the nature of investment in research, development and innovation – and must be factored into any balanced assessment of impact and value.

There is strong evidence of high impact and value

The report provides solid quantitative evidence of high value and impact, but it also addresses the reality that a proportion of CSIRO's work – and associated impacts – do not lend themselves to accurate and uncontroversial quantification. Any assessment of impact and value that looks only at the readily quantifiable impacts would not do justice to the full value of CSIRO's work. We have therefore sought to provide balance by looking carefully at a range of ways in which CSIRO delivers impact and value.

Our findings are underpinned by the analysis of seven case studies ...

The assessment has been based on a cumulative assembly of evidence. At the heart of the assessment are seven case studies of specific CSIRO initiatives. Some of these are recent projects and some are activities that have been in train over much longer time frames. The breadth and depth of activity illustrated by the eight case studies is in itself a powerful illustration of how CSIRO delivers value and impact.

... and supported by other analysis

Our analysis has been augmented by consideration of what the case studies can tell us about the entirety of CSIRO's project and program activities. We have also revisited recent analogous reviews of CSIRO impact and value, and looked in some detail at the range of values offered by CSIRO beyond project and program specific values.

1.2 Case studies

CSIRO manages a large and diverse research and development portfolio. A case-by-case detailed review of every one of its activities would be a massive undertaking, even before any attempt to develop a coherent understanding of the overall impact and value. Even if a comprehensive review of all areas of activity was feasible, such a review would struggle to do justice to the value and impact, particularly given the complex ways in which different areas of capability interact, such as through the formation of multidisciplinary teams to address priority opportunities and challenges.

CSIRO is much more than the sum of its parts

It is clear that CSIRO is substantially more than the sum of its individual research activities and that a comprehensive and balanced assessment of impact and value needs to look beyond the current individual activities.

Of course, all areas of CSIRO activity are subject to periodic review and assessment to inform strategy and investment decisions. This review (like its predecessors) has adopted an approach that involves detailed probing of seven case studies as a central component of the overall assessment of the impact and value delivered by the whole of CSIRO.

These case studies provide solid quantitative and qualitative economic, social and environmental indicators of the types of value and impact being delivered at the projects and programs level. They not only allow detailed program level consideration of investment performance for the case studies on their own, but also inform the inference of highly conservative but also highly credible indicators of the value and impact of the overall portfolio of research activity.

Our analysis provides high credibility insights into the value and impact of CSIRO

This, together with the results from previous assessments of CSIRO impact and value, delivers high credibility insights into the value and impact of CSIRO as a whole.

In selecting the case studies, emphasis was placed on illustrating the diversity of CSIRO activities. We also sought to extend the examination of past case studies and to look in detail at areas that, on their own, show good prospects for demonstrating high value and impact. The case studies have not been chosen to be 'statistically representative' of all of CSIRO's work. However, they are representative of the broad areas where CSIRO undertakes major activity. This, together with the results of past assessments and other information about CSIRO as a whole, allow us to arrive at a highly credible but still conservative assessment of the impact and value of the whole of CSIRO.

2 Discussion of the Task & Approach

This Chapter of the report provides an overview of the task that ACIL Allen was commissioned to undertake. It discusses the CSIRO's approach to project evaluation and how the organisation's mission orientation has driven the evolution of its structure. It then summarises a number of previous projects that examined the impact and value of CSIRO's research, considers how benefits have varied over time and introduces the concept of standing capability and the value that it can bring. The chapter concludes with an explanation of the approach adopted in our analysis.

2.1 What do we mean by 'impact and value'

CSIRO operating budget in 2013-14 was around \$1,249 million. About \$757.1 million (or 60.6 per cent) is directly funded through government appropriation. CSIRO 2013-14 Annual Report reports a balance sheet of the order of \$2,237million. CSIRO employs more than 5000 of Australia's brightest and most creative people. In short, CSIRO represents a substantial, on-going investment by the nation.

This independent assessment of CSIRO's impact and value seeks to deliver a better understanding of the benefits that Australia gains from making its investment in CSIRO. The community reasonably expects that significant beneficial impacts will flow from the substantial, ongoing investments made. This review has found that CSIRO is delivering value well in excess of the investment made in it.

However, the scale, diversity and nature of CSIRO's operations, along with the manner in which CSIRO complements the rest of Australia's innovation system, all indicate that we need to look beyond simple 'return on investment' to the nation considerations if we are to do justice to the full scale and scope of CSIRO's impacts and their associated value.

CSIRO defines its mission as being to

...deliver great science and innovative solutions for industry, society and the environment

R&D creates *new options* for society, by delivering new knowledge and technical capabilities relevant to the use of that knowledge. Innovation overlaps strongly, but brings a strong emphasis on tapping into knowledge to design and deliver smarter ways of meeting society's needs and objectives. Innovation provides the bridge from new knowledge into the actual delivery of realised value to society.

Classical cost-benefit analysis tends to focus on monetary wealth as a simple indicator of well-being – investments that build monetary wealth, after accounting for investment costs, are viewed favourably. Modern cost-benefit-analysis commonly extends the coverage beyond just financial wealth – allowing scope for including less tangible impacts, such as better social and environmental outcomes, provided that it is possible to approach these impacts in terms of how much wealth people might forgo, in order to secure these benefits.

The community expects to see benefits flow from the investments made in CSIRO

R&D creates new knowledge that innovation can then translate into benefits for society

Impact and value can be viewed and judged in many different ways

In looking at CSIRO's impact, and how we might assess the value of that impact, it is appropriate to start with the view that we are interested in beneficial changes in quality of life, across its many dimensions. This includes the important dimensions of:

- Personal and national wealth
- Health and welfare
- Enjoyment of amenity
- Security.

The triple bottom line impact categories used in CSIRO's Impact Evaluation Guide are listed in Table 1.

Table 1 Triple bottom line (TBL) impact categories

Environmental impact categories	Social impact categories	Economic impact categories
Air quality	Life & health	The macro economy
Ecosystems & biodiversity	Equity and equality	The micro economy
Climate and climate change	Social connectedness	International trade
Disaster mitigation	Standard of living	Management and productivity
Energy generation and use	Safety	Measurement standards and calibration services
Land quality and management	Security- civil	Economic frameworks and policies
Water quality and management	Security – military	New products or services
Oceans and marine environment	Security – cyber	
Sustainable industry development	Social consciousness	
	Social licence to operate and community confidence	
	Resilience (community and industry)	

Source: *CSIRO Impact Evaluation Guide*, CSIRO, April 2014

While all major investments have to deal with substantial uncertainty, CSIRO has a particularly strong and direct emphasis on the delivery of value by building knowledge and reducing uncertainty. This emphasis on the discovery of new knowledge, and the cultivation of new capabilities, does differentiate R&D, and innovation, from other forms of investment where the pathways to value are typically more clearly defined. This is particularly so given that the most valuable applications of those new capabilities may not yet be well understood.

CSIRO is an important element of Australia's innovation system

CSIRO is, of course, not alone in this emphasis on knowledge creation and innovation – though we argue below that it has a special role within Australia's innovation system. Other research organisations, including universities, Cooperative Research Centres (CRCs) and government research agencies, and the research arms of bigger organisations, resource exploration firms, organisations investing in emerging technologies and, to a large extent, our entire education system have analogous roles. They all rely heavily on the proposition that better knowledge and skills, backed up by a system that allows that knowledge and skill to be applied, will fuel beneficial innovation that will translate into gains for industry (and, in many cases, society and the environment) to justify their funding. All of these groups (and more) are components of Australia's innovation capability.

CSIRO is a large and diverse research organisation, even by international standards. However, CSIRO constitutes about 4 per cent of the national research workforce, and less than 8.9 per cent of the non-business sector research workforce – covering higher education, government and non-profit areas.

In general, when we consider CSIRO's impact and value, we are concerned with the *value added* as a result of CSIRO's involvement – value that would not have arisen, been delayed, or whose benefits would not be as readily capable of being captured by Australian industry and society without CSIRO's input. This value adding can arise simply from CSIRO adding to the level of resourcing of the innovation sector. However, it can also arise from the way that CSIRO can influence the shape, and overall capability of, the innovation sector – by *complementing* the rest of the sector due to its scale, scope, focus, capabilities, capacity for leadership and established networks and partnerships. These can all be tapped to yield value directly and to create opportunities for other parts of the innovation system to deliver greater value.

These matters are all legitimate concerns with any assessment of CSIRO's impact and value – and are addressed in some detail in this report. CSIRO has repeatedly demonstrated strength in delivering research leadership, in mounting rapid, mission-oriented responses to emerging threats and opportunities, and in using its scale, external relationships and diversity to allow better management of innovation risks.

2.2 CSIRO's mission-orientation

CSIRO is a mission oriented organisation

From the time of its foundation, CSIRO has had an important role to play as a 'mission-oriented' organisation, with the skills, external relationships, culture and organisational structure that allow it to move rapidly, and at a scale, to address emerging challenges and opportunities. Recent developments in CSIRO have strengthened this mission orientation. These developments include the formal emergence in 2003 of Flagships (initially in a matrix structure drawing research capability from the research Divisions) as an important focus of CSIRO activity. In mid-2014 the decision was taken to extend this approach and move fully away from the Flagship-Division matrix structure to one in which Flagships (along with Services, Facilities and Collections) have become the primary organisational units of CSIRO across which research capability can be deployed.

CSIRO influences the nature of innovation in Australia

This shift in emphasis and operating model strengthens the argument that CSIRO's value lies not just in how it *adds to the intensity of research*, especially publicly funded research, but also in how it could *complement the wider innovation system* via these differences in approach. In effect, it suggests that CSIRO changes the shape, as well as the level of investment in innovation, and may be a powerful agent for increasing the value of innovation occurring outside of CSIRO as well as within. Universities have researchers with broadly similar capability to CSIRO researchers, but there are important cultural differences. In many respects, the development of CSIRO's Flagships can be seen to reflect, and strengthen, this cultural difference towards mission directed multidisciplinary research.

Broadly analogous programs of focused, multidisciplinary research are evident in areas of medical research, in some university-based centres and in some state government research agencies. However, almost always with a substantially narrower focus in terms of disciplines covered and research priorities. Examples also exist in the commercial world, though the large-scale examples of these are mainly overseas. In general, university researchers tend to operate in ways that entail less scale and scope. They have greater reliance on talented individuals 'following their noses' – with their research efforts often delivering high value in the form of specific outputs and in the development of

knowledge and technologies that themselves deliver opportunities for future larger scale, collaborative application.

CSIRO's mission oriented approach complements the rest of the innovation system

The relatively less directed type of research undertaken by universities has a fantastic record in delivering the building blocks for high value applied innovation. In making the above observations, we are not suggesting that CSIRO offers a better way – but rather that CSIRO seeks to follow a complementary path rather than just a parallel path. In doing so it seeks to add value by changing the shape, as well as adding to the intensity of, the innovation system.

A key aspect of CSIRO's approach that appears to offer something that is both strikingly different and complementary is its focus on directing resources at major opportunities and challenges. The scale and scope of the standing capabilities that CSIRO can rapidly draw on in response to an emerging opportunity is of course crucial to its approach.

However serendipitous discoveries also play a role

In emphasising the mission orientation, we do not suggest that CSIRO cannot generate extremely high value innovation outcomes through divergent and often unexpected pathways. Serendipity has a proud history in throwing up high value opportunities to deriving value from research. However, just as important is a culture and capability geared to recognising and exploiting these opportunities. Its strong mission orientation offers a powerful way of gaining greater value from serendipitous insights that commonly flow from any research program.

Wi-fi was such a serendipitous discovery

The wi-fi capability that CSIRO delivered and commercialised in the 1980s was based strongly in its leading edge industrial physics capability, but it was application of these capabilities to the design of new radio astronomy instruments that led to a mature technology that has since been demonstrated to have a very high commercial value and has dramatically changed the world we live in.

In the early '90s, a number of research groups and companies around the globe were in a race to develop fast wireless technology. One technical solution in particular came through and has been adopted and implemented by the market - that was the invention by the CSIRO team of fast WiFi, which was then demonstrated as a product prototype by a startup company formed by a group of Australians called Radiata. The fast wireless technology that is in all of the computers and now phones and mobile devices that everyone use daily, was an Australian invention.

Back in the 1990's Australian radio-astronomer John O'Sullivan developed a key piece of technology - a mathematical algorithm that can be used for complex mathematical transformations - and he developed this for use in astronomy research. Several years later, O'Sullivan was part of a team of engineers and scientists, working at the CSIRO that set themselves the challenge of developing wireless technology with the aim of this being as fast as communication through wires. They came up with an invention that did this - and this solution was made possible through the algorithm (fast fourier transformation) that had been developed several years before in the astronomy research.

Importantly, a key factor in CSIRO resourcing the radio astronomy work that crystallised the wi-fi breakthrough was the recognition of the *inherent fertility* in achieving a breakthrough in this signal processing area, where CSIRO had developed a highly competitive capability. CSIRO was building options with diverse potential application and recognised that radio astronomy offered an attractive opportunity both to advance the interests of astronomy and to develop capabilities with strong potential for commercial application.

2.3 Previous reviews of CSIRO

2.3.1 ACIL Tasman's 2006 Review

ACIL Tasman's 2006 review of CSIRO's impact and value recognised that the introduction of the Flagships as a central feature of CSIRO's operations model was likely, given its very structure, to deliver greater value to the Australian innovation system, and to tap into and exploit CSIRO capabilities built up in the past.

The 2006 review was strongly forward looking. It examined the structure of the major programs and Flagships that had emerged, and relied strongly on *ex ante* assessment of the prospects for these activities to deliver value. Of course, CSIRO's history of strong impact was important in underscoring these assessments of forward value, but the assessments needed to recognise the ways in which the new operating arrangements could exploit past work, and available capabilities, to generate strong prospects for the delivery of value in the future.

Based on our analysis, we strongly concluded that there were demonstrable benefits well in excess of whole-of-CSIRO costs. Those benefits were strongly dependent on the value of credible forward options deemed likely to emerge from programs that were still at an early stage. The level of credibility was bolstered by the systematic use of quite conservative assumptions and aggressive 'counterfactuals' that raised the hurdle required of CSIRO for each case study to a high level.

Table 2 provides a summary of the assessment, the findings and conclusions for the eight projects assessed.

Table 2 Summary of the 2006 ACIL Tasman assessment

Project	Assessment of value created	2006 Conclusions
Preventative Health Flagship	<p>The options values created were conservatively estimated to be just over \$376m (2006-07 prices), comprising:</p> <ul style="list-style-type: none"> \$138.6 m in options value from the Colorectal cancer research; and \$237.8 m in options value from Alzheimer's disease research 	<p>The Flagship was judged to have created real options values. The total Flagship budget for the three years to 2006-07 was approximately \$70m, which gives a cost to benefit ratio of roughly 5:1.</p> <p>The assessment concluded that there was significant upside to the work of the Flagship, particularly given that most of the Flagship was not evaluated in detail, but was seen as having good prospects to deliver significant value.</p>
Water for a Healthy Country Flagship	<p>The option value created by the Flagship was estimated to be about \$900 m in present value terms, comprising:</p> <ul style="list-style-type: none"> \$200 m - Urban waterscapes \$100 m - Murray River \$600 m - AWS/WRON <p>This was contrasted with Flagship expenditure to date of \$56 m and planned expenditure of \$175 m.</p>	<p>While the valuation was acknowledged as highly subjective it was also seen as a highly conservative estimate.</p> <p>Other themes of work were said to hold good prospects for adding substantial value to the portfolio.</p> <p>The Flagship could be viewed as offering options with a ratio of value to CSIRO costs of the order of 8:1. If partner costs are included then the ratio drops to around 5:1.</p>

A 2006 review identified benefits well in excess of costs

Project	Assessment of value created	2006 Conclusions
Light Metals Flagship	<p>A conservative lower bound estimate of \$466 million in value was developed, consisting of:</p> <ul style="list-style-type: none"> ▪ \$191 million options value from the alumina projects assessed ▪ \$275 million from the titanium projects assessed. <p>This value can be compared with an investment of \$15m in R&D. Also recognised (but not valued) were public good and national interest aspects of the work of the flagship.</p>	<p>The analysis indicates that, on first pass, the research had created considerable value. The report argued that the assessment was a conservative one and that the results should be seen as lower bound estimates</p> <p>The report found that some caution was needed with the results, but concluded that CSIRO had mechanisms in place to track performance and stop investment if it was not delivering or if others solved the problem first.</p>
AAHL	<p>The analysis indicated that that AAHL's FMD and Avian flu activities had an insurance value of at least \$26.5m per annum, comprising:</p> <ul style="list-style-type: none"> ▪ between \$25m and \$52m from FMD detection and control ▪ of the order of \$1.5m in its role as the national provider of emergency response to Avian flu. <p>These two activities alone justify a significant proportion of the \$31m annual cost of AAHL.</p>	<p>The 2006 report found that AAHL represented an important investment by Government in on-going detection and management of new and emerging animal diseases.</p> <p>The 2006 estimates represented a lower bound of quantifiable value delivered by AAHL.</p> <p>The value to Australia created by all of AAHL's activities is likely to be substantially greater than the cost of operating the facility.</p>
Cotton breeding & decision support systems	<p>The 2006 analysis found that the combined benefits to the industry and the share of license fees returned to Australian researchers resulted in a total benefit of around \$80m per annum, comprising:</p> <ul style="list-style-type: none"> ▪ annual net benefits of the order of \$15m from improvements in yield ▪ plus, perhaps, \$50m (net of licence fee costs) as a result of input (including chemical) cost savings ▪ plus, returns to Australian researchers of IP via license fees of (\$10 to \$12m) ▪ in addition, the farming and wider community was expected to enjoy some degree of health, safety and lifestyle benefits associated with the changed farming practices (these benefits were not measured). 	<p>The main direct beneficiary of the post-2002 research is the cotton industry. The environment also benefits from the reduction in chemical use.</p> <p>Improvements in water use efficiency were expected to be 'banked' as increased cotton production.</p> <p>The cost of the research was about \$19m a year, of which about \$14m was public investment, including about \$11m of CSIRO appropriation.</p>
Fisheries resource management (South & Eastern Scalefish & Shark Fishery (SESSF))	<p>The 2006 report found that CSIRO has tapped into many years of highly relevant experience and capability to deliver, in a relatively short time period, a substantially improved platform for managing the SESSF.</p> <p>It also found that there is a strong likelihood that the framework had additional value in the options it provided for further extension within the SESSF and for adaptation to other fisheries.</p>	<p>The scientific information provided by CSIRO was viewed as essential for the new harvest strategy to be introduced, at least in the short term.</p> <p>The report found that the investment had created options whose value was probably several times the costs incurred. Indications of value based on broadly analogous US analysis suggested a benefit cost ratio of around 5:1.</p>
Robotic mining (Longwall automation)	<p>The report estimated that the present value of bringing benefits forward by 5 years (in 2006-07 dollars) is in the order of \$272 million. The bulk of the benefits would be captured by the companies using the technology.</p> <p>Sensitivity analysis on the discount rate and number of years of brought forward benefits indicates that the investment still shows a significant net return even if the technology was only brought forward by two years.</p> <p>The patent revenue, which was expected to be paid to CSIRO, was not included in the assessment</p>	<p>CSIRO invested \$2.3 million in the R&D and industry provided an additional \$6.9 million in contributions.</p> <p>The 2006 cost-benefit figures were regarded as conservative in the sense that the benefits are only attributed to a short period. The report noted that the vast bulk of the investment in this technology was funded by industry.</p>

Project	Assessment of value created	2006 Conclusions
PolyNovo	Based on a conservative valuation of benefits, the 2006 report estimated the present value of benefits to be \$44.1 million. The estimated total costs of the R&D was \$15.7 million, indicating a benefit-cost ratio of 2.8:1.	PolyNovo is one a number of novel polymers developed by CSIRO. CSIRO's decision to commercialise this technology brought forward implementation and final impact of the technology on the Australian community by a number of years.

Source: *Review of the Impact of some recent CSIRO research activities – Overview report*, ACIL Tasman, October 2006

2.3.2 ACIL Tasman's 2010 Review

Four years later, ACIL Tasman's second review was better placed to look for evidence of 'runs on the board' under the new model, alongside a continuing probing of the developing value of the portfolio of forward options being delivered across CSIRO's range of activities.¹ In some cases, the review was able to observe the translation from promise back in 2006 to delivery four years later.

The 2010 review highlighted the insurance value delivered by CSIRO's portfolio of capabilities

The 2010 review placed greater emphasis on the value of CSIRO as a portfolio, rather than a collection of programs. CSIRO's standing capability is a source of expert advice to governments and government processes and provides CSIRO with the ability to respond rapidly, drawing on capabilities across the organisation and externally, to support community and government needs. This role, and its value, was seen as extending beyond the then present Flagships to provide a broader and more robust value through 'insurance' against national threats and against the risks of missing national opportunities for want of timely and appropriate innovation responses.

The 2010 review summarised its approach to the value and impact assessment as follows:

[The 2010 report] is designed to provide an overview of the processes through which CSIRO has impact and creates value for the Australian community, along with some credible indicators of the scale of its impact and value. It seeks to build an understanding of the value supported by the organisation as a whole. This has been done through a combination of:

- Probing of a range of CSIRO initiatives to demonstrate forms of value and the various ways that CSIRO complements Australia's overall innovation capability. This probing has led to a number of specific indicators of value and impact, and a better understanding of how these values are likely to evolve over time.
- Briefly reviewing a number of the assessments and case studies done as part of our earlier assessment of CSIRO impact and value, providing a longitudinal dimension to the current assessment.
- Taking a higher level, whole of CSIRO, view of the ways in which CSIRO brings value to the whole system, including consideration of culture and incentives, breadth and depth of capability, including responsiveness and leadership, track record and forward prospects.
- Drawing from these elements, some conclusions about overall value and impact have been inferred – especially about overall CSIRO impact and value relative to overall CSIRO costs.

The 2010 study found that benefits were well in excess of costs

The 2010 ACIL Tasman study reinforced the 2006 assessment that value delivered was well in excess of CSIRO's costs. The study considered a range of case studies, and less detailed 'vignettes' as a backdrop for assessing overall value of benefits relative to costs. The key findings of the 2010 assessment are summarised in Table 3.

¹ *Assessment of CSIRO Impact & Value - Report prepared as input to CSIRO's Lapsing Program Review*, ACIL Tasman, July 2010

Table 3 Summary of the 2010 ACIL Tasman assessment

Project	Findings
The Climate Adaptation Flagship	<p>A top down assessment suggested that the Flagship's contribution to a reduction in Australia's costs of adapting to climate change over the period to 2030 was of the order of \$2 billion. There were also a range of other benefits and insurance values, such as:</p> <ul style="list-style-type: none"> ▪ potential value of the order of \$1 billion from climate-ready crops ▪ benefits of the order of \$200 million for coastal communities through better planning and zoning ▪ substantial value in relation to planning for increased bushfire risks.
Prawn breeding and novel feed	<p>The analysis found that the value of delivered prawn yield increased by \$430 million. Additional potential benefits were identified from extending and diversifying the applications of the technology. The report found that the novel feed was expected to add further production value and that there was the potential for future royalty streams, exports and displacement of some feed production from wild harvest fisheries.</p>
Cement substitutes and novel products	<p>The report concluded that there were plausibly conservative royalty streams of tens to hundreds of millions of dollars on niche products that can compete in domestic and potentially large overseas markets based on functional characteristics. These royalties would underwrite research risks and offer substantial upside, even before accounting for GHG mitigation effects.</p> <p>The project also provided strong options to support lower cost GHG mitigation strategies. For example, it found an indicative \$50 million in value through advancing Australian access to the technology under a moderate carbon pricing regime, though plausibly much more. It also found that there was the potential to accelerate global mitigation through practical demonstration and expansion of low cost mitigation options that are relevant to a substantial proportion of current global emissions.</p>
Murray-Darling Basin Sustainable Yields Project	<p>A conservative \$2.8 billion in value was found to be linked to more efficient deployment and better risk management of the investment funds already committed to buyback and water infrastructure efficiencies.</p>
Resistant starch grains	<p>The review very conservatively assessed the present value, primarily via improved health outcomes for Australians, at about \$100 million, and plausibly several times greater as capability is transferred to grains and crops other than barley and wheat.</p> <p>There were also additional returns to agriculture and CSIRO royalty streams from new non-commodity cereal crops capable of commanding premiums in export markets</p>
Titanium within Light Metals	<p>A revision of the 2006 assessment of the opportunities for titanium and product fabrication suggested that benefits could be significantly above the earlier assessment of value of \$275 million.</p>
The UltraBattery	<p>The commercialisation arrangements in place for both automotive and stationary applications were expected to support returns to CSIRO. While the structure of arrangements was commercially confidential, the study concluded that plausible revenue streams were of the order of tens of millions of dollars.</p> <p>The technology also provided substantial opportunities to alter the early nature of moves into more fuel efficient hybrid vehicle fleets and to support more effective early use of renewables within the energy mix. This could have plausibly large impacts via the social cost of carbon saved and improved incentives for global mitigation – further enhanced by implications for non-GHG pollutants and oil dependency</p>
Mapping undersea mineral deposits	<p>No quantified value was developed within the vignette, but immediate cultural and policy value were found to exist, and in the longer term there was potentially high value through supporting commercial exploration.</p>
Biochar	<p>This work was also not explicitly valued. However, it was found to have potentially very high value if the work supported acceptance of certain applications of biochar for purposes of carbon accounting under international protocols.</p> <p>There was found to be a plausible role for biochar as a substantial contributor to lower cost abatement, given its complementarity with several aspects of farm production – with potential value of many billions of dollars under a carbon target policy</p>
Radio astronomy and the Square Kilometre Array (SKA)	<p>This project was found to have high value for Australia if we want to participant in big science projects, which are probing important science questions.</p> <p>The analysis arrived at an indicative estimate of a conservative expected tangible value over the life of the project, of well over \$100 million. This was driven by the high prospects for the SKA being located in Australia and funded internationally</p>
Cross-CSIRO climate work	<p>This project was at the time the subject of an active proposal for a major coordinated program of activities. The project was found to have the potential to deliver very high value, but that value was not explicitly quantified.</p>

Source: *Assessment of CSIRO Impact & Value - Report prepared as input to CSIRO's Lapsing Program Review*, ACIL Tasman, June 2010

The 2010 study estimated CSIRO's value at around \$6b

The 2010 ACIL Tasman study conservatively estimated the CSIRO's value at around \$6 billion. It reinforced the findings of case studies examined in 2006.

2.3.3 The Deloitte Access Economics study

DEA's report identified benefits of over \$1.25 billion a year from four projects

In 2013 Deloitte Access Economics (DAE) was commissioned by CSIRO to recommend, test and validate an appropriate framework and methodologies for the ex-post impact evaluation of CSIRO research. As part of that project they applied the framework to four case studies. The four case studies in the DAE report identify benefits attributable to CSIRO research of \$1.254 billion a year. The findings for each of the case studies are summarised in Table 4.

Table 4 Summary of the 2014 DAE assessment

Project	Assessment of value created	2014 Conclusions
BARLEYmax™	<p>The study found a range of benefits at full adoption (expected by 2024):</p> <ul style="list-style-type: none"> additional income for growers of \$4.3 million per annum at maturity sellers of cereal containing BARLEYmax™ were estimated to benefit by some \$33.3 million per annum at maturity the benefit to BARLEYmax™ customers by avoiding the burden of developing Type II diabetes and the reduced risk of cardiovascular disease (CVD) and colorectal cancer was projected to be \$305.2 million per annum at maturity the impact in terms of reduced health system costs was estimated to \$19.3 million per annum at maturity 	<p>Taking into account the share of the benefit that can be attributed to CSIRO, the impacts are estimated to be slightly more than \$253 million a year.</p> <p>ACIL Tasman's 2010 study arrived at a rather more conservative estimate of the present value of benefits of \$100 million. However, this was several years before the DAE study and the rate of uptake was then much less certain.</p>
Sustainable Commercial Fisheries	<p>The following benefits were identified:</p> <ul style="list-style-type: none"> Assuming an average willingness to pay (WTP) for an improvement in fishing ecosystems of about \$5 per household per annum, the impact of research into sustainable commercial fisheries attaining a 5% increase in fish stocks in the long-term was estimated to be \$236.2 million per annum at maturity the impact associated with a (higher) secured volume of catch in the long-term as a result of the research was projected at \$203.7 million per annum at maturity <ul style="list-style-type: none"> some short-term reductions in fish caught associated with the introduction of a management policy were expected cost the fishing industry \$39.7 million per annum for the first three years. However, this was estimated to be \$14.7 million less than the estimated cost of the alternative approach of having a Structural Adjustment Package involving the buy-back of vessels. the benefits to the recreational fishing sector in Australia were estimated to be around \$55.3 million per annum at maturity. 	<p>The share of the benefit that could be attributed to CSIRO's research was estimated to generate \$396 million of value a year in the long term.</p>
Clinical Terminology Tools	<p>The key impact of this research will be in the interoperability and machine readability of patient data in Australia. Estimated benefits include:</p> <ul style="list-style-type: none"> the value delivered through reduced health system costs was estimated to be \$592.1 million per annum at maturity the benefits associated with the improved health outcomes was projected to be \$55.4 million per annum at maturity. 	<p>Based on an attribution to CSIRO of 25%, the impacts generated by clinical terminology tools that are expected to flow from the CSIRO research are valued at \$161.9 million per annum at maturity.</p>

Project	Assessment of value created	2014 Conclusions
AuScope	<p>The report estimated the following impacts of the package of work undertaken under AuScope:</p> <ul style="list-style-type: none"> exploration cost savings as a result of the improved availability and accessibility of comprehensive geoscientific data and thus a more targeted exploration effort were estimated to be \$35.8 million per annum at maturity the impact of new mineral resource discoveries brought forward by five years as a result of CSIRO research was valued at \$458.1 million per annum at maturity for gold discoveries alone 	Assuming 90% attribution to CSIRO, the ex-post impact evaluation indicated that the value of the impacts generated by the package of work undertaken under AuScope that are attributable to CSIRO research is \$444.5 million per annum at maturity

Source: *Evaluation of CSIRO's research impacts – Impact Case Studies*, Deloitte Access Economics, February 2014

2.3.4 The 2014 Flagship performance reports

In early 2014 each of the then CSIRO Flagships prepared an internal performance report that included an assessment of the potential value of the research being conducted by that Flagship. There was some limited quantitative information on potential value available from the Flagship Performance Reports. While ACIL Allen has not been able to assess the veracity of the findings in the performance reports, there are some impacts that, if realised, are likely to be significant.

The self-assessments quantified additional benefits of several billion dollars

For various reasons, including the commercially sensitive nature of some of the information, it is not possible to provide specific details about individual assessments of value in the performance reports. However, the performance reports collectively scoped the quantification of annual benefits of the order of \$1.5 to \$2 billion arising from the work done by Flagships. We stress that this figure is based on a relatively small subset of the Flagship projects that were identified as delivering benefits.

Only a very small proportion of identified benefits were quantified

All the performance reports identified projects that were expected to deliver benefits, however in most cases these were not quantified and further analysis would be required in order to do so. It is likely that if those benefits were quantified they would add significantly to the above figure. It is also worth emphasising that the figure of \$1.5 - \$2 billion does not include any benefits from research projects that were selected as case studies for this report.

Because we have not been able to independently assess the way in which benefits were identified and valued in the performance reports we have not used the findings in the reports in our analysis. Nonetheless, the results do provide a degree of confidence in our estimations of the elements of value that we identify as part of our efforts to determine a robust and defensible estimate of the value of CSIRO as a whole.

Benefits over time

It is worth noting that in cases where particular research projects have been examined in multiple studies the estimated benefits have tended to increase over time. For example, in the 2010 ACIL Tasman study the present value of resistant starch grains was estimated to be about \$100 million. When the same project was examined by DAE in 2014 (then referred to as BarleyMAX™) the benefits were estimated to be over \$250 million a year.

Similarly in relation to the novel prawn feed research the 2010 study identified (but did not quantify) significant expected benefits, including from royalty streams. This current study confirms that finding. It finds that the cumulative benefits from the use of the novel prawn feed will be around \$368 million between now and 2023/24. In addition, CSIRO is expected to earn over \$100 million in royalties from domestic and overseas sales of the novel prawn feed.

It is not unexpected that that the assessed benefits of a project could increase over time. There will always be some uncertainties associated with the scale and nature of benefits associated with research and therefore any assessment of benefits will tend to adopt a relatively conservative approach when estimating benefits. However, over time more information tends to become available and uncertainties will therefore reduce. That reduction in uncertainty can allow a less conservative approach to estimating benefits to be adopted.

2.3.5 The value of standing capability

CSIRO's capacity to use its standing capabilities to respond rapidly to emerging challenges and opportunities warrants additional consideration as a key element in CSIRO's value.

CSIRO's standing capability enables it to respond rapidly to emerging challenges and opportunities

The evolving structure of the Flagships provides further clear evidence of CSIRO's capacity and willingness to bring together the resources needed to attack major innovation challenges. CSIRO's structure and culture appears to be particularly well-suited to situations where there is a need for a rapid, wide-ranging, multidisciplinary response to an identified opportunity or challenge, including when a significant intensity of work is required in order to exploit a narrow time window to address a problem or capture an opportunity.

Its capability to mount such a response depends heavily on its ready access to a diverse range of skills and other capabilities, often at large scale, and its ability to direct those resources at the recognised challenge. This capacity and demonstrated willingness to rapidly redirect large blocks of skills from a wide range of disciplines is much less common in other research environments, including universities. CSIRO's extensive networks with other research institutions, governments and industry also affords opportunities to tap into wider capabilities through a strong leadership role, backed up by strong internal resourcing.

The ability to rapidly respond to changing needs adds further to the value that arises from current activities. For example, while the AAHL case study considers reasonably tangible value delivered through its response to the Hendra virus, it also pays close attention to the value of a standing capability to respond to the risk of a future Foot and Mouth Disease outbreak. The former involves an existing pathogen that presents immediate threat to human and animal health. The latter effectively provides insurance against a plausible risk that could be extremely damaging.

CSIRO is using its existing capabilities to address a new challenge posed by Ebola

AAHL has also assembled the capability for rapid response to the current Ebola epidemic in Africa, in large part through its work on Hendra virus, coupled with the biosecurity capabilities provided by the facility. Both Hendra and Ebola are bat-borne viral infections and there has been the opportunity to draw on the skills that were built up in response to Hendra to act swiftly in supporting international efforts to deal with Ebola. These matters are discussed further in Section 5.6.1.

2.4 Approach to our analysis

The approach adopted in the current review is broadly similar to that in the previous reviews. However, this review places a substantially greater emphasis on the case studies and, in respect of those case studies, it has a greater 'ex post' emphasis.

The key arguments that underpinned the analyses in the previous two reports appear to be as relevant and strong as ever. The CSIRO business model that was new at the time of the first of those reviews has progressively evolved, both in terms of the range of

Flagships and facilities and new forms of engagement with industry and government. The case studies considered this time again illustrate CSIRO's ability to deliver high value outcomes and impacts while further extending the range of innovation options available to Australia.

Given the above, great care is needed in drawing conclusions about the value of CSIRO or the return it offers on the investment being made in its operations. Too narrow a focus on projects and cost-benefit analysis could entail serious bias against some of the other important drivers of CSIRO value. Similarly, insufficient attention to real and broader types of project impacts and values could potentially undermine the credibility of the conclusions being drawn.

This assessment uses a 'weight of evidence' approach

The approach adopted in this assessment has been to build the evidence in a range of ways, leading to an increasingly confident assertion that benefits well exceed costs, rather than attempting to deliver precise estimates of rates of return across the organisation as a whole. While we have drawn inferences regarding the value of CSIRO benefits relative to costs, these necessarily involve substantial uncertainty whereas we have inferred that much more robust conclusions can be drawn from the 'weight of evidence' approach adopted in this report.

There are five elements to the overall assessment

The major elements in building up this overall assessment include:

1. Cost-benefit assessments of a selection of case studies covering a range of recent and diverse activities. Here we seek to map outcomes, impacts, risks and indicators of value and cost
2. Based on the value inferred for these case studies alone, compared to the total costs of all of CSIRO operations (and the share funded through appropriation), we believe it is possible to draw a robust conclusion that CSIRO's value is substantially in excess of its costs.
 - In analysing the case studies, we consider the value that is clearly attributable to the work done (the 'runs on the board'). We also consider the value of options that have been created. Importantly, we do so only where the options are well formed and we see a clear pathway for them to deliver value.
 - This inference is based only on the current case studies. We do not attempt to scale up the benefits to reflect the rest of CSIRO's activities. Consequently, the analysis of case study value and impact relative to whole of CSIRO costs underestimates – very substantially – the total value that CSIRO delivers. ACIL Allen therefore argues that this element of the analysis sets a highly conservative *lower bound* on CSIRO's value.
3. Examining in some detail the process by which the case studies were selected.
 - This probing highlights the many alternative projects that could have been included among the case studies, many with broadly comparable initial indicators of value.
 - Out of this, we have sought to draw defensible inferences as to what might be said about overall value of CSIRO project and program activities, moving beyond the current case studies.
4. We also consider other contemporary assessments of CSIRO Flagships and programs and the stability of inferences that have been possible over time.
 - This all adds to the weight of evidence that supports the view that the estimate of value based on the case studies alone represents only a very small proportion of total CSIRO program and project value.

- Based on that information, we propose a very much stronger estimate of CSIRO program and project benefits relative to whole of CSIRO costs. Nonetheless, we believe it remains very much a conservative estimate.
5. We then look again at the additional value of CSIRO – inherent in its strong external relations together with its advisory, leadership, educational, insurance and standing capability functions, and consider the wider options being generated in its programs and projects where the pathways to value are not yet clear.
- We argue that these wider portfolio options are likely to have large value and to be important to the overall assessment of CSIRO impact and value.

Against the background of the above steps, we draw a final set of conclusions about overall CSIRO impact and value.

3 Summary of Case Study findings

This Chapter provides summaries of the findings from the analysis of each of the case studies.² The full versions of the case studies are provided in Appendix B to Appendix H.

Short summaries of each of the seven case studies examined for this report are provided in the sections below.

3.1 Australian Animal Health Laboratory (AAHL)

Box 1 Summary of key findings - AAHL

- 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.
- 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 (or around \$170 billion).

Source: ACIL Allen Consulting

Background

AAHL 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.

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

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

² In shortening the case studies for this Chapter it was necessary to remove the references. The full versions of the case studies each contain a full set of references relevant to that case study.

economy of billions of dollars through loss of trade, tourism and other costs associated with recovery from a disease outbreak.

AAHL plays a crucial role in investigating disease outbreaks

AAHL plays an integral role in investigating exotic and emergency disease incidents, ensuring rapid implementation of control strategies if necessary.

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

Avian Influenza is the most likely potential pandemic threat facing Australia. 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.

Output, Outcomes and Impacts

A FMD outbreak would have a major impact on the Australian economy

Foot and mouth disease (FMD) is the most serious biosecurity threat facing Australian agriculture. An outbreak of FMD could cost the Australian economy up to \$50 billion over 10 years.

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. Vaccination is a vital control measure in the event of an outbreak, AAHL conducts tests to verify that existing vaccines in Australia will protect against emerging strains of the virus.

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

The Hendra virus is a highly dangerous pathogen. AAHL isolated and identified the Hendra virus within two weeks of it being reported. A horse vaccine was identified as a crucial element of the strategy for combating the virus, as it prevents the horse from developing and passing on the disease. The Equivac® HeV vaccine was announced in November 2012.

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.

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.

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

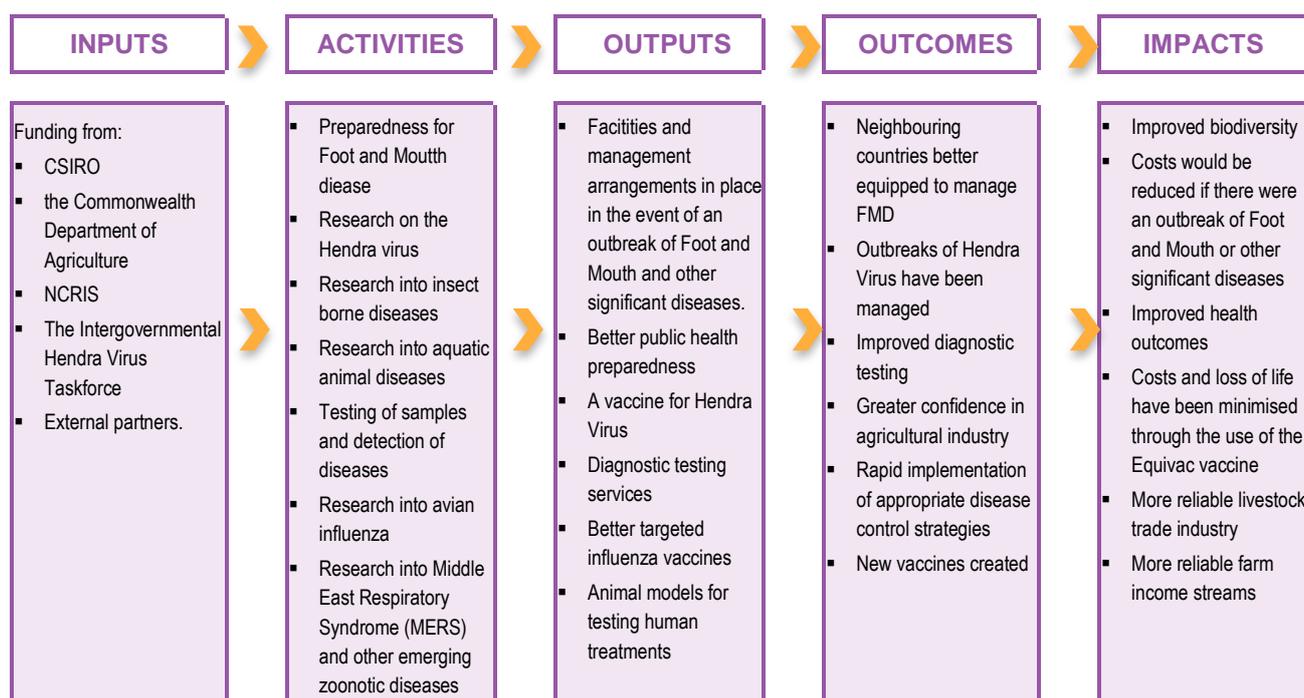
A major outbreak of Hendra virus could have severe consequences for the horse racing industry in Australia. The estimated value of the racing industry was more than \$6.2 billion per annum. It has been estimated that the 2011 Melbourne Spring Racing Carnival contributed \$210.37 million to Victoria's Gross State Product.

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

Several studies have estimated that a severe global influenza pandemic would reduce Australia's GDP by between 6.8 and 10 per cent for a year. This means that were an influenza pandemic to occur in the near future, then Australia's GDP would be reduced by \$115.6-170 billion from current GDP of approximately \$1.7 trillion.

Figure 1 presents an impact evaluation framework diagram for CSIRO/AAHL's work on animal health.

Figure 1 AAHL – Impact evaluation diagram



Source: ACIL Allen Consulting

3.2 Cotton

Box 2 Summary of key findings - Cotton

- 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.

Source: ACIL Allen Consulting

Background

The cotton industry is one of Australia's major agricultural industries. Cotton exports in 2012-13 were valued at \$2.7 billion.

The cotton industry is very important to Australia

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 enabled in part by new dam construction. 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. In 1972 the various cotton breeding programs were closed and CSIRO commenced a cotton breeding program that sought to develop full-season varieties for Australia's primary cotton growing regions.

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

CSIRO's Cotton breeding group has sought to develop cotton varieties that are capable of maximising productivity and quality under Australia's unique conditions. Major breeding goals include: increased yield and regional adaptation; resistance to diseases and pests; and increased fibre quality.

Outputs, Outcomes and Impacts

CSIRO bred cotton varieties now dominate the market

Research 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.

CSIRO's primary outputs have been improved cotton varieties

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: increased cotton yield; disease and pest resistance; higher fibre quality; regional adaptability; and water efficiency.

The benefits of the new varieties have driven rapid uptake

There has been 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 are strong. CSIRO's research has also yielded outcomes through the cotton production value chain from seed distributors to downstream processors. Increased productivity of cotton farming has also generated income for growers and additional employment in related industries such as retail, service, ginning and transporting.

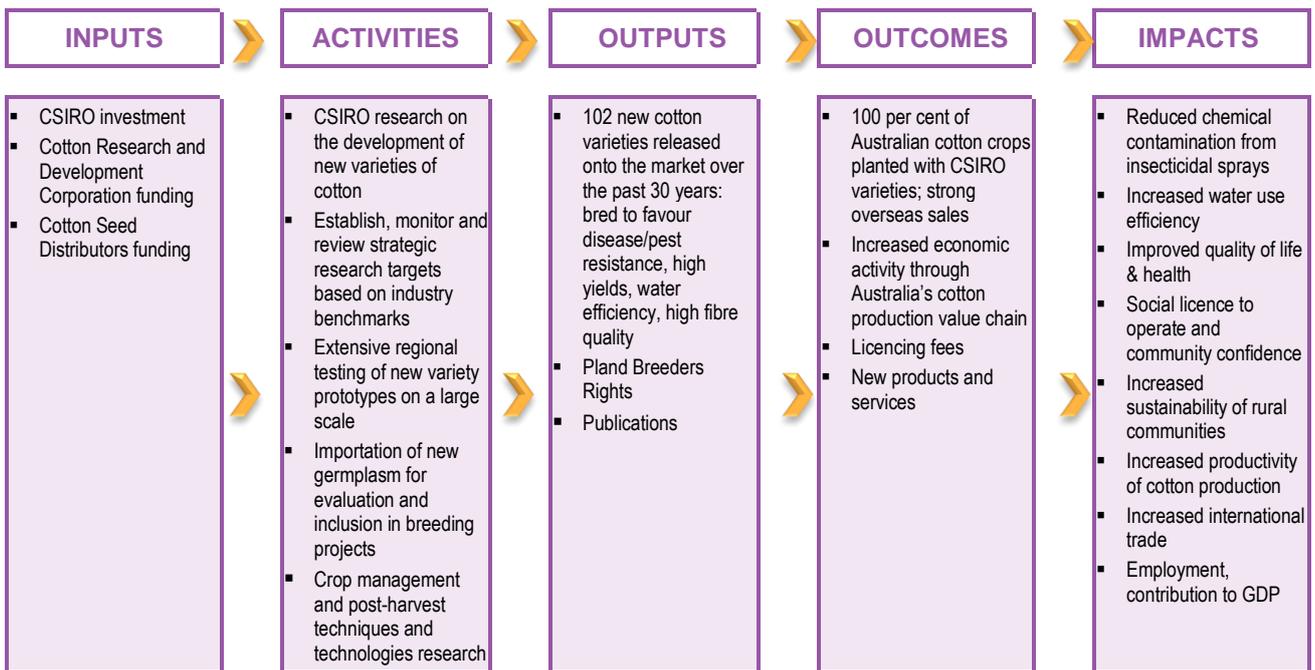
CSIRO's cotton breeding project has delivered a range of benefits

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. They include lower use of aerial insecticidal sprays, reducing chemical contamination of local air, soil and water and significantly increased water use efficiency. Over the past decade water use efficiency in cotton farming has improved by 40 per cent due in part to new cotton varieties.

CSIRO-bred cotton varieties have increased Australian cotton farmers' productivity. Australia's cotton growing productivity, measured in terms of kg of lint yield per hectare, is the highest in the world.

Figure 2 presents CSIRO's impact evaluation framework diagram for its work on cotton varieties.

Figure 2 CSIRO Cotton varieties – Impact evaluation diagram



Source: ACIL Allen Consulting

3.3 Longwall automated mining

Box 3 Summary of key findings - Longwall

The key findings of this case study are that the CSIRO's research program 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.

Source: ACIL Allen Consulting

Background

The longwall mining process involves a shearing machine with large rotating cutting drums that are driven back and forth across a coal seam. '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.

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.

CSIRO 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. In the late 1990s CSIRO researchers developed and patented an enabling technology provided the potential to automate the alignment process.

Around the same time ACARP prioritised research to improve mining efficiency

This coincided with a decision by the Australian Coal Association Research Program (ACARP) to prioritise research into improving the efficiency of the longwall mining process. ACARP subsequently provided funding to CSIRO to support longwall automation R&D. Original Equipment Manufacturers (OEMs) and mining firms provided in kind support for the R&D.

Outputs, Outcomes and Impacts

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.

As part of the licensing agreement CSIRO assisted OEMs during the roll out

The equipment manufacturers recognised the level of interest and commitment from the industry and they all accepted a non-exclusive licensing model. This approach was reinforced by CSIRO's assurance that it would use a portion of its intellectual property revenue towards the provision of technical assistance to manufacturers during the roll out of the product.

Uptake has been extremely rapid

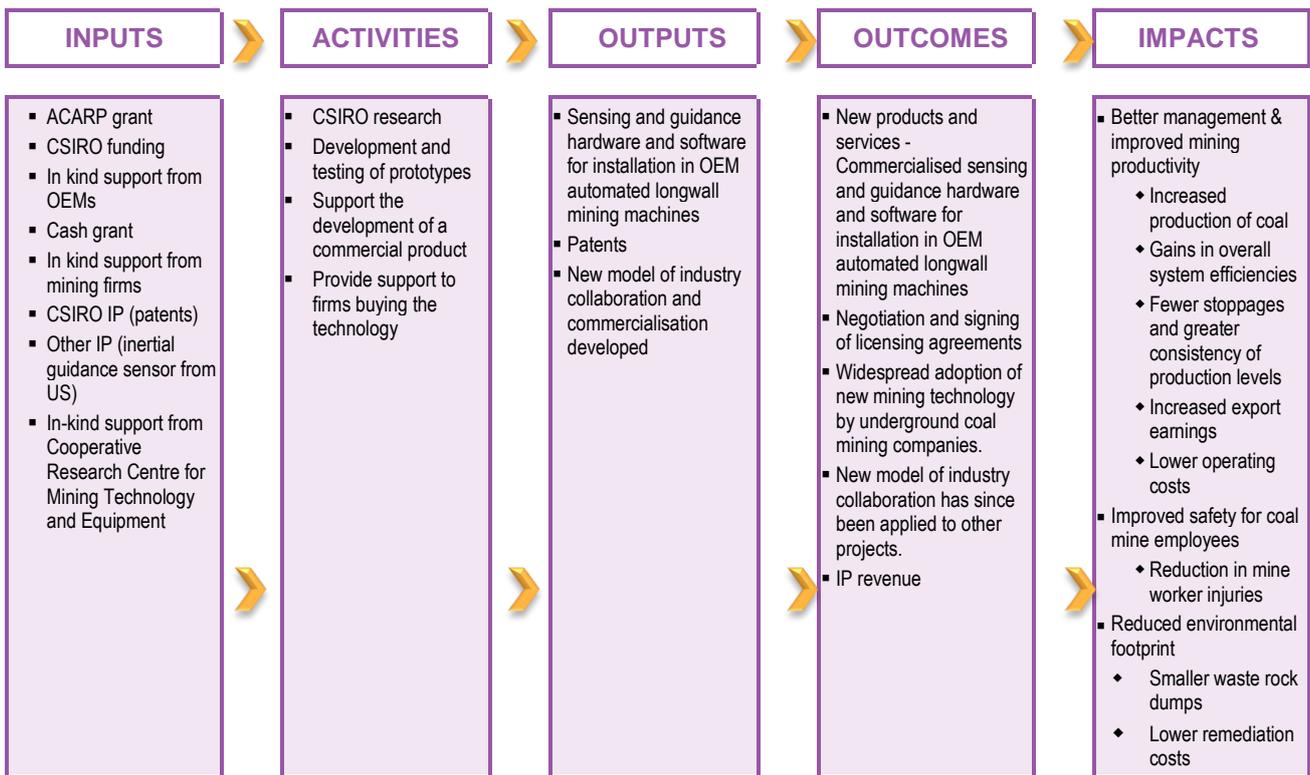
The adoption of the technology has been outstanding. To date, the technology has been adopted in 20 longwall mines in Australia, representing around 60 per cent of operating longwall coal mines in Australia.

Benefits of the technology include improved productivity and safety

The LASC Longwall Automation project has had a range of impacts. The main beneficiaries 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 the technology through safer working conditions.

Figure 3 presents CSIRO's impact evaluation framework diagram for its work on Longwall automation.

Figure 3 Longwall automation – Impact evaluation diagram



Source: ACIL Allen

3.4 OptiCOOL

Box 4 Summary of key findings - OptiCOOL

- 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.

Source: ACIL Allen Consulting

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 provide indoor comfort regardless of external climatic conditions.

HVAC systems account for 43% of energy use in buildings

However, HVAC systems are a source of significant costs for commercial buildings. In 2012, HVAC end use accounted for 43% of total building energy use. In addition, HVAC systems have been found to be an important driver of electricity demand across the network.

The OptiCOOL technology was some 10 years in the making

CSIRO first began its research into ways to improve the efficiency of HVAC systems in the mid-2004. Its main goal was to develop new technologies to reduce electricity consumption in buildings by improving the efficiency of HVAC systems. The project team was testing systems to intelligently control electricity loads and generators.

OptiCOOL controls HVAC operations based on a range of inputs

The OptiCOOL technology uses weather data, energy market pricing and feedback from occupants through online comfort feedback software whereby individuals can register whether they are too cold/hot and dispatch this information to a controller. The controller then modifies the operation of the building's HVAC to reduce energy consumption.

OptiCOOL was licensed to BuildingIQ in 2009

OptiCOOL was commercialised in December 2009 under an exclusive license to the start-up company BuildingIQ. 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.

Outputs, Outcomes and Impacts

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.

The technology has been licenced and commercialised by BuildingIQ in Australia and the United States. 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.

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

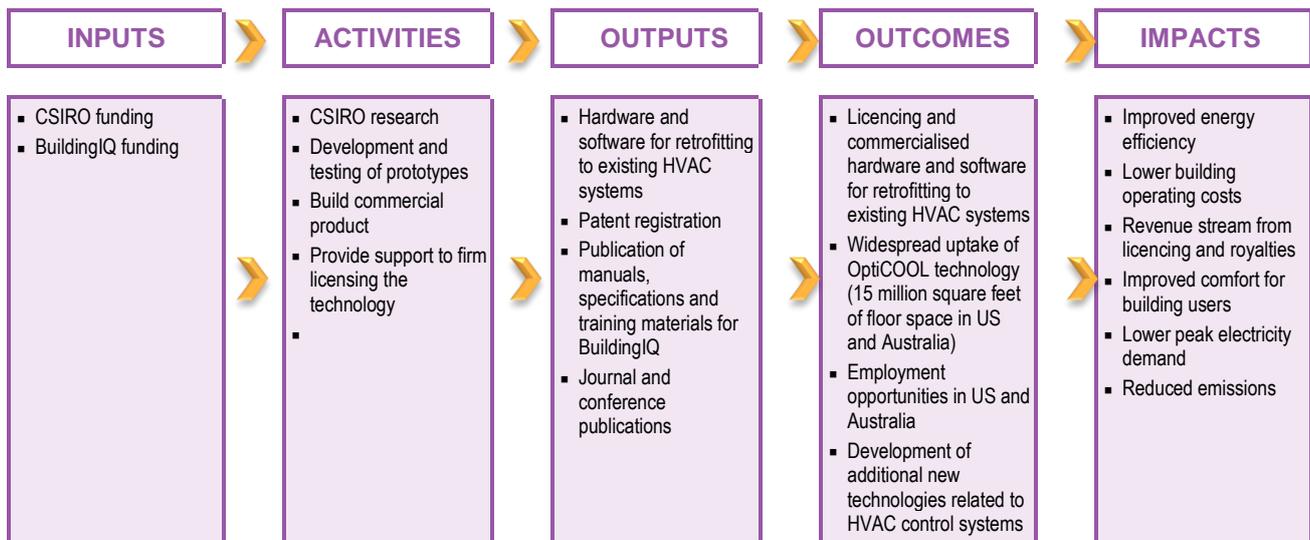
OptiCOOL technology has helped building owners to reduce their energy consumption by between 12 and 30 per cent. Argonne National Laboratories confirmed that a trial of the OptiCOOL technology decreased HVAC energy consumption in their buildings by between 22 and 45 per cent. BuildingIQ notes that its energy management technologies can offer commercial buildings payback on the original cost of buying and installing OptiCOOL within 12 months.

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

The global market for OptiCOOL is around 80,000 buildings, 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).

Figure 4 presents CSIRO's impact evaluation framework diagram for its work on the OptiCOOL Predictive HVAC Control technology

Figure 4 OptiCOOL – Impact evaluation diagram



Source: ACIL Allen Consulting

3.5 Prawn breeding and novel feed

Box 5 Summary of key findings - Prawns

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

- ◆ Improved productivity
 - ... Prawns that grow faster, are more consistent in size and more resistant to 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 from 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. Net benefits delivered to the industry to date are estimated to be around \$73.5 million. ACIL Allen estimates that CSIRO's prawn breeding programme 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.

Source: ACIL Allen Consulting

Background

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.

... one is prawn breeding ...

CSIRO is researching the domestication and selective breeding of the black tiger prawn. One aim of this research was to domesticate the black tiger prawn to eliminate the need to use wild caught prawns as broodstock to produce each new generation of farmed prawns. A second objective was to develop a prawn with improved growth, survival and feed conversion rates as well as improved resistance to endemic prawn viruses.

... the other is a novel prawn feed

Traditionally, fishmeal and fish oils have provided a major component of the feed used in prawn aquaculture. However, this has put further strain on wild fish stocks and raised questions about the long-term sustainability of prawn aquaculture. Until recently practical replacements for fishmeal and fish oils based feed were unable to provide the nutrition required to quickly grow large prawns that can compete in the market with prawns grown on fish based feed.

Outputs, Outcomes and Impacts

CSIRO has bred a healthier and faster growing prawn

CSIRO's selective breeding efforts have succeeded in breeding a prawn that has faster growth rates and a more consistent size. The CSIRO prawns also have greater resistance to common viruses.

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

Another major output of CSIRO's research is the prawn feed additive Novacq™. It is made from agricultural waste such as rice husks. Marine organisms are used to bio-convert the carbon in the agricultural waste into material that is then harvested, dried and used as the food additive. 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. The use of the novel feed additive has strengthened the sustainability of Australian prawn aquaculture.

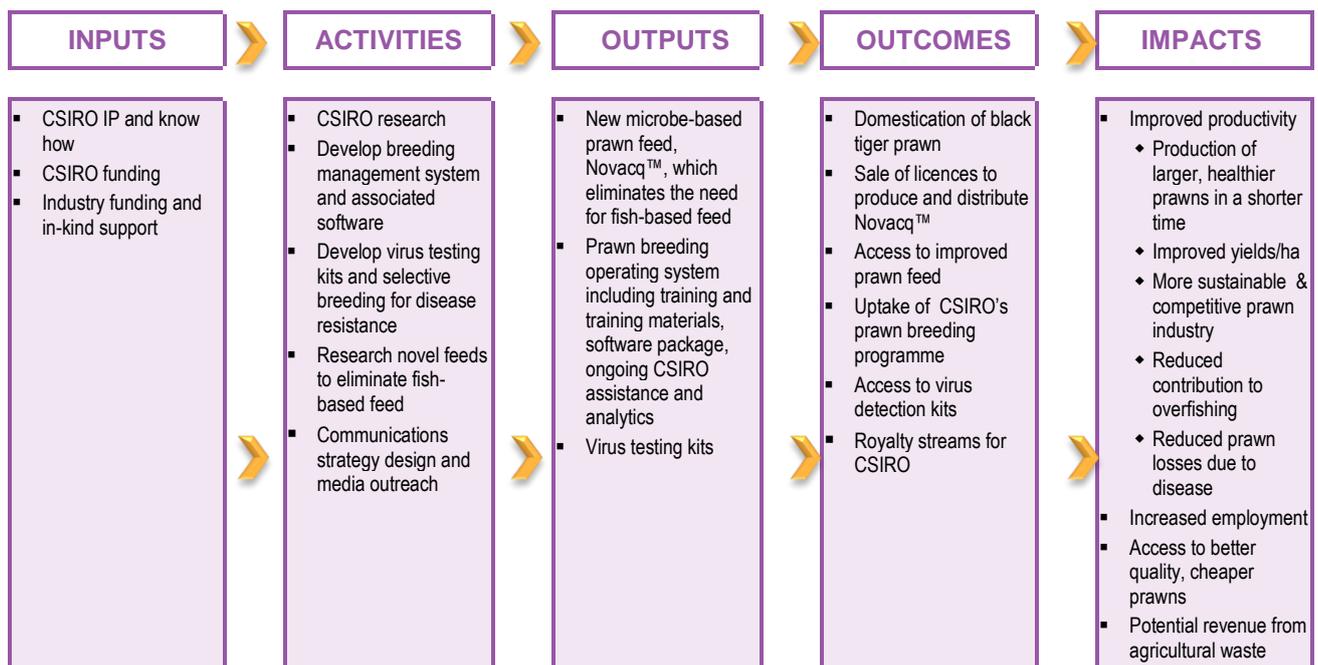
Significant productivity gains will flow from CSIRO's prawn research

Use of both Novacq™ and CSIRO's prawn domestication and breeding programme delivers significant productivity gains. On-farm trials using industry standard prawn feed have shown that prawns fed the standard feed containing Novacq™ grew 30-40% faster than those fed the standard feed without Novacq™.

On-farm evidence points to increased yields of at least 39% as a result of the application of CSIRO's black tiger prawn domestication and breeding programme. Finally, small scale tanks trails have demonstrated that the combined effects of the selective breeding and Novacq™ are highly synergistic. The projected benefits from CSIRO's prawn research are listed in Box 1.

Figure 5 presents CSIRO's impact evaluation framework diagram for its work on prawn breeding and feed.

Figure 5 Aquaculture feed and prawn breeding – Impact evaluation diagram



Source: ACIL Allen Consulting

3.6 Textor

Box 6 Summary of key findings - Textor

- 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.

Source: ACIL Allen Consulting

Background

Approximately 300,000 babies are born in Australia each year. The market for disposable nappies for young babies in Australia is around \$500 million per annum. In 2009, 5.6 million disposable nappies were used every day in Australia.

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 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 with the development by CSIRO of a new 3D fabric in partnership with Textor Technologies. Textor's alliance with Kimberly-Clark made it relatively easy to demonstrate 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.

Textor Technologies has made significant investments in new technologies and plant

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.

Outputs, outcomes and impacts

The 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 said of the innovative 3D UltraAbsorb that:

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.

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.

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 that Kimberly-Clark produces annually in Sydney. In addition, 70 per cent of Textor's product is exported to Kimberly-Clark plants in the region. This has helped Textor to double its turnover.

It is too early to assess the economic impact of the new product

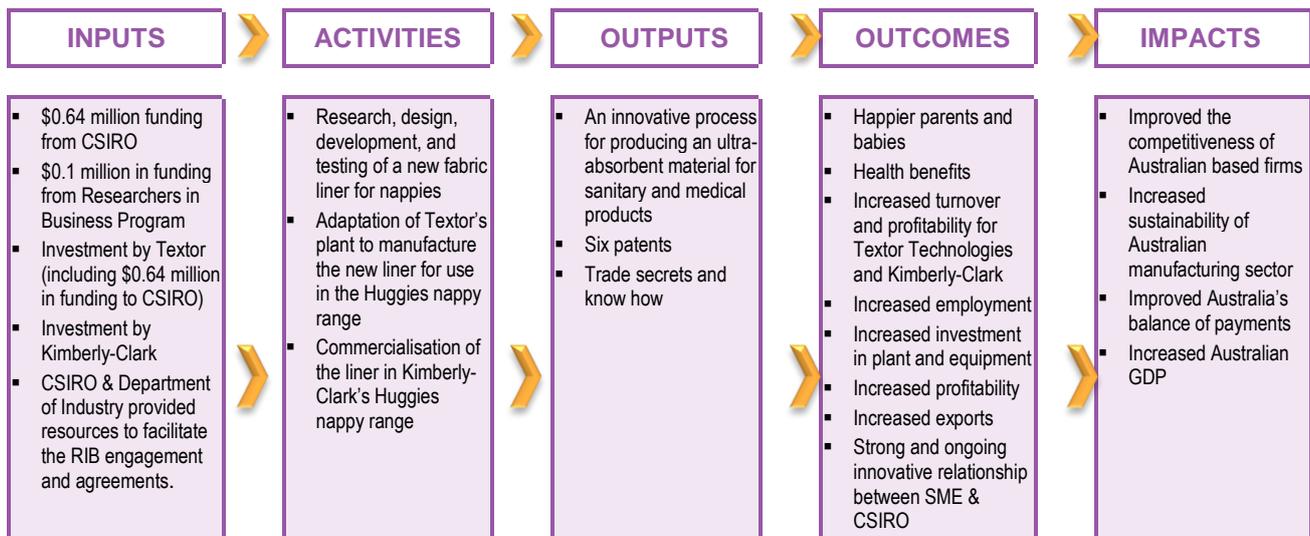
The economic impact of the creation of a new product has largely occurred since March 2013, when the new Huggies nappy range came on the market. As Textor increases its production and Kimberly-Clark starts to produce product with the 3D layer in other markets, the economic impacts can be expected to 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.

However the benefits of this project are likely to be orders of magnitude more than its costs

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.

Figure 6 presents the impact evaluation framework diagram for CSIRO's work on 3D fabrics in collaboration with Textor Technologies.

Figure 6 Textor – Impact evaluation diagram



Source: ACIL Allen Consulting

3.7 Water resource assessments

Box 7 Summary of key findings - Water

- 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.

Source: ACIL Allen Consulting

Background

WRAs were part of the government's response to a water supply crisis during the millennium drought

Each WRA produced reports and datasets on current and future regional water resources

CSIRO's WRAs yielded significant improvements in scientific understanding of water supply

WRAs have been incorporated into key water decision-making processes

By using the WRAs, water planning and investment is likely to be more efficient

In 2006 CSIRO began an independent, scientific and transparent study of current and future water supply in the Murray-Darling Basin. At the time Australia's food bowl was in the grips of a severe drought and conflict over water resources was intensifying. The approach used in this study was then adapted to underpin seven water resources assessments (WRAs) that assessed current water supply and forecast future water supply patterns under changing climatic conditions across large areas of Australia. By providing a scientific and rigorous understanding of water availability, the WRAs aim to enable effective, better-informed water management decision-making.

Outputs, Outcomes and Impacts

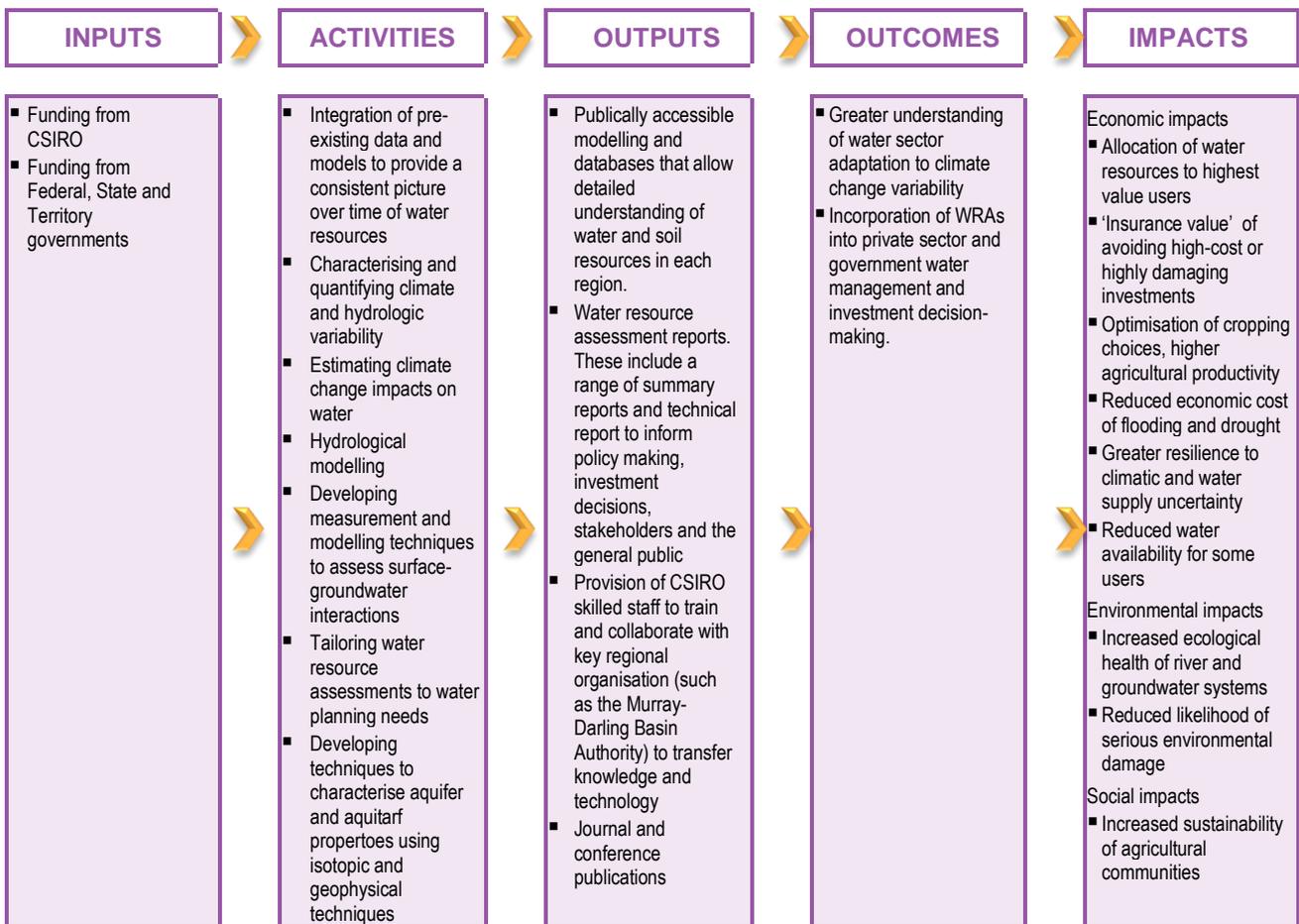
Each of the seven WRAs produced publicly accessible datasets, detailed technical reports, and accessible summary reports that provide information about water resources in each region. These were the first consistent, robust and transparent assessments of current and future water resources for that incorporated climate change projections for these regions.

One of the main outcomes of the WRAs was greatly improved understanding of the water balance across key regions of Australia, including improved understanding of areas of water supply uncertainty. The results of CSIRO's WRAs were incorporated into government and corporate water planning and investment decisions worth at least \$3.9 billion.

The WRAs have delivered positive impacts in terms of increased economic and environmental efficiency of water investment, and avoided future costs. In many cases they have identified the sustainable limits of water extraction for human use, making it less likely that water managers will invest in water assets that will lose profitability or become stranded due to inadequate future water supply, while at the same time enabling water managers to avoid environmentally damaging over-extraction of water.

Figure 7 presents the impact evaluation framework diagram for CSIRO's work on Integrated Water Resource Assessments.

Figure 7 Integrated Water Resource Assessments - Impact evaluation diagram



4 Aggregating the Case Study impacts

This Chapter considers the aggregated impact of the seven individual case studies examined in the previous section. It shows that the six case studies where we have been able to quantify the benefits deliver value well in excess of the R&D costs of those case studies.

The previous Chapter summarised the results for each of the case studies. Table 5 summarises the costs and benefits associated with each of the case studies. In the case of the Textor case study, while we were able to identify potential future benefits, there was insufficient information available to allow us to accurately quantify them.

The total benefits delivered by the six quantified case studies are substantial. The present value (PV) of the benefits from them over the period 2014-15 to 2024-25 is over \$6.35 billion (when using a 5 per cent discount rate). If we annualise the benefits then the PV of the benefits per year of R&D is just over \$1 billion. This compares with the average annual cost of R&D on the six quantified case studies of \$85 million.

The implications of the information in Table 5 for the whole of portfolio value of CSIRO are discussed further in Chapter 5.

Table 5 Summary of Case Study costs and benefits

Case Study	Benefits delivered	Costs	Comments
	\$ millions	\$ millions	
AAHL	The insurance value attributable to CSIRO in relation to foot and mouth disease (FMD) alone is some \$431 million per annum	\$339.6 million over the period 2009-20014 expenditure (including external funding of \$113 million).	The estimated benefit is a lower-bound estimate based on the value of insurance in relation to a potential foot and mouth disease outbreak only. Additional substantial benefits can reasonably be expected from the insurance value associated with other potential diseases.
Cotton	Present Value (PV) of benefits \$154 between 2006/07 and 2013/14 in 2014 dollars plus \$379.5 million between 2014/15 and 2024/25 under a 5 per cent discount rate.	\$57.367 million in 2014 NPV (\$41.681 million from CSIRO and \$15.685 million external sources)	Benefits are a measure of increased yield only. Benefits associated with improved water efficiency and pesticide reduction occurred before the time frame covered by this study and they are therefore not included.
Longwall	Total benefits attributable to CSIRO from 2001/02 to 2024/25 estimated to be almost \$801.1 million in 2014/15 dollars (PV under a 5 per cent real discount rate)	Total incremental costs from 2001-02 to 2024-25 estimated to be \$13.75 million in 2014-15 dollars (approximately 25% is CSIRO funding) (7 per cent real discount rate)	Project contributes to improved productivity, improved worker safety and reduced spoil. The research program was co-funded by ACARP, mining firms and OEMs. CSIRO is also getting IP revenue. In 2013-14 CSIRO earned almost \$1.4 million a year from licence fees.
OptiCOOL	The PV of benefits over the period 2014/15 to 2024/25 is estimated to be \$79.7 million in 2014/15 dollars (under a 5 per cent discount rate)	CSIRO invested \$412,000 between 2006-07 and 2010-11	Benefits include reduction in energy use and emissions. If BuildingIQ's growth was 25 per cent (rather than 15 per cent) the NPV of the benefits would be \$113.8 million. For 10 per cent growth the figure would be \$54.3 million.
Prawns	The PV of benefits attributable to CSIRO over the period 2009/07 to 2013/14 is \$73.5 million in 2014/ dollars. There is a further additional PV of benefit attributable to CSIRO of \$339.4 million for prawn breeding and an additional \$276.2 million for prawn feed between 2014-15 and 2023-24 in 2014 dollars (under a 5 per cent discount rate) CSIRO is expected to earn over \$100 million in royalties over the period to 2023-24.	Total research inputs of \$16 million in 2014 dollars (approximately 22 per cent is external support).	Other benefits from the CSIRO's research include a reduction in the demand for wild fish catch since the novel prawn feed is made from agricultural waste rather than fish meal or oil. The prawns from the CSIRO's prawn breeding program are also healthier and more resistant to common viruses.
Textor	The beneficiaries of this project include parents and babies (fewer problems associated with the liquid bowel movements of newborns), Textor (a new product, greater turnover and significant export opportunities) and Kimberly Clark (a new and innovative product that enjoys considerable market support).	R&D inputs totalled around \$1.194 million (\$0.643 million from CSIRO and \$0.551 external support).	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, it seems extremely likely that the benefits of the project are at least an order of magnitude greater than its costs. There is also considerable commercial sensitivity surrounding the financial results of Textor and Kimberly Clark and it unclear that we could use the data
Water	Environmental PV benefits of \$600-700 million, with an upper bound estimate of \$1.12 million, from just one decision as a result of one project among seven. Actual environmental benefits are significantly higher, and are likely to range above \$1 billion. Economic benefits of \$60-120 million from just one decision based on one of seven projects. Actual economic benefits are likely to be substantially higher than this estimate.	\$57.2 million in research costs (\$6.5 million from CSIRO and the remainder was support from various organisations and jurisdictions).	Benefits are based on two examples. Environmental benefits have been estimated by examining the impact of the Murray-Darling Basin Sustainable Yield project on the imposition of sustainable diversion limits. In reality, this is only one slice of overall environmental benefits delivered through seven WRAs. Additional economic benefits have been estimated by examining the impact of the Tasmania Sustainable Yields project on Tasmania's irrigation schemes. In reality, the economic impact of all seven of the WRAs is likely to be far higher than this one example.

Source: ACIL Allen Consulting

5 CSIRO Portfolio value

This Chapter builds on the work done to estimate the value delivered by the case studies, complementing it with additional information on the nature, impact and value of CSIRO's total portfolio of activities, to provide a more realistic view of the overall benefits delivered by CSIRO. In short, we develop a 'weight of evidence' basis for drawing more powerful inferences about the impact and value of CSIRO and developing a robust estimate of a robust and defensible lower bound for a benefit-cost ratio for the whole organisation. We conclude that the whole of CSIRO portfolio is delivering a return that supports an expected benefit-cost ratio of at least 5:1, and arguably substantially more.

Section 4 built to a conservative assessment of the impact and value created by the case studies, and considered these relative to the overall costs of CSIRO. They alone demonstrated very substantial surplus of case study value over case study costs; furthermore, they strongly suggest that the aggregate value from case studies alone is large relative to CSIRO annual appropriation and, indeed, total annual expenditure. Section 4 also discussed some of the other information available regarding the impact of value of CSIRO activities, outside of these immediate case study assessments.

This said, the assessment to date only supports inferences up to a point. The case studies involved benefits generated over a number of years, cautioning against making too much of a comparison of case study benefits to annual CSIRO costs – some adjustment is needed to allow comparisons based on comparable time scales, and this needs to allow for the fact that the different case studies spanned different time periods. Furthermore, the case studies involved only a small fraction of total CSIRO expenditure, within the case studies worked only with a subset of the likely impacts and value and, even for this subset, favoured estimates that were generally conservative – more likely to under- rather than over-estimate actual benefits.

In this section, we seek to develop a 'weight of evidence' basis for drawing more powerful inferences about the impact and value of CSIRO as a whole – viewing CSIRO as operating a rolling portfolio of investments in innovation activities. In doing this we have sought to move from a highly conservative assessment, at the program level, based on safe under-estimation of impacts and value, towards a more realistic assessment of expected (risk-weighted) impact and value of the portfolio as a whole.

This involves several elements:

1. Implementing a sound treatment to allow for the differences in time scales of the different CSIRO activities, providing a basis for soundly comparing CSIRO value through time to CSIRO costs through time.
2. Reassessing the level of conservatism applied to the case study benefits that have been probed, moving towards a reasonable basis for assessing expected benefits relative to costs – at the level of the case studies and eventually the portfolio as a whole

Individual case studies involve differing time scales

Need to adapt the case study estimates if they are to inform a balanced assessment of whole of portfolio impact and value

Standardised time scales

Adjustment for conservatism within quantified case study value

Adjustment for value from unquantified case study impacts

Adjustment for CSIRO value outside the case studies

Collation into whole of portfolio assessment

3. Introducing appropriate recognition of the impacts within the case studies that were not quantified, but that collectively could be expected to add a lot to overall impact, and whose costs have already been accounted for within the case studies
4. Introducing appropriate recognition of the approximately 92 per cent of CSIRO expenditure that falls outside the case studies, and where there is very strong evidence, outside the case studies, of high value impact
5. Drawing these various elements together into an overall assessment of portfolio impact and value, and discussion of the credibility of these inferences.

Previous studies of value add to the confidence that benefits significantly exceed costs. For example, the aggregate value of annual benefits attributable to CSIRO delivered by the four case studies in the DAE report was \$1.254 billion a year. None of the DAE case studies was included among those examined in this report.

The case studies all involve work that has been undertaken across different time periods, and in all cases the research has been occurring over periods substantially greater than a year, so care is needed in drawing out of the case study assessments indicators of value that can sensibly be compared to whole of CSIRO costs. The approach we have adopted involves the following steps and assumptions:

Stable, evolving CSIRO portfolio

Standardised time scales – annual costs and value created

1. We assume that CSIRO is now evolving in a reasonably stable manner, managing a very large portfolio, with sufficient diversity to support a relatively stable flow of whole of portfolio benefits through time, with this being linked to a relatively stable level of expenditure through time.
2. Given this, we have sought to convert the performance of each case study into a form that captures ‘average’ annual outlays across the period of the investment, and average annual value gained across the period of the investment.
 - These annualised indicators provide a more logical basis for extension to typical average annual cost and performance of the whole of CSIRO portfolio.
 - It is important to recognise that, even where the work will result in a flow of benefits for many years into the future, we have sought to assess the average annual benefit created per year of CSIRO activity.
 - › Effectively, at the end of the CSIRO investment or the case study assessment period, some benefits will have been delivered, and some options for future benefits will have been created. These benefits will have a present value that can be expressed as an average annual increment in present value delivered across the period of the assessment.
3. We have then sought to interpret these case study performance indicators in the context of CSIRO’s wider portfolio. We seek to take into account impacts and values that are not accounted for in the case study assessment. We also seek to address the fact that we take a very conservative approach to assessing values that does not fully recognise the value of the upside. Finally, we examine the value of the services that CSIRO provides outside of its R&D work.

Extension to wider portfolio

Our emphasis in looking at portfolio performance is on the performance delivered out of CSIRO’s application of its capabilities and expenditure, including expenditure of funds not obtained from appropriation.

5.1 Annualized costs and benefits

It is natural to think of CSIRO's total expenditures, across its whole portfolio, in annual terms, and to enquire as to the rate of return being achieved on that rolling annual investment. Reflecting the discussion in Section 2, CSIRO's annual operating expenditure is of the order of \$1.25 billion, of which just over 60 per cent comes from appropriation – with the remainder being generated internally and coming from various partnering arrangements with industry and government agencies. In the discussion that follows, we are working up to an assessment of the value that CSIRO delivers from this level of rolling investment.

CSIRO can be viewed as a rolling, evolving investment portfolio characterised by annual costs and values

CSIRO manages a large, diverse and constantly evolving investment portfolio. In the discussion that follows, we assume this portfolio has evolved to a point of being reasonably stable in its performance characteristics through time. Some areas of research mature and are sensible passed out to industry and other users. Some do not live up to expectations – a feature inherent in sound research strategy so resources are redirected. New opportunities emerge, or existing areas begin to show greater promise – and resources are applied. But over time we assume the outcome is a *rolling investment strategy* with a flow of benefits. There will be occasional major breakthroughs of very high value, but we assume that it is reasonable to proceed on the basis of CSIRO having a portfolio that involves annual investment as above, and an 'average' rate of benefit generation. Our objective is to assess whether these 'average' benefits support the level of investment being made.

Same logic applies to programs and case studies

The same logic can be applied down to the level of individual programs – and the case studies undertaken in this review. Each of these investments involves investment over a number of years – that can be translated to an average level of annual expenditure. Each case study yields impacts with value – value that will typically accumulate over many years into the future, and that has been summarised above in terms of a net present value. This block of value can similarly be translated into an average annual value created across the years of the activity being assessed.

For example, a three-year program that delivers forward value of \$60m, that will flow over the next 10 years could be said to have delivered average benefits of \$20m per year of that program. Here we are measuring the average annual increase in the value for forward options delivered per year that the program ran. If the program cost \$6m, or \$2m per annum, then we could conclude that the average annual performance of the program was to deliver incremental value of \$20m for incremental cost of \$2m, suggesting an average benefit-cost ratio of 10:1.

Using annualized benefits and costs allows aggregation across activities

Of course, this benefit cost ratio is the same as would be obtained looking at the whole of program costs and benefits, without translating to annual terms. However, this assessment of average annual benefits and costs allows for comparisons between program operating over different time scales and, crucially, allows aggregation of average annual benefits and costs in a way that can be mapped directly into annual CSIRO expenditure. This capacity for sound aggregation at an average annual level supports the capability to build to assessment of whole of CSIRO value relative to costs, despite the different time scales of the different programs.

Another feature of this approach is that it can inform an assessment of current CSIRO impact and value even from case studies that are now complete.

5% and 7% discount rates yield similar answers

Against this background, Table 6 sets out a summary of the quantitative results of the earlier case study assessments translated into the above 'average' annual terms. Results are based on both the standard CSIRO discount rate of 5 per cent and a higher rate of 7

per cent. This has been done to test the sensitivity of the results to the choice of discount rates. The table shows that the choice of discount rate does have an impact but that the two discount rates deliver very similar answers. Accordingly, in what follows we have largely restricted the discussion to the results based on CSIRO's 5 per cent rate.

Table 6 Indicative annualized benefits and costs by case study, 5% discount rate, 7% in brackets

Case study	PV of benefits (2014-15 to 2024-25)	Total R&D costs (not discounted)	R&D Time Period	Average annual R&D costs	PV of benefits per year of R&D
	\$m, 2014-15 dollars	\$m, 2014-15 dollars	Years	\$m, 2014-15 dollars	\$m, 2014-15 dollars
AAHL	3,584 (3,235)	340	5	68	717 (647)
BuildingIQ	80 (69)	0.4	4	0.1	20 (17)
Cotton	380 (338)	57	8	7.2	47 (42)
Longwall	801 (600)	17	12	1.4	67 (50)
Prawns	755 (659)	12	9	1.4	84 (73)
Water (WRAs)	753 (730)	54	8	6.8	94 (91)
Textor	Not quantified				
<i>All 7 case studies</i>	<i>6,352</i>	<i>481</i>		<i>85</i>	<i>1,029</i>

Source: ACIL Allen Consulting

Table 6 alone enables strong conclusions to be drawn in relation not just to the set of case studies, but also in relation to the CSIRO portfolio. In particular, we can infer that:

Case study value is over \$1b annually

Case study benefit-cost exceeds 12:1

Six case studies account for only 7% of total CSIRO costs and 11% of appropriation ...

...suggesting a lot more value outside case studies

1. The six case studies where quantification was possible are very conservatively estimated, on their own, to have conservatively delivered an average annual value in excess of \$1 billion.
 - This compares with an average annual cost (appropriation and other funds) across the 6 case studies of \$85m, implying a benefit cost ratio for these six initiatives, viewed as a block, well in excess of 12:1.
 - This is before consideration of the conservatism in the estimates provided in respect of those case study benefits that were quantified, and the fact that some benefits were not quantified at all
2. The average annual costs for the six case studies that were quantified account for less than 7 per cent of total annual CSIRO expenditure, and just 11 per cent of total annual appropriation spending.
 - This is strongly supportive of the proposition that a comprehensive assessment of the whole of CSIRO's portfolio, using the same methods as were used for the six case studies, would yield benefits of at least several times the above figure of \$1 billion, which was itself conservative.
 - However, we do not suggest that extending the above benefit-cost ratio of more than 12:1 to the whole of CSIRO is appropriate. This would only be possible if we could argue that the case study economic performance is statistically representative of whole of CSIRO performance.

5.2 Conservative vs expected benefits

Conservative estimates support some strong inferences...

The emphasis in the case-study assessments to date has been on developing a conservative assessment of case study benefits relative to actual case study costs. This approach has high value particularly when, as has occurred here, those conservative benefit assessments comfortably exceed, not just case study costs, but in fact total CSIRO appropriation costs. This allows for the highly robust conclusions about the aggregate investment in CSIRO is delivering good value for money.

...but are not well-suited to guiding resourcing decisions

However, these conservative estimates are just that – highly conservative. This supports the above strong conclusions that benefits are well in excess of costs, but does not support well a consideration of the overall investment performance of these programs, in a way that might inform decisions of future direction for resourcing within CSIRO and between CSIRO and other forms of investment.

A few points are relevant:

Expected values more relevant

1. Conventional investment analysis typically focuses on *expected*, or risk-weighted, benefits and costs – taking account of the value of the high probability upside above such conservative values.
 - Two programs with the same conservative valuations could actually have very different expected values – and could therefore command very different resourcing – if one has far more upside than the other.
2. More generally, reliance on highly conservative value estimates could be quite misleading if applied to decisions on resource allocation between an agency like CSIRO dealing with innovation opportunities relative to more tightly specified investment alternatives.
 - The high levels of uncertainty involved in research will tend to imply a wide spread of possible value outcomes, with lower bound, or conservative, assessments likely to fall well below expected values – and much more so than for many other investments.
 - Failure to consider expected values could therefore introduce significant bias in any comparisons across investment alternatives – bias that deals unfairly with the opportunities offered by CSIRO.

Any assessment of expected value of CSIRO's case studies, or portfolio as a whole, will necessarily entail significant subjectivity, but this subjectivity can be well-informed by the available evidence to deliver substantial credibility, especially at the portfolio level.

Of course, at the level of individual case studies, there will always remain significant scope for 'overs and unders'. Any realistic assessment of expected value will bring with it prospects for substantial departure, either over or under. The expected value seeks to strike a balance that is fair to both these possibilities.

At the CSIRO portfolio level, 'overs and unders' will tend to average out

However, as individually programs are aggregated up into a large and diverse portfolio of R&D investments, this volatility at the level of individual programs should shrink dramatically, as actual outcomes across different programs deliver 'overs and unders' that cancel out. Average performance across a diverse portfolio can be expected to be far less volatile than for individual programs. This feature adds to the suitability of using expected values in building up to a balanced assessment of the portfolio as whole.

Having said all this, in the discussion that follows ACIL Allen has tended, if anything, to remain relatively conservative in its assessments, with the view that this can add to their credibility. The objective of building to an estimate of whole of portfolio value provides

considerable flexibility for being less conservative at the program level – because of the way that portfolio volatility will shrink dramatically relative to program volatility.

5.3 Conservatism in the case study estimates

The individual case studies involved some conservatism in the values that were quantified, significant dimensions of unquantified value in the case studies there were quantified, and one case study where quantification was not undertaken. All of these have implications for the assessment of benefits created within these case studies.

Where case study benefits have been quantified, the level of conservatism in these quantified estimates could be considerable, placing the estimates well below realistic expected values.

- An example of this arises with the assessment of AAHL’s benefits in reducing the risk, and cost, of a FMD outbreak in Australia.
 - The analysis has assumed that there is a 1:50 risk of a FMD incursion into Australia in any one year – and then traced through AAHL’s impact on the implied level of damage.
 - However, the figure of 1:50 emerged only after considerable probing, taking into account trends that could well be pushing up the risk
 - › Other figures were suggested – all involving greater likelihood than 1:50.
 - › If the risk, looking ahead, were really 1:35 as opposed to 1:50, the annual value delivered, through Foot and Mouth response only, by the AAHL case study would increase by over \$270m; plausible variations in this key parameter would increase the value very substantially.
- Analogous value could be drawn out of some of the quantified values of the Integrated Water Assessments, were we to explicitly consider the possibility that these assessments may have reduced the risk of major damage in a system that might prove essentially irreversible.
 - There is necessarily a high level of uncertainty about key parameters, even in relation to the quantified values of this case study – and the assumptions made have been somewhat conservative.

We are not suggesting that the AAHL analysis shift to the 1:35 basis. However, the fact that the case study used the lowest probability suggested, and that higher probabilities (up to 1:25) were seriously suggested, does highlight substantial conservatism in this assessment, linked to the necessary uncertainty about this parameter. Similarly, we are standing by the estimates of the quantified value of the water assessments. Realistically, however, they are conservative, and a reasonable correction towards an expected value could plausibly be worth up to hundreds of millions of dollars per year of the programs.

Alongside these ‘underestimated’ case study values are the ‘un-estimated’ dimensions of value within the case studies.

- There has been no quantification of Textor value, even though the arguments set out in the case study suggest it could be substantial.
- Within AAHL, no value has been attributed to AAHL’s impact on the threats for Australia posed by other diseases, including the threat from an influenza pandemic, where the potential damage.
 - Quite modest assumptions about likelihood and CSIRO impact could again support credible arguments for including additional risk weighted value well in excess of \$100m – spread across modest mitigation of the threat to GDP discussed in the

Conservatism is potentially high – implying estimates well below expected values

Difference across the set of case studies could amount to hundreds of millions of dollars annually

‘Un-estimated’ values add further to conservatism

case study (\$170 billion in the first year, potentially of the order of \$300 billion across the life of a pandemic), plus conventional assessment of the potential social cost of morbidity and death (for example, attaching quality adjusted life year calculations to the assessment).

Box 8 Other non-quantified benefits in the water case study

The water case study did not seek to quantify the flow-on benefits of the WRA work for many other water management decisions being made across the country. A strong example of this is the utilisation of CSIRO's WRAs (particularly, the South Eastern Australian Climate Initiative or SEACI) in a wide range of water decision-making processes in Victoria, primarily in the following ways:

- **Urban and rural water corporations:** In 2012 all of Victoria's 19 water corporations used SEACI modelling in their climate change and water availability scenarios in the 2012 round of their Water Supply Demand Strategies. These strategies form the basis of water corporations' investment decisions on infrastructure and other supply/demand options, and have fed into investment plans that total well over \$1 billion.
 - ◆ Another example of uptake of SEACI is use by rural water corporations. For example, Southern Rural Water has used SEACI climate scenarios in its planning for the Western Irrigation Futures (WIF) project, which seeks to develop robust options for the future of the Werribee and Bacchus Marsh irrigation districts (Southern Rural Water 2010)
- **Sustainable Water Strategies:** These are another very direct use of the SEACI findings. The last round of regional resource planning undertaken across Victoria was the Sustainable Water Strategies, which cover four regions of Victoria. These strategies were developed under Division 1B of the Victorian Water Act 1989, and identify threats to water availability and formulate policies and actions to help water users, water corporations and catchment management authorities manage and respond to the identified threats. Outcomes from the SEACI research formed an important source of climate information (including for climate scenarios) that assisted with decision making on policy and actions. The final strategies document the actions & policies, which are many and varied - one example of an action with relevance to climate is the carryover policy in northern Victoria.
- **Flooding:** Climate information, including from SEACI, has helped inform responses to flood risk and response. For example, the 2012 Victorian Parliamentary (Environment and Natural Resources Committee) inquiry considered flood mitigation infrastructure in Victoria, and drew on SEACI information about the future likelihood and size of flooding in Victoria. That inquiry estimated that the cost of flood damage in 2007 (which was a flood year but not as severe as later floods in 2010 and 2011) in Victoria was \$350 million. Including SEACI in flood mitigation infrastructure would be expected to mitigate and lower this level of loss (Parliament of Victoria 2012).
- **Catchment Management Authorities:** CMAs also use climate information to inform their planning and management. For example the Glenelg-Hopkins CMA Waterway Strategy: the CMA waterway strategies are a key planning document for river, estuary and wetland management, and guide investment.

Sources: Sharon Davis, Victorian Department of Environment and Primary Industry (pers. comms.), CSIRO, ACIL Allen Consulting

The value of these 'gaps' in the estimation are uncertain. However, they seem almost certain to be of quite substantial value. In terms of a reassessment of expected value of the case studies, viewed as a block, we believe it would be quite reasonable to suggest an expected value of the order of 25 per cent on top of the formal quantification provided earlier – and that a credible case could be mounted for a substantially higher figure.

Expected case study value assumed 25% higher...
...pushes case study value above whole of CSIRO costs

This suggests that the estimated average annual value of the case studies, as set out in Table 6, might reasonably be reassessed from \$1029m to around \$1,286 – which exceeds the whole of CSIRO operating budget, while accounting for only around 7 per cent of these total costs.

5.4 Value of other program activity

The case studies used in this review were selected following detailed consideration of the range of CSIRO's Flagship, Program and project activities. They were deliberately not chosen using a random sampling approach. Had we used such an approach, it would have been necessary to draw a much larger sample of activities for case study assessment in order to support the conclusions set out above to be drawn with sufficient confidence. This would have required a much larger and more costly review. The method

used, namely a purposive sample selected as discussed below, allowed strong inferences to be drawn from a modest number of case studies.

A specific objective of the purposive sampling was to provide representation of some areas that had not been subject to earlier scrutiny, recognising that the history of Lapsing Program Reviews has already built a strong body of information, across many areas of CSIRO activity, pointing to high value and a solid rate of return on investment.

These past studies were documented in Section 2. They add strongly to the inference that, there is substantial value outside of the set of case studies examined in detail in the current review.

For example, the four case studies in the DAE review – which covered four areas not included in the current report – identified benefits attributable to CSIRO valued at \$1,254 billion a year.

90% of CSIRO expenditure is not covered by the case studies

The figures in Table 6 show that average annual expenditure on the case studies has been of the order of \$85 million – about 7 per cent of total CSIRO expenditure, around 11 per cent of the appropriation budget, and around 8 per cent of total CSIRO expenditure on Flagships and Core Research Programs (\$1,073m in 2013-14). It would be very pessimistic to assume that the remaining 89-91 per cent of expenditure delivered no additional gross value. It is important that that additional gross value be recognised in weighing the return on CSIRO investment.

5.4.1 Scope of CSIRO's project and program activities

CSIRO has itself attempted to set out graphically some understanding of the richness of its portfolio, both cross-sectionally and through time. Figure 8 provides a dramatic and impressive overview of this portfolio since the late 1970s and extending into the future. The chart depicts the demonstrated or expected impact of specific initiatives across time, with the size of the circles used to provide a simple indicator of relative impact, and colour coding used to indicate the nature of the impact using the Australian Bureau of Statistics' Socio-Economic Objective (SEO) codes.

It is clear from this chart that the case studies constitute only a small part of the overall CSIRO activity and that, importantly, many initiatives that have been identified as offering relatively high impact, compared to some of the case studies. For example, we note the following as projects that have not been covered in this study:

- Carbon capture technologies
- Nitrogen efficient wheat
- High tonnage ore sorting

What is shown in Figure 8 is far more than a set of projects and outcomes. Rather it depicts a much more dynamic system that is constantly drawing on capabilities developed through past work to address new challenges and deliver current and future value. Indeed, the current CSIRO operating model is strongly grounded in processes that constantly seek out high value applications of capability in order to realise opportunities for Australia.

The emphasis in the figure is strongly on the nature of the impacts, rather than the nature of the skill sets, relationships, management systems and business support facilities that were the enablers for these different classes of impact. A key feature of CSIRO lies in this enabling role, with these systems capable of being justified, from a national perspective, on the basis of the flow of current project and program impacts alone. This enabling role – which we see as supported by, but separate from CSIRO’s current Flagship program and project activity, is considered in more detail in Section 5.6.1.

Appendix A sets out the processes used to settle on the 7 case studies actually probed in this review. In doing so, it works through a much longer list of initial proposals, with strong value propositions underpinning their being included in the ‘long list’, and discusses several of these where, had they been subjected to probing of the type done with the case studies, would almost certainly of led to very substantial additional value.

5.4.2 Reconsideration of program and project value

This accumulating weight of evidence, looking at the case studies as a share of total activity, looking at the value propositions that could have underpinned an expanded set of case studies and considering the results of other recent assessments all builds to a compelling argument that the overall value of CSIRO’s research activities must be a substantial multiple of the value identified in the case studies themselves.

If the remaining case studies were to deliver a return on their investment comparable to that assessed for the case studies, noting that total outlays on Flagships and Core Research Programs in 2013-14 was \$1,073m, then the value from the other Flagship and Core Research Program areas would be estimated as around \$12 billion annually, on top of the case study value. Results from other assessments, including past Lapsing Program Reviews and the DAE review discussed earlier, certainly point to a multi-billion dollar block of additional annual value.

However, for reasons set out earlier, and in Appendix A, we would see an assumption of equal performance by these other areas of CSIRO as justified on the basis of available information – while not detracting from strong pointers to substantial additional value. A more appropriate assessment of the expected additional value might be of the order of a third of this figure – or an additional \$4 billion. This figure is itself highly subjective but, given the weight of evidence, is not considered optimistic.

Assessed additional value of \$4 billion annually, assuming the remaining activities offer only a third the rate of return of the case studies

5.5 Options not valued within case studies

An important feature of most research work is its propensity to yield capabilities, and insights into potentially high value applications for these insights, that were not anticipated at the time a program was designed and its budget justified.

As CSIRO manages its extensive research program, it is building technical skills, research infrastructure and the opportunities to see potentially high value ways of directing these capabilities. As was noted in section 2.3.5, the rationale for investing in basic research rests heavily on the track record of such research, undertaken by skilled people, leading to high value applications that have not yet been recognised. For example:

- CSIRO’s work on phased array antenna systems as candidates for inclusion in the design of the Square Kilometre Array has already found valuable application in medical scanners.
- Early CSIRO work in industrial physics and large scale chip design created the capability, later tapped, to develop signal processing capabilities in radio astronomy that allowed CSIRO to pursue high value commercial opportunities in wi-fi – while

CSIRO’s capabilities embody and create new ...

analogous current work in support of Australian hosting of part of the Square Kilometre Array telescope is building capability at the leading edge of big data

- CSIRO's investment in AAHL and its high security research facilities, and its recent work in developing an effective response to the Hendra virus, spread by bats in Australia, has delivered a unique capability for investigating possible responses to the recent Ebola epidemic in Africa and that is increasingly being linked to bats as the primary hosts

A related set of options lies in the way that current research programs often lay the foundations for the next generation of programs. The water case study is a clear example of high impact and value work that was only possible because of the extensive foundations built over decades in different parts of CSIRO.

The Cotton breeding program provides an example of how one generation of capability forms the basis for the next generation of capability, not dissimilar to the evolutionary crop breeding process. Almost all of CSIRO's current Flagships have built on long traditions of earlier research that delivered the capabilities now being tapped. Just as the current programs are undoubtedly laying the foundations for future research programs – some as 'logical' extensions of work now being done, but some likely to fan off in quite different directions.

The value in many of these options will lie in uncertain future developments. Just as AAHL delivers value by supporting readiness to respond to a possible FMD outbreak (even though it is unknown whether or when this will happen) other options may have value only if external developments take a certain form.

... CSIRO's nature gives it the capacity to identify uses of these options to create value

The real value in such options relies not just on the chance event or insight that occurs, but on having the motivation and capability to see the implied opportunity and to act to exploit that opportunity. The diversity of CSIRO, its internal processes for planning and managing its innovation investments, its ability to assemble multidisciplinary, mission oriented teams to pursue opportunities and its processes for moving research outcomes through to commercialisation or other means of delivering impact, all suggest that CSIRO should be well-placed to deliver value out of these types of options. Given this, some recognition of the value of these options is appropriate.

But unplanned option value is commonly not valued or undervalued

However, such option values are commonly not included in the assessment of the value of research programs, or are picked up only indirectly and undervalued. Options for future responses to as yet unknown developments admittedly can sound far too remote or unlikely to be relied on – yet the track record does suggest that ignoring such value will involve systematic downwards bias in assessing impact and value.

Interpreted this way, it is important to recognise that such options do add to the value of current research activity – and failure to include them in the valuation of the case studies adds to the conservatism of those value assessments. These issues are revisited in Section 5.6.1, since these options are part of the standing capability of CSIRO.

There is another side to the option valuation issue. Research undertaken around the world is generating new insights and opportunities. CSIRO is likely to offer value as a result of its substantial systems for monitoring overseas developments and exploring the scope for making use of them in Australia. CSIRO is well-placed, through its networks, monitoring systems and cross-sectoral innovation planning processes to extract value from these options, in addition to their own internally developed options. These matters are also examined further in Section 5.6.1.

5.6 Insurance value, beyond expected returns

Investments such as AAHL allow Australia to reduce the level of risk it faces from plausible threats, such as an outbreak of FMD. The analysis of the AAHL case study provides an insight into the expected (probability-weighted) value of such insurance, in the form of lower expected financial costs to Australia from dealing with an outbreak. In that case, the expected financial value of the insurance is well above the ongoing cost, and provides support for sustaining this capability.

The demonstrated responses to Hendra and Ebola provide further illustrations of the potential for this type of capability to emerge even where it was not a central part of the planning for and justification of the investment. From amongst the case studies, a lot of the recent water work reflects exploitation of established capability in response to emergency developments – such as the pressures on systems that accompanied severe drought conditions – with such response capability effectively affording a level of insurance against worse case outcomes.

The same was true of ACIL Tasman's 2011 economic assessment of the Climate Adaptation Flagship, where again substantial financial value was identified. That value was sufficient to cover costs, but where there was also a layer of reduction in wider risks. An important element in that study was the recognition that a lot of the identified value could be tapped even if there were no strong trend in the underlying climate. The strategies emerging from CSIRO's work offered high value given the current level of climate volatility as reflected in events such as flood and tidal surges. The value delivered extended beyond the avoided financial costs of rebuilding after a devastating flood or surge event and includes reduction in the social trauma associated with such events and associated risks of death and injury.

These elements of insurance value – reduction in risks both through investments specifically targeted at those risks and where there is a strong propensity for reductions even in risks not specifically targeted, feature prominently across CSIRO portfolio. Section 5.6.1 discusses the value of CSIRO's standing capability which can be viewed as insurance against new risks or opportunities where the capacity for rapid innovation at scale can reduce the risks of damage or lost opportunity. A significant part of CSIRO's work is directed at providing and maintaining better tools for understanding the systems – natural and manmade – that shape our world and our lives and where better understanding could provide high value insurance in the form of early warnings or early identification of opportunities. These features are very apparent in CSIRO's work in developing models of complex systems.

Some specific examples of this type of insurance value include:

1. Flood Prediction Tool

- New computer modelling techniques enabling very realistic water simulations including difficult-to-model behaviours such as wave motion, fragmentation and splashing to assist in the future planning and management of catastrophic floods.
- The Flood prediction tool has been used in Queensland and China to develop emergency management procedures. Working with China's Satellite Surveying & Mapping Application Centre, CSIRO scientists modelled the effects of flooding from a hypothetical failure of the massive Geheyuan Dam in China's Hubei province.
- This work has helped Chinese authorities to develop appropriate emergency procedures and plan new town infrastructure safely. CSIRO's modelling techniques were also used during the recent flood crisis in Queensland.

2. Air Pollution Model Software

- The Air Pollution Model increases our ability to pinpoint pollutant behaviour in a wider range of atmospheric conditions. The software package predicts local meteorology and assesses the likely pathway and concentration of pollutants as they disperse. Earlier versions of the software are widely used throughout Australia by government, researchers and consultants, as well as internationally by 190 customers in 25 countries.
- A new version of the software has been released, and over the coming years the new model will continue to fill a gap between simple air pollution dispersion models and the much more complex earth system models such as The Australian Community Climate and Earth-System Simulator (ACCESS).

3. Indian Ocean Climate Initiative

- The Indian Ocean Climate Initiative (IOCI) began in 1998 and involves the West Australian Government, CSIRO and Bureau of Meteorology. Climate-related decision making in Western Australian has benefited greatly from this long-running research partnership between national and state levels of government and will continue to do so in the future.
- Importantly, the information generated by the partnership has been incorporated into state level policy such as the State Water Policy. In November 2006, as a result of IOCI research, Australia's first large-scale desalination plant was commissioned. This research also assisted the WA Government, in July 2011, to make an informed decision to approve a \$450 million expansion of south-west WA's second desalination plant.

4. Marine Report Card

- *2012 Marine Climate Change in Australia Report Card* demonstrates that climate change is having significant impacts on Australia's marine ecosystems. The report card provides information about the current and predicted-future state of Australia's marine climate and its impact on our marine biodiversity. The report card also outlines actions that are underway to help our marine ecosystems adapt to climate change.
- The information is helping to ensure that ocean managers and policy makers are best placed to respond to the challenge of managing the impact that climate change is having on these systems.

5. Simulations of Marine Ecosystems (*Atlantis* and *InVitro* models)

- Simulations of marine ecosystems dynamics is a world leading modelling of marine systems. The models, *Atlantis* and *InVitro*, are used both within Australia by the Australian Fisheries Management Authority and by governments around the world, to predict and give insight into the management of human interaction with the marine environment.
- The reason why these models help find the balance between conflicting issues of industrial use and development and the conservation of the oceans and coasts is that they give equal attention to the biophysical and human components of the marine system. The first models in the world to do this, they were also the first to assess a whole-of-fishery management plan from an ecosystem perspective.
- These achievements were in part why *Atlantis* is beginning to be applied globally and why it was rated best in the world for strategic evaluation of marine management issues in a 2007 Food and Agriculture Organization (FAO) report that reviewed the world's leading 20 ecosystem modelling platforms.

6. The risk management software 'Reditus' for the financial sector.

- CSIRO's Reditus™ software is a tool for pricing complex financial options. Reditus™ is not a conventional options-pricing tool. It is a tool for exploring, manufacturing and trading new instruments efficiently.
- Reditus™ is already in use at the Commonwealth Bank of Australia and the National Australia Bank. Sales to banks in Europe, Japan and the United States have also been completed; over 900 banks now use the software globally.
- Reditus™ is distributed by GFI Group Inc as an optional module within FENICS FX, GFI's award-winning platform for pricing, analysing and managing foreign exchange option positions.

All of the above represent products developed specifically to deliver tools for better monitoring and prediction in the presence of uncertainty, and to aid in the development of strategies to hedge risks and to tap identified opportunities. Each would be amenable to normal cost benefit analysis in terms of these identified, and planned, capabilities. However, the very approach of developing powerful models that can simulate the behaviour of complex systems in our environment and society can be expected to deliver a broader capability to respond rapidly to new, unexpected, developments and to provide greater coverage against the risks from extreme developments within these systems – or threats to these systems.

Potential value in reductions in major risks to society

It is appropriate to recognise that individuals and communities may value insurance against rare but highly damaging risks even more than is indicated by calculations of expected financial damage. Whenever a car or house is insured, the premium paid will have been carefully calculated by an actuary to exceed the expected value of any claims on the insurance. This does not mean such insurance is irrational. There is an active market in insurance precisely because people do not weigh risks on the basis of expected financial costs – they tend to attach greater weight to possible outcomes that would have a devastating impact, even where they are extremely unlikely.

Sound research and access to innovation capabilities can offer additional insurance in the form of both advice on pre-emptive strategies to lower risk, and access to the type of innovation needed to move, in the wake of a threat materialising, to respond more effectively. These mechanisms may reduce expected costs but their justification may also rest in recognising some of the wider risk reduction value associated with traumatic events.

The extra insurance value reinforces the conservatism of our assessments

We have not sought to attach a specific value to this insurance effect, other than in the discussion below of the value of CSIRO's standing capability. However, it should be seen as an additional element that reinforces the conservatism of the benefit-cost assessments that have been done.

5.6.1 Value of standing capability

There is value in CSIRO's standing capability

Section 2.3.5 discussed the concept of the standing capability of CSIRO – and its associated value, and drew parallels with the approach that might be taken to valuing Australia's defence capability. The CSIRO business model is strongly focused on processes directed at identifying opportunities and deploying capability suited to exploiting those opportunities. This flexibility, and the diversity of CSIRO's capability, suggest there is potentially high insurance value – that is derived and maintained almost as a by-product of current Flagship and Core Program activities.

Given the earlier arguments for CSIRO adding value to the entire innovation system, in part through its complementary role in coordinating responses to emerging opportunities and challenges, and given the evidence of high value in some of the focused activities,

ACIL Allen is strongly of the view that there is a great deal of value held in CSIRO's standing capability, over and above the value delivered by current projects and programs.

To build a better understanding of the value here, it is useful to look at CSIRO activities through a different lens. Figure 8 provided an overview of CSIRO as defined by its activities. Table 7 provides a perspective more closely aligned to areas of capability, though each Flagship of course involves teams with diverse capabilities – many if not all of which are highly mobile capabilities – able to be redirected to new issues or priorities.

Table 7 **CSIRO's Flagships**

Flagship	Budget (\$m)	Aim
Agriculture Flagship	126.5	Helping Australian farmers and industry improve productivity and sustainability across the agriculture sector.
Biosecurity Flagship	16.9	Helping to protect Australia from biosecurity threats and risks posed by serious exotic and endemic pests and diseases.
Digital Productivity Flagship	46.1	Addressing some of Australia's and the world's most pressing economic and developmental challenges using data digital technologies.
Energy Flagship	85.5	Enhancing Australia's economic competitiveness and regional energy security while enabling the transition to a lower emissions energy future.
Food & Nutrition Flagship	41.6	To transform the international competitiveness of the Australian Agrifood sector, adding \$3 billion in annual value, by applying frontier technologies to high potential industries.
Land & Water Flagship	76.8	Enabling the sustainable management of our land, water, and ecosystem biodiversity assets.
Manufacturing Flagship	71.3	Developing cleaner advanced materials and technologies to enable manufacturers to secure a competitive and sustainable future.
Mineral Resources Flagship	52.1	Growing Australia's resource base, increase productivity and driving environmental performance.
Oceans & Atmosphere Flagship	69.0	To secure Australian agriculture and forest industries by increasing productivity by 50 per cent and reducing carbon emission intensity by at least 50 per cent between 2010 and 2030.

Source: CSIRO Operational Plan, 2014-15

A key point to be made about the value of standing capability is that this value flows naturally from the structure of CSIRO and the ongoing conduct of its current research programs. ACIL Allen's assessment that the value of current research substantially exceeds the whole of CSIRO's costs suggests that there is little or no additional real cost in maintaining this standing capability.

That value is hard to quantify but is likely to be large

As with Australia's Defence capability, trying to quantify the value of this standing capability is problematic, although there clearly is value, and probably large value. This is particularly true given the earlier discussion of how CSIRO can complement other areas of the innovation system and direct resources in ways not open to many other public research organisations.

So, while we have not sought to quantify the value of standing we believe it adds to the overall strength of our assessment of CSIRO's value for money.

5.7 Other Services

5.7.1 Value of education services

CSIRO undertakes a wide range of activities directed at building public awareness of science and technology, and in particular at building the interest and knowledge of young people who may go on to develop careers in science and engineering. Placing a dollar value on the benefits of such activities is difficult, but significant engagement of the

CSIRO provides large-scale delivery of educational services

community could be expected to translate into future value – especially given the value of science and technology and commonly expressed concerns that too few Australians are progressing to careers in these areas.

Included in CSIRO's activities in this area are:

- CSIRO Education centres, maintained in all capital cities and in Townsville, with over 360,000 visitors annually – pitched strongly at providing hands-on experience of science to primary and secondary students
- CSIRO's Canberra Discovery Centre, with over 120,000 visitors annually, including school groups comprising almost 40,000 students in 2012-13
- Visitor centres at CSIRO's major astronomy and space facilities, attracting over 160,000 visitors annually
- CSIRO's Creativity in Science and Technology program that, in 2013, helped over 11,000 students plan and carry out research projects, with over 70 per cent being awarded for their work
- Active support for university training of scientists and engineers, with the current programs including over 1000 sponsored or supervised postgraduates, and employment of 325 postdoctoral fellows.

The costs of these activities are included in CSIRO's budget and largely funded out of its appropriation. Any balanced assessment of benefits relative to these costs needs to recognise the value of these investments in building Australia's capabilities in science and technology. Ultimately, the value is likely to lie mainly in the value of the extra options Australia acquires as a result of developing the interest of students in science and engineering as well as encouraging more talented young people to consider careers in these areas and/or in other areas calling on strong quantitative and analytical skills.

At the same time, there is additional value in building and sustaining wider public understanding and appreciation of science and what it is telling us about our world. Such understanding supports both inherent cultural value and builds an understanding of emerging technologies in ways that support better engagement by the community in using these technologies in high value ways.

There are other non-CSIRO facilities in Australia, including some museums, Questacon and analogous facilities in other cities etc. However, the number of people, and especially students, visiting CSIRO's educational facilities each year certainly suggests scope for significant impact with substantial long-term value.

5.7.2 Value of advisory services

CSIRO research leaders are experts in their fields, often with international standing and with strong networks that keeps them abreast of developments in their field. In turn, this allows CSIRO to provide high value advisory services – in many cases through a trusted adviser role – across a wide range of Government activities. It is appropriate to recognise the value of such services – where this capability is assembled and maintained by CSIRO. In any assessment of the return on overall investment in CSIRO, these services, and their value, is relevant – especially as they have been made possible by the appropriation investment that has been made in CSIRO.

CSIRO is represented, and provides advice, across many panels. Clearly CSIRO fulfils the role of trusted advisor on a broad range of matters. We have not sought to provide a comprehensive list of areas where CSIRO fulfils this role. However we have been

Substantial long term value of education services, but hard to quantify

CSIRO has an extensive role in advising governments

provided with a recent list of areas where CSIRO has provided an advisory role through Executive-level or Flagship Director-Level involvement. These include:

- Co-Chair of Inquiry into Environmental Performance Matters, Port of Gladstone [reporting to Minister Hunt]
- Australian Government High Level Coordination Group on Climate Change Science
- Governing Board – Centre for Australian Weather and Climate Research [CSIRO-BoM collaboration]
- Governing Board – Water Information Research and Development Alliance [CSIRO-BoM collaboration]
- Australian Government National Plan for Marine Environmental Emergency committee (AMSA)
- Oceans Policy Science Advisory Group
- Reef Advisory Committee, Great Barrier Reef Marine Park Authority
- Board Member of FSANZ (Food Standards Australia and New Zealand)
- Chair of the National Food Nutrition Strategy - National RD&E Framework Department of Agriculture
- Animal Health Committee (AHC)
- Sub Committee on Animal Health Laboratory Standards (SCAHLs)
- Animal Biosecurity RD&E Strategy Steering Committee
- Expert Reference Panel for the Energy White Paper
- Expert Reference Group on the design of the Emissions Reduction Fund
- Australia-China Coal Mine Safety Collaboration Technical Committee

It is worth noting that many other CSIRO experts have also been involved in providing advisory services to governments and others.

We have not sought to quantify the value of these advisory services. However, we note the significance of a number of these boards and committees, and the potential for insights, of the kind that CSIRO may be able to provide, to influence decisions in ways that could deliver a lot of value. As with research capability more generally, we see both direct value in tapping into knowledge and capability, and probably significant additional insurance value in protecting against overlooking key information or insights.

The direct, and opportunity, costs of providing these advisory services are already factored into the CSIRO budgets used to assess the costs and benefits of R&D activities.

5.8 Conclusions regarding whole of CSIRO value

The above discussion does not lend itself readily to compilation of a series of value figures that add to a definitive total. However, a strong overall picture does emerge, with the following ‘indicator’ elements emerging in sequence:

1. The six quantified case studies account for around 7 per cent of CSIRO’s annual operating costs. ACIL Allen has conservatively estimated that they have created more than \$1.029 billion per annum in value. We note that this value is based on only a subset of some of their benefits.
 - This indicates a conservative benefit-cost ratio of around 8:1, calculated on the basis of total CSIRO expenditure, i.e. appropriation plus revenue obtained from other sources. If recalculated to reflect the return only on appropriation funds, the figure is closer to 12:1 for this bloc of CSIRO activities.

CSIRO’s role as a trusted advisor has considerable potential value

Case study benefits conservatively exceed \$1b annually and a benefit-cost > 12:1

A more realistic estimate of expected benefits from the case studies exceeds whole of CSIRO costs

Taking into account other areas of research pushes the expected value past \$5 billion annually...

...delivering an estimated benefit-cost for Flagship and core activity of 5:1

Other unquantified value components would add significantly to the overall benefit-cost

Shifting to a 7% discount rate has limited impact

2. Probing both the nature of the assumptions used, and some of the dimensions of value that were not quantified, suggests that the case studies alone should be attributed a substantially higher value than the conservative assessment above.
 - Taking a still reasonably conservative approach to estimation, we inferred that a more realistic estimate of the expected benefits from the bloc of case studies would be \$1,286m annually. This exceeds CSIRO's total operating budget for Flagship and Core Research Program areas of \$1,073 million annually.
3. Examining areas of Flagship and Core Program activity not covered by the case studies, but drawing on information from other studies, from the nature of the case study selection process and considering some of the long- and short-listed 'candidates' for case study examination, led to the view that these other areas could readily add expected value of around \$4 billion. Arguably this figure could even be a lot higher.
 - This pushes the estimate of expected annual value from CSIRO to more than \$5 billion – and arguably it could be substantially greater.
 - This reasoning supports a still somewhat conservative assessment of the expected benefit-cost ratio of CSIRO's activities of around 5:1.
4. On top of these figures, we have recognised, and assessed as highly valuable, a number of other elements of CSIRO's whole portfolio – including value in its standing capability and associated value in options generated as by-products of the main research programs and value in its advisory services and educational services
 - We have not sought to quantify these benefits, but are confident they would add substantially to overall value. This implies that the expected benefit-cost ratio of CSIRO as a whole is well above 5:1.

Of course, key elements in this chain of reasoning involve subjective assessment. We have sought to strike a balance between extreme conservatism and arriving at a reasonable and highly defensible assessment of the magnitude of the benefit-cost ratio that could realistically be expected to emerge if the analysis were extended across the whole portfolio.

The above figures are based on the use of CSIRO's indicator discount rate of 5% (after inflation). However, the calculations were also done using a discount rate of 7%, and the overall picture was little affected.

We conclude that the whole of CSIRO portfolio is delivering an expected return that supports an expected benefit-cost ratio of at least 5:1, and arguably substantially more.