Appendix H Case study: Integrated water resource assessments

SUMMARY OF KEY FINDINGS

- For the first time, Australia has systematically developed and applied a nationally consistent framework for assessing water resources and water availability under changing climatic conditions, covering roughly 72 per cent of total water for agricultural use.
- The key findings, tools and methodologies developed under CSIRO's integrated water resource assessments (WRAs) provide a basis for responsible water resource management by allowing water managers to make better informed decisions about current and future trade-offs between different water users (both human users and water for environmental use). This generates more efficient water usage over the long-term and it helps water managers avoid investments with large unexpected future economic and environmental costs.
- The assessments have delivered significant economic and environmental value. We conservatively estimate that CSIRO has likely delivered benefits of around $685-795 million in present value terms, although our analysis also shows that benefits from these two decisions may be as high as $1.24 billion present value. These estimates are based upon our analysis of just two major water management decisions (sustainable diversion limits in the Murray-Darling Basin and the construction of irrigation schemes across Tasmania) that arose as a result of two water resource assessments that together formed only 30 per cent of the total research budget.
  - In reality, CSIRO's WRAs have been incorporated into many other water management and investment decisions across Australia, not just the two decision for which benefits have been costed in this case study. As a result, total environmental and economic benefits are likely to be significantly higher than $685-795 million at a conservative estimate, and potentially in excess $1.24 billion.
- This suggests a return on research ($54.2 million) of roughly 12 to 1, if the lower estimate of $625-735 million in benefits is used, and a return on research costs of almost 30 to 1, if the higher estimate of $1.24 billion in benefits is used..

H.1 Introduction

H.1.1 Purpose and audience

This independent case study evaluation has been undertaken to assess the economic, social and environmental impacts of CSIRO's integrated water resource assessments (WRAs). This case study has been prepared so it can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of CSIRO's activities.

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

H.1.2 Background

Water demand continues to rise in Australia due to population growth and the expansion of industries such as agriculture and mining. Australia's aridity and the high variability of water runoff from year to year means that large dams, river regulation and water distribution systems are required to ensure reliable water supplies. In some areas, water resources have been over-allocated and high levels of water use have caused unacceptable levels of environmental degradation and, in some cases, severe water rationing.

Australia faces rising water supply insecurity, and a pressing need to better understand current and future water supply

Water resources were severely strained during the 1997-2009 drought in south-eastern Australia – the source of Australia's largest proportion of food production and the area of greatest population density – resulting in drastic rationing of water use and extensive environmental degradation. Given that most of Australia's water use is concentrated in south-eastern Australia, the drought had a substantial economic, environmental and social impact. While the drought was broken by two summers of flooding in eastern Australia, dry conditions in other parts of the year have persisted and drought has returned to some areas. In Australia's south-west, the drought was just one episode in a larger 35-year trend of declining rainfall levels (CSIRO, 2008).

Going forward, Australia's water resources are expected to face the additional burden of expanding agricultural and minerals production combined with drier overall climatic conditions across the continent due to climate change. The means that Australia will need to develop more resilient water management systems underpinned by robust water resource assessments, in order to withstand the recurrence of shocks such as the millennium drought.

H.1.3 Approach

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

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

Note that steps 7 and 8 above are less relevant for this individual case study as the integrated water resources assessment program is being considered in isolation. However, the results of this individual case study have fed into the synthesis report in order to estimate a lower bound of the total value of CSIRO.

H.1.4 Program origins and inputs

The objective of CSIRO's Water for a Healthy Country Flagship, under which the water resources assessments analysed in this case study took place, is as follows:

> Consistent with Australia's national interest, the Flagship will develop science and technologies that improve the social, economic and environmental outcomes from water, and deliver $3 billion per year in net benefits for Australia by 2030 (CSIRO, 2013b).

CSIRO's WRAs have been a key component of achieving this overall Flagship goal. Water resource assessments are studies undertaken by CSIRO in a number of Australia's major river and underground water basins, which seek to assess current and future water supply under changing climate conditions. The assessments aim to provide the knowledge, tools and information necessary to make water management decisions that can take current and future regional water balances into account. By enabling water managers to make decisions based on a stronger information base, the WRAs contribute to water management and investment decisions that can deliver higher and more reliable economic returns and better outcomes for the environment over the long-term. This is possible because the tools and information contained within the WRAs provide a basis for water managers to more effectively manage the trade-offs between short-term and long-term economic gains, protecting environmental flows and ecological habitats, and protecting water resources that have cultural and aesthetic value.

History of the program

CSIRO has a long history of scientific research aimed at understanding and better managing Australia's water resources. Research that currently falls under the Land and Water Flagship was previously under the Water for a Healthy Country Flagship, and other parts of the organisation before that. The water resources assessments surveyed in this case study took place between 2006 and 2013.

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

CSIRO's water resource assessments began in 2006, when the then-Prime Minister John Howard called on CSIRO to conduct a sustainable yields assessment of the Murray Darling Basin at a time when Australia's food bowl was in the grips of the millennium drought. As the severity and length of the drought deepened, conflict over water resources in the Murray-Darling Basin intensified and water sharing arrangements ceased. Prime Minister John Howard called upon CSIRO to carry out an independent, scientific and transparent study of current and future water supply in the Murray-Darling Basin to underpin the creation of a new water management plan – the Murray-Darling Basin Plan.

The Murray-Darling Basin Sustainable Yields (MDBSY) Project began in 2006. The tools, methodologies and capabilities developed in the course of MDBSY and a related project, the South-Eastern Australian Climate Initiative, were then adapted and applied to sustainable yields projects in three other areas of Australia (northern Australia, south-west Western Australia and Tasmania), after the Council of Australian Government (COAG) highlighted the need to better understand water resources and water development constraints and opportunities in key regions around Australia. Following this, the techniques and experience gained as a result of four sustainable yields assessments were extended and applied to the Great Artesian Basin, and the Flinders River and Gilbert River catchments in north Queensland. Together, these seven projects form the focus of our analysis in this case study.

Over the course of these seven water resource assessments, CSIRO gradually built up a core set of capabilities that enabled it to conduct thorough and robust assessments of current and future water availability across many regions of Australia. In some of these project, such as the Flinders and Gilbert Agricultural Resources Assessment, this core set of capabilities was extended so that CSIRO was able to assess water supply and water infrastructure development.

While ensuring long-term balance between water supply and demand is a well-established principle, Australia was until recently a sparsely monitored area and the ability to quantify key terms in the water balance and provide reliable estimates over time was lacking. This lack of basic data and analysis was previously a major hurdle for water managers and government policy makers as they sought to make equitable decisions about water infrastructure, allocation and use that would yield sustainable water supplies over the long-term. In some areas, such as the Murray-Darling Basin, lack of information also contributed to friction and disagreement over water management between different users. This lack of current and future water resource data and information in many key areas of regional

Australia – and the large barrier this has created to effective, well-informed water management decision-making – is the gap that CSIRO's WRAs have sought to fill.

Project inputs

Total funding for the six assessments covered in this case study was:

- CSIRO funding equal to $6.5 million over eight years
- External funding equal to $47.7 million over eight years

Funding for the projects covered in this case study provided by external partners is highlighted below:

Table H1 **Significant contributions by external partners**

Project	Sources of revenue	Revenue
Australian and state governments	South Eastern Australian Climate Initiative	$7.9 million
Australian Government	Murray Darling Sustainable Yields Project	$12 million
Australian Government	Great Artesian Basin Water Resource Assessment	$6.3 million
Australian and state governments	Northern Australia Sustainable Yields Project	$5.9 million
Australian and state governments	South-West Western Australia Sustainable Yields Project	$5.2 million
Australian and state governments	Tasmania Sustainable Yields	$4.2 million
Australian and state governments	Flinders and Gilbert Agricultural Resource Assessment	$6.2 million

Source: CSIRO

H.2 Program activities

In the period 2006 to 2013, CSIRO undertook six water resources assessments focusing on different parts of regional Australia, as well as the South Eastern Australian Climate Initiative.

CSIRO has built up capabilities needed to develop and apply a nationally consistent water resource assessment framework

As a result of the cumulative capabilities built up through these projects, Australia has systematically developed and applied a nationally consistent framework for assessing water resources and water availability under changing climatic conditions to serve as a basis for responsible water resource management.

Each of these projects has seen techniques and methodologies originally applied to the Murray-Darling Basin Sustainable Yields Project, the first of CSIRO's water resource assessments, adapted for regional conditions and varying levels of data availability. Each project has also yielded new techniques and methodologies that have both improved CSIRO's integrated water resource assessment capabilities, and allowed the WRAs to be applied to a greater range of areas.

In the following summary of each of the water resources assessments undertaken and completed between 2006 and 2013, sub-sections labelled 'the issues' outlines what problems necessitated an integrated water resource assessment, 'project focus' outlines what each assessment consisted of and what activities were undertaken, and 'significance' outlines how each project contributed new tools and methodologies to CSIRO's integrated water resource assessment and analysis capabilities.

H.2.1 South Eastern Australian Climate Initiative (SEACI) – generating foundation knowledge

The issues: From 1997 to 2009 south-eastern Australia was gripped by one of the most extreme and long-lived droughts on record, which inflicted large damage to the region in terms of agricultural production and ecological degradation. While there was significant speculation at the time about the relationship between the millennium drought and climate change, and whether droughts of this kind would become a recurring feature of south-eastern Australia's climate, there was a need for a comprehensive study to address these questions in a scientifically rigorous way.

Project focus: The South Eastern Australian Climate Initiative (SEACI) was a six-year research program that ran from 2006 to 2012 and aimed to better understand the impacts and drivers of climate change and climate variability on water resources in south-eastern Australia. SEACI sought to achieve this by placing extreme events into historical context, and developing improved seasonal and long term projections of future climate and water availability.

Significance: SEACI produced foundation knowledge and a number of methodological breakthroughs that were critical to the development of subsequent integrated water resource assessments.

SEACI demonstrated that robust water availability forecasts are impossible absent climate change modelling

SEACI established climate change scenarios (based upon broader Intergovernmental Panel on Climate Change [IPCC] global climate scenarios) and water supply forecasting methodologies that would be refined, tailored and applied to other water resource assessments and sustainable yields assessments. SEACI also made significant improvements to existing models such as the Predictive Ocean Atmosphere Model for Australia (POAMA) (CSIRO, 2012).

SEACI delivered greater confidence and understanding as to the anthropogenic causes of climate events in the region (CSIRO, 2013b). Importantly, SEACI demonstrated that historical water supply data can no longer be considered to be a reliable basis for forecasting future water supplies and water flow patterns. The experience of the millennium drought underlined the findings of SEACI: that a robust forecast of water supply is impossible absent detailed climate change scenarios and modelling (SEACI, n.d.).

H.2.2 Murray-Darling Basin Sustainable Yields (MDBSY) – the nation's first integrated, basin-wide water resource assessment

The issues: Former Prime Minister John Howard called on CSIRO to undertake its first 'sustainable yields' assessment in response to a water scarcity crisis in Australia's food bowl. The Murray-Darling Basin generates roughly 40 per cent of the gross value of Australia's agricultural production (CSIRO 2008b). However during the 1997-2009 millennium drought, water availability fell significantly and water sharing plans were suspended as upstream irrigators came into conflict with downstream irrigators. The millennium drought also exacerbated a longer-term decline in the ecological health of the basin, reflecting the fact that a very high proportion of water resources have been extracted for consumptive use over many decades. In 2008, only one of the 23 river valleys in the basin was in 'good' ecological condition, and the basin was characterised by a long-term decline in waterbird population health, floodplain vegetation and native fish (CSIRO, 2012b).

By the time that Howard initiated CSIRO's assessment of the Murray-Darling Basin in 2006, it was clear that water resources management plans in place at the time had failed to successfully adapt to the extreme dry conditions of the millennium drought, and that a thorough, scientific assessment of current and future water availability, carried out by an independent and trusted scientific research body, was needed to underpin a new water management plan in the Murray-Darling Basin.

Project focus: MDBSY project ran from 2006 to 2008 and involved the development of methodologies for determining the extent of current and future water resources available in the basin. The assessment of water availability and demand in the area factored in scenarios for future catchment development, groundwater extraction and climatic conditions to 2030. This was achieved using four scenarios of future development based upon:

- historic climate and current water development (i.e. human water consumption associated with the development of water usage infrastructure such as farm dams, plantations, groundwater systems and proposed irrigation development);
- historic climate for the last ten years and current water development;
- climate change forecasts to 2030 and current development, and;
- climate change forecasts to 2030 and projections of water development to 2030.

For each scenario, the MDBSY project provided an assessment of the impact and current and future predicted water resource development of key environmental assets.

The project involved development, integration and application of new hydrological models, water data collection and involved the building of effective teams across disciplines and organisations, including partnerships between CSIRO and industry.

Significance: The MDBSY project was the first of CSIRO's water resource assessments, involving the development of water resource assessment tools, methodologies and capabilities that underpinned all subsequent water resource assessments.

MDBSY tools and methodologies formed the foundation for subsequent WRAs

This was the first time that CSIRO had engaged in research that assessed how rainfall is linked to runoff, headwater region river flows, extraction of water for irrigation or other uses, and watering of wetlands and downstream flows, all the way to the river mouth. As such, it was the most comprehensive Basin-wide assessment of water availability ever undertaken. Due to the richness of existing water data in the area, CSIRO was able to provide detailed basin-wide information on current and future water balances by linking climate, groundwater, surface water and surface water-groundwater interaction models, and adapting new and existing models to have the same time-steps and time-periods (CSIRO, 2013b).

The MDBSY also triggered several new innovations that have proven important for measuring and analysing surface water-groundwater interactions and flows. These innovations included:

- Defining a criterion for rivers that have become disconnected from groundwater sources that previously recharged those rivers;
- Providing guidelines to improve the identification and modelling of rivers that are recharging groundwater (rather than the other way around);
- Developing field research approaches to determine the state of connectivity between groundwater sources and rivers (CSIRO 2013b).

CSIRO also demonstrated that climate change is already having a strong impact on water supply and water flow in the Murray Darling Basin, reinforcing the conclusions of SEACI, that climate modelling is needed in conjunction with analysis of historic trends to produce robust climate and water supply forecasts. In particular, the project demonstrated that the millennium drought was worse than previous droughts, and that the traditional autumn and winter 'filling season' (i.e. the traditional season of greater rainfall and filling of dams) saw far less rainfall and higher temperatures. Changes in runoff amplified this, resulting in lower overall water supply (CSIRO, 2013b).

H.2.3 Northern Australia Sustainable Yields (NASY) – busting the myth of "excess water"

The issues: Northern Australia is characterised by high overall rainfall unevenly spread over very wet monsoon months and very dry winter months, tropical environments and relatively low levels of development. Less than 1 per cent of the total area of the North-East Sea, Gulf of Carpentaria and Timor Sea Drainage Divisions has been cleared and used intensively, with the rest of the area dedicated to pastoralism, nature conservation, indigenous land use, mining and forestry (CSIRO, 2009b). While high rainfall levels would seem to suggest that there are opportunities for greater development of the region's agricultural potential, a lack of information about current and future water supply patterns in northern Australia has made assessing the region's development potential very difficult, particularly in terms of the possible expansion of irrigated agriculture.

Moreover, there is a perception that has been reflected in the popular press in the past (and particularly during the millennium drought) that the north of Australia has a water surplus, and that some of this water should be delivered to the southern states, who suffered large water shortages in the period 1997-2009 (CSIRO, 2009a). In the absence of a scientific understanding of Northern Australia's water balance, the viability of such water diversion proposals could not be properly assessed.

Project focus: The NASY project was initiated by COAG in March 2008 and ended in 2009. It assessed past, present and possible future water resources for each of the 13 regions across three drainage divisions in northern Australia. The NASY was part of the larger Northern Australia Water Futures Assessment, which was managed by northern state governments. The project assessed current and future water supply under the four scenarios (outlined above the description of the MDBSY) for three drainage divisions: the Gulf of Carpentaria Drainage Division, the Timor Sea Drainage Division and the Northern North-East Coast Drainage Division, which together encompass the north coasts of Queensland, the Northern Territory and Western Australia (CSIRO 2013d). While no new data was collected for the project, as the NASY was largely a desktop study, new data was generated through numerical modelling using existing data as a base, and new interpretations of existing data were undertaken (CSIRO, 2009b).

The NASY project provided a water *resource* assessment (which indicates how much water there is at any given time and location) for the whole region and a water *availability* assessment (which indicates how much water can be diverted or extracted from each source at any given time and location) for some parts of the region where there was a greater wealth of data to allow more detailed availability analysis (CSIRO, 2009b).

Significance: The NASY project was most comprehensive survey of northern Australia's water balance ever undertaken, and it was the first such study of the region to incorporate climate change projections. Lack of existing data on water resources and extraction rates across northern Australia posed a new challenge to the application of models that had been used in the MDBSY, where there was a wealth of existing water data and water models made providing detailed water balances easier. To address this, the NASY developed new models specific to the region and the NASY identified key data gaps that prevented more detailed water availability assessments in many areas, indicating areas of further study.

NASY developed innovative new ways to deal with lack of pre-existing water data and identified areas of further study

Importantly, NASY also found that there are significant constraints on the development of water storage and irrigated agriculture across many areas of the north. This conclusion was partly a function of data issues: due to lack of data it was difficult to estimate future changes in environmental flows due to development in many areas. However, this conclusion was also supported by findings that there is a high level of year-to-year and season-to-season water flow variability, few perennial rivers, low levels of soil suitability for irrigation across many areas, and a strong need for seasonal flooding to ensure the viability of local ecosystems. These findings effectively busted the myth that the entire north of Australia would be suitable for irrigated agriculture to a scale that the north could become a 'food bowl of Asia', although, as will be seen in the case of the Flinders and Gilbert Catchment Assessment, subsequent studies showed potential for more intensive irrigated agriculture on a smaller scale in some discrete areas of the north (CSIRO, 2013j).

H.2.4 Tasmania Sustainable Yields – supporting responsible water resource development

The issues: While agriculture has long been an important part of Tasmania's economy, lack of water infrastructure and uncertainty about feasible options for alternative cropping in many areas of the country have acted as a hindrance to increased investment. Unlike mainland Australia, Tasmania has abundant water supplies and was largely unaffected by the millennium drought.

Project focus: The Tasmania Sustainable Yields project was initiated by COAG in March 2008 and ended in 2009. The objective of the project was to undertake an assessment of current and future water supply and supply variability in Tasmania under four climate change and development scenarios (the same scenarios as those outlined in the MDBSY project, above, with the exception that Tasmania SY included development of forest plantations in its analysis).

The project aimed to provide the necessary information to ensure that the Commonwealth government co-invested only in those scheme which were robust under the most extreme climate change projections. The study covered Tasmania's five major agricultural regions: Derwent-South East, South Esk, Pipers-Ringarooma, Mersey-Forth and Arthur-Inglis-Cam. Together, these areas constitute almost 50,000 square kilometres, or 72 per cent of Tasmania's land area (CSIRO, 2009d).

Significance: As neither surface water nor groundwater extractions are metered in a consistent way in Tasmania, CSIRO developed and applied a comprehensive suite of river models, as well as three groundwater models for different groundwater areas. In order to assess the ecological impacts of irrigation and other water developments, CSIRO used flow stress ranking to determine ecological impacts of changes to streamflow at key ecological sites and sub-catchments.

TasSY incorporated plantation forests into WRA methodologies and developed models to cope with lack of pre-existing data

This was the first time that the impacts of Tasmanian catchment development (commercial plantation forests and future irrigation development), changing groundwater extraction rates, climate variability and anticipated climate change on water resources at a whole-of-region scale were quantified. This was achieved through the most comprehensive hydrological modelling ever attempted in the region, using rainfall-runoff models, groundwater recharge models, river models and groundwater models (CSIRO, 2009c).

The Tasmania SY was also significant in its focus on assessing the impact of plantation forests on overall water availability, demonstrating that plantation forests can reduce streamflow to a greater extent than climate change (CSIRO, 2013b).

H.2.5 South-West Western Australia Sustainable Yields (SWWASY) – groundwater is significant for water supply

The issues: The south-west is one of Australia's most water-challenged areas, due to rapid population growth and associated development, decreasing rainfall, and a high level of vulnerability to further decreases in water supply due to climate change. Between 1975 and 2008, runoff to metropolitan dams decreased by more than 75 per cent, while groundwater storages in the Gnangara Mound decreased by over 45 GL each year (CSIRO, 2008). As a major agricultural area, food production has also been affected by the 35 year trend of dry conditions. While a need for diversification of water sources and better water management has been recognised, lack of integrated understanding about south-west WA's water current and future water supply had hindered decision making.

Project focus: The South-West Western Australia Sustainable Yields project was initiated by COAG in March 2008 and ended in 2009. It assessed current and future water yield for the entire south-west of Western Australia over an areas extending from Geraldton in the north, to Albany in the south. The assessment estimated future water balance in the region using four climate change and water resource scenarios (outlined in the section on the MDBSY project, above). The study focused in particular on modelling groundwater resources and mapping the interconnectivity of aquifers. Activities undertaken in the project included the formation of climate scenarios and modelling of climate change effects on catchment runoff, aquifer recharge and rainfall levels, modelling of surface-groundwater exchanges, and assessment and reporting of the implications of these factors for water yield.

Significance: The SWWASY project was one of the first detailed studies of the impacts of climate change of the recent past on existing water supplies in the region. The project demonstrated that there have been changes in the rainfall-runoff relationship in the region over the past decades, and that lower groundwater levels are due to a drier overall climate. This has led to reduced surface-groundwater interactions and hence reduced streamflows (CSIRO, 2013b).

SWWASY developed new techniques to measure surface-groundwater interactions

SWWASY also utilised a number of modelling techniques to measure surface water-groundwater interactions and groundwater characteristics. Many of the techniques for measuring and analysing groundwater flows utilised in SWWASY formed a basis for the subsequent Great Artesian Basin Water Resources Assessment (CSIRO, 2013b).

H.2.6 Great Artesian Basin Water Resources Assessment (GAB WRA) – supporting the management of a globally significant resource

The issues: The Great Artesian Basin (GAB) is one of Australia's most important water resources and is the largest and deepest underground water reservoir in the world. It lies under an area of 1.7 million square kilometers covering Queensland, New South Wales, South Australia and the Northern Territory, or approximately 22 per cent of the continent. However, there has been growing concern about the sustainability of GAB water use, with increasing extraction rates and a history of inefficient extraction causing dropping water levels and pressure decline in the basin (although pressures have started to recover over the past decade or so).

Project focus: The GAB WRA was commissioned by the then-Commonwealth Department of Sustainability, Environment, Water, Population and Communities and the National Water Commission in July 2010 and ran until 2013. CSIRO partnered with Geoscience Australia to provide an analytical framework to assist water managers across the four main sub-basins that comprise the GAB (West Eromanga, Central Eromanga, Surat, and Carpentaria). The

GAB WRA represented a continuation of the sustainable yields projects and drew upon many of the core tools and methodologies developed in the course of the Murray-Darling Basin and south-west Western Australia Sustainable Yields projects. CSIRO's assessment involved a basin-scale investigation of water resources and the potential impacts of climate change and groundwater development to 2070. The study revealed that the complex geological features such as faults and ridges govern groundwater movement in the GAB and identified areas where underlying geological basins and overlying shallow groundwater are potentially connected with aquifers of the GAB.

GAB WRA developed sophisticated groundwater tracking tools

Significance: A key contribution of the Great Artesian Basin WRA was the development and application of isotope hydrology – a process that measures the specific isotopic fingerprint of water molecules to trace water flows and water age. While CSIRO has maintained an isotopic hydrology laboratory for over 40 years, the GAB WRA was significant due to the incorporation of a noble gas laboratory for the project in 2009. This laboratory was primarily established to measure helium-4 in order to aid tracing old groundwater discharge to rivers in the Great Artesian Basin. By incorporating noble gas analysis into historic water level and quality monitoring data, hydraulic testing, environmental tracers and geophysical techniques, the GAB WRA improved the techniques used to assess the connectivity of aquifers (CSIRO, 2013b).

The GAB WRA brought together knowledge of geological and hydrological conditions in a consistent way for the entire basin for the first time, drawing together and harmonising existing research and data on the GAB, as well as adding new CSIRO-developed and collected models and data.

The GAB WRA identified the complex geological features such as faults and ridges that govern groundwater movement in the basin and where deep geological basins and overlying shallow groundwater are connected to aquifers in the GAB. It demonstrated that many more reservoirs and basins have connected water flows than was previously thought. This involved the creation of a series of maps of reservoirs and basins that gauged the potential for connected water flows (CSIRO, 2013e). The assessment also demonstrated that groundwater has a greater potential to move vertically across GAB formations than previously thought.

H.2.7 Flinders and Gilbert Agricultural Resource Assessment (FGARA)

The issues: High levels of annual rainfall had prompted speculation about the viability of intensive irrigated agricultural in the areas of north-east Queensland surrounding the Flinders and Gilbert River for many years. However, until CSIRO carried out the Flinders and Gilbert Resource Assessment (FGARA), lack of consistent information on current and future water supplies in the region created high levels of risk for potential agricultural investors and inhibited informed discussion on changes to land usage regulations. While previous studies of the area had highlighted the potential for intensified irrigated agricultural production, these studies either assessed irrigation proposals at the local level only, without assessing how such developments may fit into a sustainable catchment and regional development framework, or they identified constraints to greater agricultural activity in over larger areas of north Queensland, without assessing how these constraints could be addressed in a sustainable way (Rudwick and Miller, 2014). Water resources and development potential was broadly mapped in the NASY project, but detailed information on where and when surface water could be taken, how much water could be reliably and sustainably removed, and where and how it might best be stored was still lacking (Dickson, 2014).

Project focus: CSIRO's Flinders and Gilbert Agricultural Resource Assessment (FGARA) was one component of the larger North Queensland Irrigated Agriculture Strategy (NQAIS), which began in January 2012 under the leadership of the Queensland Government, James Cook University and CSIRO and ended in December 2013. Building on the reconnaissance-scale Northern Australia SY data and methods, the FGARA involved comprehensive analyses of water resources in the Flinders and Gilbert river catchments, in order to identify and test the commercial viability of irrigated agricultural opportunities and assess the potential environmental, social and economic impacts and risks of such development. The FGARA sought to: 1. identify and evaluate water capture and storage options; 2. identify and test the commercial viability of agricultural opportunities, and; 3. assess the potential environmental, social and economic impacts and risks of water capture/storage and irrigation development.

The project's activities included:

- Fieldwork to collect data, establish the value, costs and risks of irrigated agricultural production or other water developments, and benchmarking of new production methods.
- Region-scale geochemical and geophysical surveys to map salinity risks and connectivity and surface and groundwater.
- Mapping land and soil agricultural suitability and production risks (such as salinity and floods) across agricultural, horticultural and pastoral systems.
- Topographic mapping and automated terrain analysis to identify and evaluate water storage and development options.
- Hydrodynamic and river modelling to assess the extent, magnitude and duration of floods, land suitability, and connectivity between surface water and groundwater.
- Assessments of potential environmental impacts under a range of climate and development scenarios and identify Indigenous water values.
- Socio-economic cost–benefit analyses, including demands placed on key resources under a range of development scenarios.
- Information and data distribution through web-based information products, reports and regular community-based information sessions (CSIRO, 2014c).

Significance: Where previous assessments focused on single development activities or assets – without analysing the interactions between them – FGARA considered the opportunities presented by the simultaneous pursuit of multiple development activities and assets. By this means, the Assessment used a whole-of-region (rather than an asset-by-asset) approach to consider development. As such, FGARA provided a blueprint and a set of methodologies for rapidly assessing future land and water developments in other parts of northern Australia (Rudwick and Miller, 2014).

FGARA linked WRAs directly to a range of water infrastructure and agricultural development opportunities

FGARA was also significant because it analysed the commercial viability of water development and infrastructure choices, with reference to current and future water supply and supply reliability. Where other WRAs aimed to inform government decision-making and provide information to agriculturalists, the FGARA provided information that can be tailored to meet the due diligence requirements of private investors and lenders, by addressing questions of profitability and income reliability of agricultural and other developments.

CSIRO applied new digital soil mapping techniques to better understand soil properties and create land suitability maps for a variety of crops across the region. This involved integrating the use of airborne electromagnetic surveys, to measure soil salinity and quality, with noble gas tracer analysis applied to the GAB WRA. This allowed CSIRO to conduct run-of-river tracer studies, in order to better understand the geological conditions surrounding surface water-groundwater interactions. This was the first time that multiple tracers had been used to quantitatively measure local and groundwater discharges (CSIRO, 2013b; Jolly *et al.*, 2013).

FGARA saw the first operational application of the 'DamSite' model, developed by CSIRO researchers, which enables researchers to automatically identify potential dam locations. DamSite involved the creation of high-resolution digital elevation models for dam sites, assessing streamflow uncertainty and assessing the risk of water table rise, even in areas with little pre-existing water data. (CSIRO, 2013b).

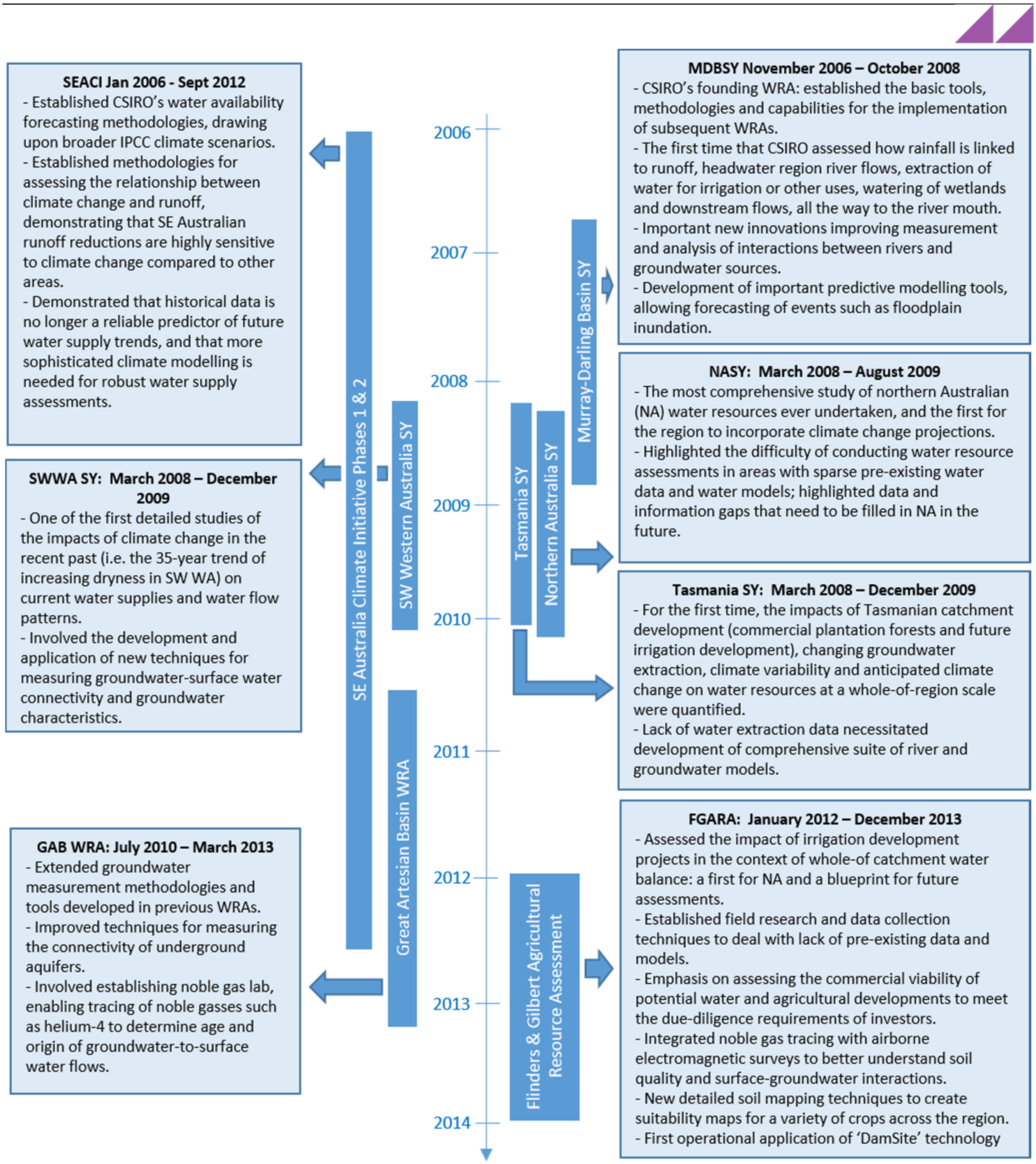
In addition, FGARA built on previous WRA work in data-poor regions, such as Tasmania and northern Australia, to create a new model to assess the risk of groundwater rise under irrigation in data sparse areas (CSIRO 2014c).

H.2.8 Cumulative capabilities built over the course of the WRAs

The cumulative experience of these water resource assessments and the SEACI enabled CSIRO to build its capabilities to assess current and future water balances to a high level of geographic detail, across large basins and water systems. The implementation of WRAs in highly diverse water system and climate areas of Australia have also enabled CSIRO to develop flexible tools and methodologies for conducting water resource assessments both in areas that are rich in existing water supply and consumption data, and in areas where pre-existing data is relatively sparse.

The timeline below presents a visual summary of each of CSIRO's water resources assessments (as well as SEACI), highlighting how each subsequent project built upon and extended the tools, methodologies and capabilities developed in the preceding projects.

Figure H1 **Timeline of cumulative water resource assessment capabilities**



Source: ACIL Allen Consulting

H.2.9 Summary of common activities across all WRAs

A number of activities are common across all of the water resources assessments, are summarised in the table below:

CSIRO's WRAs incorporated a diverse and cross-disciplinary set of capabilities and activities

Table H2 **Common activities across all sustainable yields assessments**

Activity	Detail/example
Integration of pre-existing data and models to provide a consistent picture over time of water resources	This involved the collection of existing models for different water sources in the region, critical assessment of the models, harmonisation of time periods and units across the models, and integration with newly developed CSIRO models for each WRA and the SEACI.
Characterising and quantifying climate and hydrologic variability	This involved: ▪ analysing hydroclimate variability over annual, decadal and longer time scales; ▪ long-term trends in climate and streamflow series, and; ▪ large-scale ocean–atmosphere drivers of regional climate and changes to these drivers.
Estimating climate change impacts on water	This involved: ▪ assessing and weighting global and regional climate models; ▪ climate–water modelling to predict future water availability and river flow characteristics; ▪ providing recharge estimates over large land areas and water systems.
Hydrological modelling	This involved: ▪ attributing past and future changes in water availability to changes in climate inputs and changes in dominant hydrological processes; ▪ quantifying biosphere influence on water availability through catchment vegetation; ▪ modelling of individual catchment-scale hydrological processes (land use change, high and low flows, surface water – groundwater interactions, and floodplain processes); ▪ estimating changes in water balance components under future scenarios of land use change; ▪ developing a floodplain inundation model to predict the size, depth and volume of floodplain inundation.
Developing measurement and modelling techniques to assess surface-groundwater interactions	This involved ▪ comparing methods of estimating groundwater contributions to surface water flows and developing new methods where necessary; ▪ developing modelling methodologies; ▪ developing field-based approaches to determine the state of connectivity in losing rivers
Tailoring water resource assessments to water planning needs	This involved: ▪ communicating water availability projections to important stakeholders; ▪ developing risk-based methods that can better utilise climate–water prediction to consider alternative water planning and adaptation options; ▪ working with catchment, state and Australian Government agencies to incorporate climate–water prediction in basin and regional water sharing plans and climate adaptation options.
Developing techniques to estimate and quantify uncertainty and probability in water resource models	This involved: • providing a methodology to account for uncertainty in forecasts of groundwater flows; • exploring different options to deal with uncertainty in hypothetical future water allocations; • developing a range of benchmark techniques and methodology for recognising and estimating uncertainty in water supply forecasts.

Source: ACIL Allen Consulting; CSIRO 2013b

H.3 Program outputs

H.3.1 Key outputs of the program

The outputs of each WRA were a series of reports and datasets on regional water resources

Outputs from the WRA projects have varied depending upon the region of study, but a number of outputs have been common throughout the five regional studies. These include:

- Publicly accessible modelling and databases that detailing water resources in each region: in all of the areas covered by the assessments CSIRO's WRAs provided the first consistent, robust and transparent assessment of current and likely future water resources for each region, including an assessment of possible future climate implications.
- Region-specific water resource assessment reports. These include a range of summary reports and technical report to inform policy making, investment decisions, stakeholders and the general public.
- Benchmarking of standard water resource assessment models and methodologies. CSIRO benchmarked standard methodologies for measuring rainfall and surface water evaporation.

In addition, each project has yielded a number of outputs that are particular to each project.

South Eastern Australian Climate Initiative

The primary outputs of SEACI were a series of scientific journal papers, reports, and datasets, which included:

- Synthesis reports for phases 1 and 2 of SEACI, covering major research findings on climate and water availability in south-east Australia.
- Program annual reports for the years 2009/10 to 2011/12, detailing project activities, publications and major findings in phase 2 of the project per year.
- A series of final reports covering major research findings on issues including rainfall and evaporation patterns, climatic and weather patterns, runoff and drainage, model assessments and forecast data.
- A series of accessible factsheets covering the SEACI project itself, major research findings on issues such as the millennium drought, prediction of seasonal climate and streamflow, future climate and streamflow, and a summary of all of SEACI's major research findings.
- 75 peer reviewed academic journal articles
- Downloadable data on projected changes in climate and water runoff under 1ºC of warming and 2ºC of warming (South Eastern Australian Climate Initiative, n.d.).

Murray-Darling Basin Sustainable Yields

The primary outputs of the MDBSY were a series of reports and datasets, which included:

- Whole-of-basin water resource assessment reports, including detailed and summary reports.
- Detailed and summary reports outlining project methodologies and the terms of reference for the project.
- Water resource assessment reports for 18 regions within the Murray-Darling Basin, with a detailed report, a summary factsheet and snapshot and summary presentations/reports of main research findings for each region.

- 17 technical reports covering issues and topics including: water resources in the parts of the Great Artesian Basin that underlie the Murray-Darling Basin; climate data and hydrological scenario modelling; data management and methodologies; groundwater and recharge modelling and groundwater management; water evaporation modelling; surface-groundwater interactions modelling, rainfall and runoff modelling, historical reports and data of relevance; surface-groundwater connectivity assessment; region-specific modelling reports, and; use of satellite observations for water balance estimates (CSIRO, 2013j).

Northern Australia Sustainable Yields

The primary outputs of the NASY were a series of reports and datasets, which included:

- Summary reports of current and future water balances covering both the entire area of northern Australia, as well as the three individual drainage basins (the north-east coast, Gulf of Carpentaria and Timor Sea drainage basins).
- Detailed reports and summary factsheets containing current and future water balances in localised drainage sub-divisions within the broader North-East Coast, Carpentaria and Timor Sea drainage divisions.

Six technical reports outlining groundwater recharge modelling, streamflow simulation, northern Australian climate data, and detailed summaries of high and low flow regime changes under different climate scenarios, river modelling, and rainfall runoff modelling (CSIRO, 2013i).

Tasmania Sustainable Yields

The primary outputs of the Tasmania SY were a series of reports and datasets, which included:

- Two summary reports covering the whole of northern and eastern Tasmania: one examining water availability in Tasmania, another outlining climate change projections and impacts of water runoff levels in Tasmania.
- Six technical reports
- One of these technical reports is a large five volume publication containing detailed water availability reports for the five surveyed regions: the Arthur-Inglis-Cam region, the Mersey-Forth region, the Pipers-Ringarooma region, the South Esk region, and the Derwent-South East region.
- The remaining five technical reports and datasets include: climate scenario, rainfall-runoff modelling, groundwater assessments and modelling, detailed river modelling for each of the five surveyed regions, a report on the ecological impacts of water availability, and a glossary of water-related terminology.

In addition to these reports, the Tasmania SY project involved the creation of a comprehensive suite of river models to measure movement and use of water within a project area, to compensate for the lack of existing data and water metering infrastructure in many areas of Tasmania (CSIRO, 2013g).

South-West Western Australia Sustainable Yields

The primary outputs of the SWWASY were a series of reports and datasets, which included:

- Three detailed reports covering surface water yields, groundwater yields, and water yields and demand in south-west Western Australia, including water supply projections under climate change scenarios out to 2030.

- Summary reports and factsheets covering the detailed reports.
- Two technical reports describing project methodologies and climate analyses for south-west Western Australia (CSIRO, 2013h).

Great Artesian Basin Water Resources Assessment

The primary outputs of the GAB WRA were a series of reports and datasets, which included:

- Water Resource Assessment reports for the whole of the Great Artesian Basin
- Water Resource Assessment reports for each of the main sub-basins (the West Eromanga, Central Eromanga, Surat and Carpentaria sub-basins)
- Five technical reports outlining groundwater models and modelling methodologies, assessments of future climate and groundwater development on springs, hydrostatigraphy, hydrogeology and system conceptualisation, outline of main lexicon, and models of climate and groundwater development.
- Datasets available through Geoscience Australia, including a 3-D visualisation of the GAB, and data reports (CSIRO, 2013c)

Flinders and Gilbert Agricultural Resource Assessment

The primary outputs of the FGARA were a series of reports and datasets, which included:

- Two detailed reports covering the Flinders and Gilbert catchments respectively, providing comprehensive analysis of the feasibility, economic viability and sustainability of agricultural development in each catchment.
- Summary reports, FAQs and factsheets covering FGARA project management, key findings, two separate agricultural resource assessments of the Flinders River Catchment and the Gilbert River Catchment, socio-economic impacts, Indigenous values surrounding water and agricultural development in the region and airborne electromagnetic mapping (AEM, a techniques used to map soil salinity and groundwater quality).
- 17 technical reports covering methodology and research findings for issues such as: river system, streamflow and surface-groundwater modelling; climate data and hydrological and agricultural scenario modelling; dam and sediment modelling; flood and floodplain mapping and modelling; Indigenous water values, rights and interests; irrigation costs and benefits; socio-economic impact evaluations; land suitability assessments and agricultural production.
- Soil datasets accessible through CSIRO’s Data Access Portal covering soil properties and modelled irrigation land uses (i.e. crop and irrigation combinations), with more detailed information on location-specific soil sample results available upon request.

In addition to these reports and datasets, CSIRO applied a new digital soil mapping approach to create land suitability maps for a variety of crops across the region.

H.3.2 Awards and public recognition

CSIRO's has received a number of awards for its water resources assessments.

Table H3 **Awards related to water resources assessments (2009-2014)**

Year	Award
2013	Eureka Prize for Research and Innovation finalist: The South Eastern Australian Climate Initiative led by Dr. David Post and Dr. Francis Chiew (CSIRO), Dr. Bertrand Timbal and Dr. Harry Hendon (BOM) for enabling better management of Australia's precious water resources in the face of future climate challenges.
2012	CSIRO Land and Water Division award: Excellence in Research Award to Dr. David Post and team for the South Eastern Australian Climate Initiative.
2010	Dr Tom Hatton awarded Public Service Medal.
2010	Finalist: The South-West Western Australia Sustainable Yields Project in the Australian Water Association (Western Australia) Water Awards ('Program Innovation' category).
2008	CSIRO Chairman's Medal for Murray Darling Basin Sustainable Yields Assessment team.
2008 & 2009	Finalist: Australian Museum Eureka Awards – Water Resource and Innovation for Murray Darling Basin Sustainable Yields Assessment Team.
2009	2009 Team of the Year by the eWater CRC: to Dr Alice Brown and Dr Wendy Welsh for their exceptional efforts in research and stakeholder engagement in support of the new River Manager modelling tool.

Source: CSIRO 2013b

H.4 Status of Outcomes and Impacts

H.4.1 Nature of Outcomes and Impacts

Water resource assessment outcomes

Improved understanding of water balance in Australia

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

CSIRO's water resource assessments have strengthened understanding of the current and future water balance in a number of key regions that together comprise roughly 72 per cent Australia's water resources. CSIRO has achieved this in the following ways:

Provision of comprehensive information that is consistent across large areas, but also detailed and area-specific.

One of the main tasks of the water resource assessments involved the collation of existing data, models and research on water supply and demand in each region of study, critically assessing these pre-existing research resources, and harmonising pre-existing research so that underlying methodologies, units, time-steps and other features could be analysed on consistent terms. For projects that were chiefly desktop studies, such as NASY, harmonising existing research and data and applying CSIRO's own new modelling and analysis to this data was the main task. For other studies involving intensive data collection, new data and models were meshed with pre-existing data.

…provision of consistent and detailed scientific information on regional water resources …

By incorporating and harmonising pre-existing research, CSIRO was able to produce a picture of the current and future water balance in each region that represented the result of cumulative research not just of CSIRO, but of the broader scientific community. This was important not only for the provision of comprehensive and consistent information for the broader public, but also to strengthen CSIRO's image as a trusted and impartial provider of information in an area (water consumption and water trade-offs) that is often highly contested (the value of public trust in CSIRO's research findings is discussed further below).

Moreover, the WRAs provided rigorous, whole-of-basin assessments side-by-side with detailed assessments of smaller regions within each basin. In all cases where CSIRO undertook WRAs, this was the first time that a whole-of-basin water resources assessment, which was consistent across the entire basin and incorporated future projections based on climate change analysis, had been undertaken. At the same time, smaller region-specific studies provided the ability to drill down to specific areas within this same broader analytic framework, providing new understanding of the links between water supply and consumption in the larger basin and local areas.

Information of this level of consistency, detail and scale had never been provided to this extent in the Murray-Darling Basin, northern Australia, north and east Tasmania, south-west Western Australia, the Great Artesian Basin, and the Flinders and Gilbert Catchments before.

Improvement of climate change projections and incorporation into large water resource assessments.

All of CSIRO's water resources assessments included climate change projections under a range of scenarios. All of the sustainable yields projects included climate change projections out to 2030, while the GAB WRA included climate change projections out to 2070, in recognition of the fact that flow processes are slow in large regional groundwater systems. For all of the regions covered by CSIRO's WRAs, this was the first time that projections of future water supply on a whole-of-basin level were undertaken based on a combination of historical data and sophisticated climate modelling.

…incorporation of robust climate change projections in water availability forecasts …

This involved the creation and improvement of climate change models, starting with SEACI. SEACI saw the adaptation and improvement of many key models that describe current climate patterns and their future development under IPCC scenarios of higher atmospheric greenhouse gas concentrations. These improvements underpinned new and important research findings in the Murray Darling Basin in relation to the role of the millennium drought and changes in water flow patterns that have already taken place, and projections of how weather and water flow patterns will evolve out to 2030. Improvements to climate models in other parts of Australia were similarly key to the credibility of future water balance and water flow projections in other WRAs.

Improvements to climate models, particularly the coupled atmosphere–ocean–land climate model (POAMA) has also significantly increased the accuracy of shorter-term seasonal climate and weather forecasting in Australia (CSIRO, 2013b).

Improved understanding of key water flow characteristics.

…improved methodologies for measuring and understanding water flows …

CSIRO's WRAs saw progressive improvements to modelling and understanding of key characteristics of water flows across basins. A few examples of these are:

- *Improved understanding of aquifers and groundwater*. For example, the GAB WRA saw the development of models and research techniques that gave a much more comprehensive picture of where underground connections exist between the Great Artesian Basin and other aquifers and basins, showing that the Great Artesian Basin is more interconnected than was originally thought.
- *Improved understanding and forecasting of floods*. One of the major breakthroughs in flooding forecasting was the development of the River Murray Floodplain Inundation Model (RiM-FIM) which was applied in the course of the MDBSY project. The RiM-FIM allows water resource managers to predict the timing and extent of flooding on any given floodplain.

— *Improved forecasting of rainfall and understanding of seasonal rainfall variability*. All WRAs resulted in significant improvements in seasonal streamflow forecasting in each region of study. Streamflow forecasting methodologies developed in the course of SEACI and MDBSY, which were then extended to NASY and FGARA, have formed the basis of an ongoing Bureau of Meteorology streamflow forecasting service.
— *Improved understanding of the water runoff levels*. CSIRO's WRAs involved refining and improving established methodologies for assessing the relationship between climate change and water runoff levels. In this way, projects such as SEACI and SWWASY were able to demonstrate that in many areas of Australia, runoff levels are very sensitive to rainfall levels, with reduced rainfall as a result of drier overall conditions leading to disproportionate declines in runoff levels.
— *Improved streamflow forecasts*. Building on work to improve streamflow forecasts developed under SEACI, CSIRO and the Bureau of Meteorology (BOM) researchers developed a seasonal streamflow forecasting tool, which is now used by the BOM in its routine forecasts (CSIRO, 2013b). Streamflow forecasting methodologies have been adapted and applied in other WRAs to predict the future viability of water infrastructure projects such as dams and irrigation systems.
— *Improved understanding of soil characteristics and crop suitability*. CSIRO developed new ways to gauge soil qualities such as salinity and crop suitability, producing detailed crop suitability data and maps as part of the TasSY and FGARA water resource assessments.
— *Novel water data collection techniques.* While the first sustainable yields assessment, the MDBSY, was characterised by a wealth of existing water extraction data as a result of extensive water metering and measurement infrastructure, many subsequent water resources assessments took place in areas with sparse water supply and consumption data. CSIRO developed novel techniques to tackle lack of pre-existing data, including through the developed of new region-specific models, and through new and efficient data collection techniques, such as noble gas tracing for groundwater measurements in the Great Artesian Basin and the use of airborne electromagnetic surveys in FGARA.

Quantification of water supply uncertainty. As well as providing unprecedented levels of information on current and future water balances in each area, the WRAs also developed novel techniques folr highlighting and quantifying future uncertainty of water supply. In many cases, new awareness of future water supply uncertainty came about as a result of the research findings themselves. For example, one of the most important research findings of SEACI was that the movement southward of tropical weather patterns means that the traditional 'filling season' (i.e. times of high rainfall when water storage infrastructure such as farm dams is filled) in the autumn and winter will no longer be as reliable as it has been previously, and that more rain may come in the summer months in some years. Key research findings such as these can help water managers better factor uncertainties into their decision-making.

…defining uncertainties and quantifying the degree of uncertainty associated with future water flows …

CSIRO's WRAs also developed a novel method of quantifying streamflow uncertainty to produce streamflow probability forecasts. This was applies in the Tasmania SY and FGARA projects, allowing users to pinpoint specific large water infrastructure and access an expected rate of future streamflow. Analysis and quantification of streamflow uncertainty gives water managers an important new tool in assessing the long-term viability of major water infrastructure investments.

Effective communication to ensure that research findings and new water planning resources reach a wide and diverse audience

A key part of improving understanding of Australia's current and future water balance has been the effectiveness with which CSIRO has communicated its research. Enabling CSIRO's research findings and new methodologies to be understood by the diverse set of stakeholders involved in water management decisions means that they are more likely to be incorporated into water resource decision-making.

…improving public understanding of Australia's water supply constraints and opportunities …

An important avenue through which this has been achieved is through the reports themselves, which cater to a wide variety of stakeholders through a combination of highly detailed, technical reports, which can be used by government water regulators, departments and agencies, corporations and banks and a range of other users, and easy-to-access, plain English summary reports and factsheets, which make WRAs accessible to the broader public and other non-experts.

The combination of accessibility, breadth and detail in the WRAs has been key to ensuring that the main messages of each WRA spread more effectively to CSIRO's diverse target audience, enabling each WRA's key findings, tools and methodologies to be incorporated in a greater number of high-impact water management decisions and decision-making processes. Moreover, transparency of methodologies and accessibility of WRA findings have been important for the success of the projects, particularly in cases where some major stakeholders, such as farmers, were at times doubtful of the benefits of such assessments (Woodhouse, 2014).

…maintaining and enhancing CSIRO's reputation as a source of trusted advice and information on water resource management, and …

Provision of trusted and authoritative research. CSIRO has been able to establish itself as an authoritative voice in Australia's public discussion about water supply and management. This is important because greater levels of trust in CSIRO's research findings from more stakeholders mean that the research and methodologies developed in the course of WRAs are more likely to be incorporated into water decision-making on the part of governments, companies, lenders/investors, environmental groups and private individuals such as farmers. CSIRO has employed a number of strategies that have contributed to higher levels of public confidence in the WRAs, including:

- Publishing extensively in peer-reviewed scientific journals
- Incorporating pre-existing research and data into WRAs
- Building Australia's largest water resources research group with a wide breadth of cross-disciplinary skills and expertise
- Partnering with key organisations to supplement in-house skills and capabilities and build confidence with these organisations
- Transferring technology and skills to these partner organisations
- Engaging with a diverse array of stakeholders in the course of WRA research project.

…providing a benchmark for future WRAs

Formation of a benchmark for further water resource assessments. Beginning with SEACI and MDBSY, CSIRO's WRAs have established a set of methodologies, tools and research that forms a benchmark for rigorous and detailed basin-scale water resource assessments in other areas. This set of research, tools and methodologies is now being extended and applied to other areas and water management issues in Australia. This framework is also being extended to further projects in Australia and internationally (see Section H.H.5).

Incorporation of WRA findings into regional water management plans and decision-making processes

CSIRO's success in improving understanding of current and future water balances in key areas of Australia has led to the widespread adoption of WRA methodologies and research in a number of water management plans, regulatory processes and investment decisions across the country. While it is difficult to precisely characterise all of the ways in which

WRAs have been adopted by water managers, the following highlights the most significant examples of uptake of each WRA.

South Eastern Australian Climate Initiative

CSIRO's WRAs have been incorporated into key water decision-making processes by a wide range of water managers

Adoption by Victorian government. SEACI research findings have been incorporated into state and local water planning, trading, management, and investment decisions in Victoria since 2006. Specifically, the Victorian government has instituted 'Sustainable Water Strategies' for each of four regions in the state. Previously, water supply planning had been based on the assumption that historic rainfall and streamflow records provided a reliable basis for forecasting future resources availability. The new regional Sustainable Water Strategies draw on SEACI analysis to provide a holistic review of water resource management, considering surface water and groundwater resources and environmental and consumptive needs, and incorporating future flow scenarios from SEACI under different degrees of global warming. Victoria's Central Region was the first to release a Sustainable Water Strategy incorporating SEACI climate scenarios in 2006, followed by the Northern Regional Sustainable Water Strategy released in 2009, and the Gippsland and South West Strategies released in 2011 (Fitzpatrick, 2013).

The Victorian government has also mandated that the state's 17 water corporations responsible for supplying water to cities and towns produce 'Integrated Water Cycle Strategies'. These Strategies involve forecasting future water supply and demand in order to underpin business cases for investments in new large scale water infrastructure such as dams. The Integrated Water Cycle Strategies are reviewed every five years. Victoria's water corporations are required to consider a range of future water supply and water flow scenarios that are underpinned by SEACI data and forecasting methodologies (Fitzpatrick, 2013).

Adoption by the Bureau of Meteorology. The Bureau of Meteorology (BoM), which was a major partner of CSIRO in SEACI, has adapted and adopted the improved POAMA seasonal climate model to produce the official seasonal climate outlook (CSIRO, 2013a). SEACI also provided the initial foundation for a BoM new seasonal streamflow forecasting service covering the east and north-east regions of Australia.

Adoption by ACTEW Water: The ACT's water and sewerage operator, ACTEW Water, has incorporated SEACI's research in the planning of the Cotter Dam extension, which involves the construction of a new 80 metre high dam to help secure the ACT's water supply over 2009 to 2013 (CSIRO, 2013b).

Murray-Darling Basin Sustainable Yields

Adoption by the Murray-Darling Basin Authority: As a result of the MDBSY project, CSIRO has become an ongoing provider of scientific research to the Murray-Darling Basin Authority (MDBA). The MDBSY project was established by former Prime Minister John Howard under the 2007 Water Act to create and enforce the Murray-Darling Basin Plan for the management of water resources in the basin. Following the end of the MSDBSY project in 2009, CSIRO used the techniques and research developed in the course of that project to undertake further research projects on contract for the MDBA, in order to answer specific research questions related to the development of the Murray-Darling Basin Plan.

In particular, CSIRO used research from the MDBSY as a basis for the River System Modelling Project and the Groundwater Assessment Project, which was implemented over 2009 and 2010. The methods, systems and input data were used by the MDBA in the development of sustainable diversion limits (SDLs), set under the Plan. SDLs set annual volumes of water to be recovered from irrigators and returned to the environment as environmental flows, with specific SDL for each catchment and aquifer, and an SDL for the

Murray-Darling Basin as a whole. SDLs seek to cap total water consumption across the basin at 10,873 GL/year by 2019, a target which entails the reclamation of 2,750 GL/year of water for environmental flows from human consumption, to be achieved by a combination of water buybacks and investment in greater water infrastructure efficiency. The MDBA also uses the River Murray Floodplain Inundation Model (RiM-FIM) tool applied in the MDBSY project, to determine floodplain areas impacted by various management scenarios (CSIRO, 2013b).

CSIRO extended research done under the MDBSY and SEACI to provide advice to the MDBA on defining climate scenarios for Basin Plan modelling and modelling of climate impacts on groundwater. CSIRO also provided training for the purpose of best research practices and knowledge transfer to the MDBA, including through the secondment of staff.

Northern Australia Sustainable Yields

The NASY have been incorporated into a number of submissions to the Joint Selection Committee on Northern Australia for the Northern Australia White Paper that is currently being drafted by the Commonwealth Government. One submission from the Australian Academy of Science used the NASY to demonstrate the importance of including scientific knowledge in the drafting of the White Paper, highlighting the many data and knowledge gaps that were uncovered by the NASY relating to northern Australia's water resources and agricultural potential (Australian Academy of Science 2014).

NASY methodologies and research also provided an important foundation for CSIRO's review of sustainable development in northern Australia, which was commissioned by the Northern Australia Land and Water Taskforce (CSIRO, 2011). This review formed the scientific foundation for the Taskforce's final report, which urged caution in the developed of large-scale irrigation and water storage infrastructure in northern Australia, highlighting the ecological limitations on water diversions in many areas of the north and supporting the conclusion of the Taskforce that "the potential for northern Australia to become a 'food bowl' is not supported by evidence" (Northern Australia Land and Water Taskforce, 2009).

Tasmania Sustainable Yields

Adoption by Tasmanian government: In 2009, the then-Tasmanian Premier David Bartlett announced a plan for The Tasmanian government of Premier name used the findings and tools developed under the Tasmania SY project to underpin a plan to significantly expand the area of Tasmania under irrigated agriculture and bring an additional 188,900 mega litres of irrigation water to Tasmanian farmers (The Australian, 2009). The information underpinning this decision was directly based on the findings of the Tasmania Sustainable Yields project as well as ongoing partnership research between CSIRO, the Tasmanian Department of Primary Industries and the Tasmanian Institute of Agricultural Research (David Bartlett, quoted in The Australian, 2009).

Tasmania Irrigation, a state-owned company established in 2011 to develop and operate government-subsidised irrigation schemes, uses the modelling and data developed by CSIRO in the Tasmania SY project in its due diligence investigations for investment decisions. According to Tasmania Irrigation, all of its irrigation and dam-building schemes must demonstrate 95 per cent reliability of water provision over 100 years. Tasmania Irrigation quantifies water supply reliability on a project-by-project basis with reference to a combination of historical hydrology data, and the climate change projections out to 2030 developed by CSIRO, which incorporate wet, median and extreme dry scenarios (Tasmania Irrigation, n.d.).

Adoption by Federal Government: In 2009 the Australian Federal Government has made use of the Tasmania SY project to guide its co-investment under a National Partnership

Agreement in nine new irrigation projects in Tasmania, involving Federal Government investment of up to $140 million, to ensure that all co-invested projects are economically and environmentally sustainable out to 2030 (Department of the Environment).

Great Artesian Basin Water Resources Assessment

As the GAB WRA drew to a close relatively recently (March 2013), it is somewhat early to assess the adoption of its research findings and methodologies. However, the Great Artesian Basin Sustainability Initiative (GABSI), which seeks to improve water use efficiency across the basin, is scheduled to draw to a close this year. It is likely a that government efforts to put a new Great Artesian Basin management framework in place will involving consulting the research findings and methodologies of GAB WRA, given that the GAB WRA is the most comprehensive and up-to-date study of the Great Artesian Basin available.

Advances in understanding of the Great Artesian Basin as a result of CSIRO's WRA are also underpinning a new CSIRO research program examining the impacts of coal mining and coal seam gas developments on groundwater. Given the high level of public disagreement over the impacts of unconventional gas exploration and production on shared groundwater resources, the impacts of this current set of studies on policy-making and regulation is expected to be significant.

Flinders and Gilbert Agricultural Resource Assessment

As this project finished relatively recently (December 2013), it is too early to review the uptake of FGARA. However, as a result of the key findings of FGARA – that farm dams could support between 10,000 and 20,000 ha of irrigation in 70-80 per cent of years in the Flinders catchments, and that large dams could support 20,000 to 30,000 ha of irrigation in 85 per cent of years in the Gilbert catchment – there has been growing momentum to increase the area of irrigated agriculture from roughly 1,000 ha at present (CSIRO 2013f; CSIRO, 2014a). FGARA findings are being incorporated into the revision of the Queensland Government's Water Resources (Gulf) Plan and FGARA has provided the information to underpin two separate water infrastructure development proposals, each entailing development of over 15,000 ha of irrigation (CSIRO, 2014a).

FGARA may also provide the information needed to underpin changes to many of the restrictive statutory rules in place in the region at present, which limit the areas in which intensive agriculture is allowed to take place. Changes to these regulations could help to open up greater finance and lending opportunities for agricultural developers in the region (Woodhouse, 2014).

CSIRO market and non-market impacts

The uptake of CSIRO's WRAs by water managers and decision-makers has yielded a range of economic, environmental and social impacts.

WRAs have delivered a wide range of economic, environmental and social impacts

Table H4 **Summary of impacts**

Impact	Detail
Economic impacts	
Allocation of water resources to highest value users	CSIRO's water resource assessments provide water managers and water markets with information needed to direct water resources to water uses that can be expected to deliver higher long-term benefits compared to decisions that would have been made absent this rigorous information base. In many cases this means that incorporating WRAs into water decision-making can underpin better economic outcomes, for example by enabling investments that are more likely to produce returns under future climate change. In many cases this means that incorporating WRAs into water decision-making will also underpin better environmental outcomes. Improvements in both of these areas can be expected to deliver greater overall value in the long-term.
'Insurance value' of avoiding high-cost or highly damaging investments	Better understanding of future water supply scenarios reduces the likelihood that water managers will invest in agricultural or water projects that will become loss-making or unviable in the future as a result of changes in climate or water supply patterns. This likelihood can be expected to become lower as WRAs are increasingly incorporated into regular water investment planning. At the same time, better information on future water supply risk can help investors avoid higher risk investments, while at the same time freeing up capital in agricultural regions that are more water secure going forward.
Optimisation of cropping decisions and higher agricultural productivity	Cropping suitability maps and seasonal water flow forecasts from the WRAs allow farmers to optimise cropping choices and manage crop production uncertainty more effectively than previously. This can reduce risk of misallocation of farming land to sub-optimal uses and risk of loss from water supply stress.
Reduced economic cost of flooding and drought	More accurate and effective forecasting of weather and water supply events, such as flooding and drought, facilitates timely preparation for such events by water managers, potentially mitigating loss of property and production.
Greater resilience to climatic and water supply uncertainty	Improved understanding of key areas of future climate and water supply uncertainty and quantification of water annual supply probability for certain sites enables water managers to factor uncertainty into their water plans, allowing greater preparedness and flexibility in the face of extreme events.
Reduced water availability for some users	In areas where CSIRO's WRAs have shown a need to greater environmental flows, some water users potentially face reduced water access. An example of this is the Murray Darling Basin, where CSIRO's MDBSY and subsequent related research informed the setting of sustainable diversion limits (SDLs).
Environmental impacts	
Increased ecological health of river and groundwater systems	Information on current and future regional water balances enables water managers to be better informed about the impacts of different levels water extraction on the environment. In some cases, such as the Murray-Darling Basin, WRAs have demonstrated the need for increased environmental flows in order to restore damaged rivers and ecosystems. CSIRO has estimated the ecological and economic benefits to be gained from returning 2,800 GL/year of environmental flows (almost the same level as the 2,750 GL/year that is currently being implemented by the Murray Darling Basin Authority) to the Murray-Darling Basin at $3-8 billion (CSIRO, 2012b). In other cases, such as parts of Tasmania and the Flinders and Gilbert catchments, WRAs have demonstrated the local ecosystem's ability to absorb greater levels of water extraction, while at the same time setting upper limits on sustainable levels of water extraction.
Reduced likelihood of serious environmental damage	Better information on thresholds for sustainable water extraction levels lowers the likelihood that water managers will extract water far in excess of these thresholds. Apart from a desire to ensure sustainable levels of water use over the long-term, understanding of sustainable water extraction thresholds by the broader public, government policy makers, environmental groups and downstream water users has the potential to create pressure for other water users to extract within agreed sustainable levels.

Impact	Detail
Social impacts	
Increased sustainability of agricultural communities	CSIRO's integrated water resource assessments can help mitigate shocks from natural disasters, water supply and climate variability and longer-term water supply and climate change, potentially reducing losses and creating greater resilience for communities that are directly dependent upon local water supplies, such as agricultural communities and rural indigenous communities.

H.4.2 Counterfactual

Absent CSIRO's WRAs, water managers would have made decisions without the benefit of rigorous water supply information, increasing the probability of costly delay or error

In the absence of CSIRO, water management and investment decisions would still have been undertaken, but in coming to these decisions the various governments involved would have sought advice from other researchers in either universities or the private sector, most likely through an open tender process. However, an open tender process would not have yielded the diverse and multidisciplinary range of resources and capabilities such as already existed within CSIRO. The advantage CSIRO had was that it was able, on request, to mobilise a large research staff to work on the issues. This was particularly important in light of the difficult and contested questions facing governments in 2006 in relation to the Murray-Darling Basin. It is unlikely that as highly focused a research effort as that delivered by CSIRO could have been mounted through government tendering a range of projects to other researchers.

The experience prior to the initiation of this work suggests that:

- The level of community acceptance of the investment decisions, particularly in areas where there were significant differences of view about competing water use (for example, between environmental or irrigation uses) would have remained low – CSIRO's reputation for high quality scientific research, and consistent delivery of that in the case of water assessments, was an important factor in creating common agreement in the underlying science of water management.
- Information gathering for decision making would have been slower, resulting in loss of efficiency and value. In cases such as the formulation of the Murray Darling Basin Plan, it would have been much more challenging and technically demanding for the Murray-Darling Basin Authority to bring together a fragmented base of evidence, rather than the consistent evaluation framework delivered through the MDBSY and later associated CSIRO research projects.
- Risk of investment in water management systems and infrastructure that may not have proven viable in the face of future climate and water supply change would have been higher.
- Overall, water management and investment decisions in each of the regions covered by CSIRO's WRAs would have been less well-informed and therefore more prone to costly error.

H.4.3 Attribution

Attribution of research effort

70 per cent of the research outputs of the WRAs are attributable to CSIRO

Undertaking multidisciplinary, system-scale R&D is one of CSIRO's key strengths. CSIRO has considerable expertise in terms of quantifying the hydrological resource base, the physical processes, management rules and constraints that affect water balance in basin river systems. Bringing hydrological and climate scientists together was a unique and important part of CSIRO's success in its integrated water resource assessments. CSIRO is the only organisation that holds capability at this scale and breadth of operation in Australia, and probably the world – particularly with its specific focus on integrated river basin modelling (CSIRO, 2013b).

At the same time, CSIRO partnered with a range of organisations, including partners in government agencies and the private sector, in order to increase CSIRO's capacity and access to information. These partner organisations such as the Bureau of Meteorology, Sinclair Knight Merz (now Jacobs) and Geoscience Australia made important contributions to CSIRO's water resource assessments. However, CSIRO remains the largest water research organisation in terms of both its scale and the breadth of operations in Australia, housing a relatively comprehensive set of cross-disciplinary skills and expertise necessary to carry out ambitious water resources assessments. Moreover, while different partner organisations brought important research capabilities to individual WRAs, CSIRO remained the chief organising force. Therefore, ACIL Allen attributes 70 per cent of the research outcomes of the WRAs to CSIRO.

H.4.4 Adoption

CSIRO's water resource assessments have been commissioned by Australian Governments. As the discussion of project outcomes above indicates, incorporation of WRA tools, methodologies and research into water management and investment decisions making has been substantial, particularly in the case of the MDBSY, SEACI and the Tasmania SY.

CSIRO's WRAs have been brought to bear on water investment decisions worth billions of dollars

However, while it is possible to roughly estimate the value of investment decisions that have utilised WRA research, tools and methodologies so far, the primary function of the WRAs – to provide better information to underpin better and more efficient decision-making – makes ascribing an exact adoption rate difficult. As there has been no coordinated and comprehensive effort to track when, how and to what extent CSIRO's WRAs have been incorporated into government and private section decision-making, precisely quantifying the level of adoption of WRAs is challenging. Nonetheless the impacts of adoption so far can have been significant, considering the large value of just a few investment decisions that WRAs have influenced:

- In the Murray-Darling Basin, the government has committed to water buy-backs worth $3.2 billion and investment in new water-efficient infrastructure necessary to return 2,750 GL/year of environmental flows by 2019 (Department of the Environment [b]).
- SEACI modelling, methodologies and data have been integrated into 'Sustainable Water Strategies' for each region in Victoria over the period 2006-2011 as well as each of Victoria's 17 water corporations' 'Integrated Water Cycle Strategies'. As such, SEACI has the potential to influence the decision-making process for all major water investments in Victoria. Many of these water investments involve projects with capital costs of several billion dollars in government and private spending, such as Victoria's irrigation modernisation projects (Department of Environment and Primary Industries, 2014; see also Department of Sustainability and the Environment, 2011a and 2011b).

- The Tasmanian and Federal governments and private investors have committed a total of $310 million according to the construction of ten irrigation schemes in Tasmania, with investment decisions resting heavily on sustainability assessments derived from CSIRO's Tasmania SY project (Tasmanian Irrigation, 2012).
- ACTEW Water incorporated SEACI climate modelling into its water security assessments that underpinned the $363 million expansion of the Cotter Dam in the Australian Capital Territory (Independent Competition and Regulatory Commission, 2010).

This indicates that CSIROs WRAs have been integrated into water management decision making that has produced investment of at least $3.9 billion in water management systems and infrastructure. As ACIL Tasman noted in its previous review of the Water for Healthy Country Flagship, the domain in which CSIRO's WRAs operate has 'big dollar games' afoot, meaning that there are potentially very large values associated with early identification of the more cost effective approaches available and even marginal gains in efficiency (ACIL Tasman, 2006).

H.5 Assessment of impacts

H.5.1 Impacts to date

The WRAs have delivered benefits to Australia, due to …

By enabling better understanding of current and future water supply, CSIRO has delivered information that which allows water managers to make decisions about where water should be directed and how it should be used, with better understanding of what impacts and trade-offs those decisions will involve.

….increased economic and environmental water use efficiency, and …

This increases the probability that those decisions will deliver more efficient water use. In particular, the WRAs enable water managers to deliver two distinct types of efficiencies. One is greater economic efficiency: for example, as a result of the WRAs, water managers now have a better idea of what areas of Australia can sustain irrigated agriculture up to what level of water extraction. As a result, these water managers can make decisions that deliver lower long-term costs and higher returns. Another is greater environmental efficiency: for example, water managers now have a better idea of what areas of the environment are most vulnerable to environmental degradation, and where restoring certain volumes of environmental flows will produce the largest environmental benefits. This means that water managers' decisions on returning environmental flows can be better targeted to produce maximum environmental outcomes.

…lower probability of high-cost/loss-making water investments

In addition to delivering greater economic and environmental efficiency, the WRAs enable water managers to better avoid large costs. Again, these avoided costs are both economic and environmental. The WRAs can enable water managers to avoid large environmental costs by highlighting the environmental sustainability 'thresholds' above which further water extraction could lead to severe environmental damage. Because these 'thresholds' are now known and backed up by rigorous science, CSIRO's WRAs decrease the likelihood that water decisions that bring severe environmental loss will proceed. This is particularly relevant in the context of the original rationale for the WRAs themselves – providing information needed to underpin better water management in the Murray-Darling Basin at a time (2006) when a combination of severe drought and water mismanagement meant that some areas of the Lower Murray were threatened with irreversible environmental damage over a wide area. By the same token, the WRAs can enable water managers to avoid large economic costs. By highlighting the sustainable limits of water extraction in a given area, the WRAs can help guide investment decisions in water infrastructure, such as irrigation and dams, that will be underpinned by more consistent water supply into the future. This minimises the danger that large water infrastructure investments will become stranded or loss-making, due to shortages of water supply.

Some of these benefits lie in future, but many have already been delivered due to strong uptake of WRAs

Given that WRAs have already been closely incorporated into water decision-making in Tasmania (in relation to irrigation), the Murray-Darling Basin (in relation to sustainable diversion limits), Victoria (in relation to regional and corporate water planning), and the Australian Capital Territory (in relation to ACTEW Water's water infrastructure investment planning), these benefits of greater efficiency and avoidance of large potential future losses have already been delivered, and will continue to be delivered with the extension of research from the WRAs and uptake by more water managers.

H.5.2 Potential future impacts

Future integrated water resource assessment projects

Pilbara water resource assessment – partnering with WA government and industry

WRAs are being adapted and extended to a range of new applications.

CSIRO is currently undertaking a further integrated water resources assessment in the Pilbara region of northern West Australia in partnership with the WA government and BHP, the findings from which will be delivered in March 2015. This WRA follows in the tradition of previous WRAs outlined in this report and builds upon previous WRA methodologies, tools and research findings. This has led to initial cooperation with a range of resource sector companies and government agencies interested in the Pilbara on the development of a cumulative impacts management framework for water management in the Pilbara, which is in early stages of development. Should CSIRO be asked to proceed with this work, the value to the iron ore mining industry in WA alone is expected to be significant (water is the single largest compliance issue for iron ore miners in WA in dollar terms).

National Water Accounts and Australian Water Resources Assessments – operational delivery by the Bureau of Meteorology

Underpinning the new National Water Accounts and Australian Water Resources Assessments (which are delivered through the BoM website) is the work of the Water Information Research and Development Alliance (WIRADA), a partnership between CSIRO and BoM. WIRADA has expanded innovations developed under SEACI and the MDBSY to improve the quality and range of BoM's water data reporting, making BoM water data consistent, integrated, and easy to use. BoM's National water accounts and Australian Water Resources Assessments provide information on climatic conditions and landscape characteristics, patterns and variability in water availability over time, surface water and groundwater status, floods, stream flow salinity and inflows to wetlands, and urban and agricultural water use. The Australian water resource assessments include an integrated landscape, groundwater, river routing and data assimilation modelling system that can produce water balance terms on a 5km grid covering the entire continent on a day-by-day basis. National water resource assessment reports have been published for 2010 and 2012 by the Bureau of Meteorology.

Bioregional assessments

Just as public concern over water management in the Murray Darling Basin launched the sustainable yields projects in 2006, growing public concern over the water trade-offs involved in coal seam gas (CSG) and large coal mine developments has prompted the Commonwealth Government to initiate a program of risk-based cumulative bioregional impact assessments to assess the impact of CSG exploration and production and coal mining on water resources and water-dependent assets. The bioregional assessments program builds upon the success of the Sustainable Yields projects and involves many of the same core partners: CSIRO, the Bureau of Meteorology and Geoscience Australia. The mandate involves CSIRO and its partners carrying out 15 bioregional assessments for Australia's major coal basins, to be delivered by June 2016.

In particular, bioregional assessments will involve an extension of the Great Artesian Basin Water Resources Assessment study. The methodologies and capabilities developed in that study will be extended to assess deep groundwater, connectivity and impacts on ecological assets.

The new methodologies, tools and informatics capabilities developed in the course of the bioregional assessments will provide an information platform and capacity to transparently audit and repeat further future bioregional assessments.

Improved Bureau of Meteorology streamflow forecasting

CSIRO and the Bureau of Meteorology have formed a partnership, the Water Information and Research Development Alliance (WIRADA), which draws on past work developed under SEACI. In particular, WIRADA has extended SEACI research to produce a new seasonal streamflow forecasting service delivered by BOM, covering the east and north-east regions of Australia. This tool can also be used by farmers, irrigators and water managers to manage their water based on likely inflows into their catchments over the coming three months (CSIRO 2013a).

International water resource assessments

CSIRO is in the process of applying the suite of methodologies, tools and capabilities developed in undertaking Australian water resources assessments to water basins overseas. WRAs are currently being undertaken in Bangladesh by CSIRO in partnership with the Australian Department of Foreign Affairs and a number of local partners including the Bangladesh Water Development Board (CSIRO 2014b). CSIRO is also intending to expand its WRA work into other areas of South Asia characterised by difficult water use trade-offs and large reductions in environmental flows, including Nepal, India and Pakistan.

Greater monitoring of uptake

Going forward, CSIRO is seeking to develop methodologies to more accurately track the uptake and use of its integrated water resource assessments, in order to better understand the end-application of this work and inform future development of further water resources assessments.

H.5.3 Benefit Valuation Analysis

In this benefits valuation, ACIL Allen has assessed the economic and environmental benefits from two water management decisions – the imposition of sustainable diversion limits (SDLs) in the Murray-Darling Basin and Tasmania's irrigation building scheme – that have been directly influenced by CSIRO's WRAs. Valuation of the benefits derived from these two examples forms a lower-bound estimate of the impact of all the WRAs. This report does not seek to place a value on the total benefits delivered by all of the seven WRAs. Because the WRAs are primarily focused on delivering information that aims to change how water is allocated, quantification of benefits would require data on:

1. how water was allocated before WRAs were incorporated into decision-making,
2. what decisions were made and to what extent the WRAs influenced those decisions,
3. how water allocations changed as a result of those decisions, and,
4. what benefits were gained as a result of changes in these water allocations.

Satisfying this four-step process is not possible for all of the seven WRAs. In many of the regions where CSIRO has carried out WRAs, such as northern Australia and Tasmania, detailed water consumption data is difficult to obtain due to lack of data collection. Moreover, there has been no coordinated and consistent effort to track all of the water management and investment decisions in Australia that utilised WRAs information or methodologies, or to analyse the extent to which WRAs have influenced specific water management decisions. Finally, even where information exists on decisions that incorporated CSIRO's WRAs, many of these decisions have not been subject to a separate analysis of the economic, environmental and social benefits arising from changed water management. While the WRAs have collectively delivered significant benefits to Australia, these information constraints make quantifying the entire impact of all of the WRAs surveyed in this case study challenging.

We quantify benefits delivered by CSIRO's WRAs through two examples: environmental benefits in the Murray-Darling Basin, and economic benefits in Tasmania.

While examining only two examples of the impact of CSIRO's WRAs can only represent a slice of the overall benefits that CSIRO's WRAs have delivered, examining the impacts of SDLs in the Murray-Darling Basin and irrigation schemes in Tasmania, and analysing how much of those impacts can be attributed to CSIRO, enables us to pinpoint a lower-bound monetary value that can in turn suggest the magnitude of likely benefits that all of the WRAs together have delivered.

Environmental benefits delivered by the WRAs: returning environmental water to the Murray-Darling Basin

CSIRO's Murray-Darling Basin Sustainable Yields project has delivered substantial value through its influence on the imposition of sustainable diversion limits (SDLs) in the Murray-Darling Basin. ACIL Allen has chosen this example to illustrate the environmental benefits that the WRAs deliver, because it satisfies the four-step process described above:

1. We have information on how water allocations before SDLs were introduced. In 2009, which is the baseline year for the Murray-Darling Basin Authority's SDLs, an average 13,623 GL/year was diverted for human consumption.
2. We also have a specific decision that was made based upon CSIRO's WRAs: when the Murray Darling Basin Authority set sustainable diversion limits for each area of the basin, and for the basin overall, the scientific research underpinning those limits was largely provided by CSIRO and delivered through the River System Modelling Project and the Groundwater Assessment Project. These two projects were based heavily upon the research findings, tools and methodologies developed in the MDBSY.
3. We also have information on how water allocations have changed/will change as a result of this decision. The Murray Darling Basin Plan aims to return 2,750 GL of water per year to environmental flows by 2019, which means that by 2019, long-term human water consumption in the basin will have dropped to 10,873 GL/year.
4. As discussed below, studies commissioned by the MDBA have assessed the benefits and costs associated with returning 2,800 GL/year of water to the Murray Darling Basin (a figure only slightly above the SDL target that was eventually agreed upon, which is 2,750 GL/year).

Benefits of returning 2,800 GL/year to the environment

A CSIRO study identified $3-8 billion in environmental benefits from returning 2,800 GL/year of water to environmental flows in the Murray-Darling Basin

In 2011-12, CSIRO was commissioned by the Murray-Darling Basin Authority (MDBA) to identify and quantify the ecological and ecosystem services benefits that are likely to arise from recovering 2,800 GL/year of water for the environment in the Murray–Darling Basin and, where possible, to elicit the monetary value of those benefits. The baseline scenario for this analysis was water flow in the Murray-Darling Basin under June 2009 water management arrangements (including dams, environmental works infrastructure and consumptive uses). CSIRO's study also incorporated the findings of a range of previous studies also commissioned by the MDBA. The benefits estimated from this study can be assumed to closely correlate with likely benefits from the sustainable diversion limits (SDLs) imposed by the MDBA.

The CSIRO study found that the additional Basin-wide value of enhanced habitat ecosystem services – arising from floodplain vegetation, waterbird breeding, native fish and the Coorong, Lower Lakes, and Murray Mouth – is worth between AU$3 billion and AU$8 billion in present value 2010 dollar terms under the 2,800 GL/year scenario relative to the baseline scenario.[17] This estimate of the value of ecosystem services rested primarily on benefits transfer analysis.

Other benefits due to improvements in other ecosystem services include:

- Additional carbon sequestration within river red gum and blackbox floodplain vegetation that is maintained in a healthy condition, which is worth between AU$120 million and AU$1 billion.
- Increased supply of aesthetic appreciation ecosystem services under the 2,800 GL scenario relative to the baseline scenario, potentially worth more than AU$330 million
- Avoided damage and treatment costs associated with the supply of fresh water, worth in the order of AU$30 million.
- Tourism benefits, estimated to worth up to AU$160 million annually.

However, CSIRO cautioned that, to avoid the risk of double counting, monetary values such as the above should not be summed to a single value because of possible overlaps. For example, the non-use values that underpin the habitat values might also capture some aspects of other ecosystem services such as recreation and mental health, or aesthetic appreciation and cultural inspiration (CSIRO, 2012b).

Attribution of benefits to CSIRO's MDBSY

How much of the estimated environmental benefits, $3-8 billion, are attributable to CSIRO, and specifically to the role CSIRO played in the MDBSY project? To establish a lower-bound estimate, ACIL Allen assumed that the MDBSY resulted in water management and usage that delivers a 10 per cent increase in overall environmental value compared to the counterfactual, i.e. the decision that would have been made absent the rigorous information base that the MDBSY provided. This level of attribution is in line with previous related studies: a 2009 review of the Water for a Healthy Country Flagship by Deloitte Access Economics attributed 5-10 per cent of the benefits linked with the Flagship's research to CSIRO, while a 2006 review of the Water for a Healthy Country Flagship by ACIL Tasman's ascribed 10 per cent of the benefits linked to the Flagship to CSIRO.

When this attribution rate is applied to CSIRO's lower-bound estimate of the benefits of returning 2,800 GL/year of environmental flows to the Murray-Darling Basin, the share of benefits attributable to the MDBSY would be equal to $300 million (i.e. 10 per cent of $3 billion in estimated benefits). Remembering that other organisations contributed to the research outputs of the MDBSY, and that this report ascribes an average 70 per cent of the research outputs of all WRAs to CSIRO, the share of roughly $3 billion in benefits

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[17] Note that the CSIRO report does not provide information on the timing of the stream of benefits for the ecological indicators or water quality benefits that underpin the monetary values calculated in the report. However, the report uses pre-existing Centre for International Economics (CIE) methodology to estimate present value for values related to ecosystem service of habitat. CSIRO's report does not include a discount rate. Other estimates of value are estimated in annual 2010 dollars. More details of this methodology are available on p. 146 of CSIRO's report (CSIRO, 2012b).

attributable to CSIRO's work in the MDBSY would be equal to $210 million in present value 2010 dollar terms (i.e. 70 per cent of 10 per cent of $3 billion in estimated benefits).[18]

$210 million: our lower-bound estimate of the environmental value delivered by CSIRO's MDBSY through sustainable diversion limits

$210 million is an approximately lower-bound estimate of CSIRO's contribution to the expected benefits of restoring 2,750 GL/year of environmental flows to the Murray-Darling Basin under the MDB Plan, as delivered through the MDBSY. This is well in excess of $54.2 million in total costs for all seven of CSIRO's integrated water resources assessments (including SEACI), meaning that this figure alone – a lower bound estimate of the benefits attributable to only one decision based on only one of the seven WRAs – covers the costs of the entire research program.

However, we consider a 10 per cent attribution rate to be a highly conservative estimate of the impact of MDBSY on the imposition of sustainable diversion limits. Whereas previous Deloitte and ACIL Tasman reviews examined the highly diverse programs and impacts of the entire Water for a Healthy Country Flagship, in this case we are examining a situation in which there is a clear line of sight between the one project, MDBSY, and its influence on one decision, sustainable diversion limits:

- CSIRO provided the main modelling and research tools upon which the calculation of SDLs for each part of the basin rested. Moreover, the transfer of water systems modelling capability to MDBA provided the opportunity to extend the WRA as part of Basin Plan modelling.
- Absent CSIRO's input into defining and quantifying sustainable diversion limits, there would have been a less rigorous scientific based for establishing those limits, because there would have been no study that assesses water supply in a consistent way across the entire basin, including forecasts of future water supply based on climate change modelling.
- Even if other researchers had been called upon to conduct a water resources assessment in the Murray-Darling Basin in 2006, no other organisation in Australia has the range and depth of in-house capabilities that could be brought to bear on this sort of project that CSIRO has. Rather than the consistent, basin-wide framework delivered by the MDBSY, the outcome of an open tender process would likely have been a far more fragmented and ultimately less useful research output.
- The political process that lead to the Murray-Darling Basin Plan, and the aim to return 2,750 GL/year of water to environmental flows, would likely have been longer and more contested absent CSIRO's scientific assessment and trusted public image.

$1.12 billion: our upper estimate of the environmental value delivered by CSIRO's MDBSY through sustainable diversion limits

Therefore, to establish a more realistic estimate of benefits delivered by the MDBSY, we assume that 20 per cent of the impacts of returning 2,750 GL/year to environmental flows to the Murray-Darling Basin can be attributed to the MDBSY. Using CSIRO's upper-bound estimate of benefits ($8 billion) as a result of returning 2,800 GL/year to environmental flows, the total benefits attributable to the MDBSY are equal to $1.6 billion (i.e. 20 per cent of $8 billion). Remembering that 70 per cent of the research outputs of the MDBSY are

[18] Actual benefits may be slightly lower than this estimate given that returned environmental flows that the environmental flows assessed by CSIRO in its benefits estimate (2,800 GL/year) is roughly 1.8 per cent higher than the SDL target that was eventually agreed upon (2,750 GL/year). Benefits attributable to CSIRO's role in the MDBSY that are based on CSIRO's 2,800 GL/year benefits estimates have not been adjusted for this difference ($1.8 per cent) because the marginal benefits of higher or lower levels of environmental flows do not increase in a linear way. Modest increases in environmental flows may produce an increase in the value of total benefits that is far higher than the rate of increase in environmental flows when an ecosystem has suffered from very low levels of environmental flows historically. Conversely, for an ecosystem with historically healthy levels of environmental flows, large increases in environmental flows will not necessarily produce equally large benefits.

attributable to CSIRO, the total benefits attributable to CSIRO's work in the MDBSY are equal to $1.12 billion in present value 2010 dollar terms.[19]

$600-700 million: our mid-point estimate of the environmental value delivered by CSIRO's MDBSY through sustainable diversion limits

Given the large variation between these upper and lower bound estimates, and given the fact that the lower-bound estimate represents a highly conservative level of attribution, we argue that a mid-point figure, $600-700 million in present value 2010 dollar terms, represents a more reasonable estimate of the environmental benefits delivered by CSIRO's MDBSY as a result of its influence over sustainable diversion limits in the Murray-Darling Basin.

Costs of returning 2,800 GL/year to the Murray-Darling Basin

Returning 2,750 GL/year to environmental flows also entails costs, at least over the short-to-medium term, to irrigated agricultural production, as much of the 2,750 GL/year will be allocated away from irrigators. The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) has estimated at an annual cost of $542 million in gross lost agricultural production from 2,800 GL/year of water being returned to environmental flows (CSIRO, 2012b).

An ABARES study has identified costs to agricultural production as a result of SDLs, which we calculate to be $477 million

Given that this is an estimate of gross (rather than net) loss, ABARES' estimate does not take into account the cost of that agricultural production, which in 2013 was equal 78 per cent of the total value of grain production, meaning that average net returns were 22 per cent of total revenue from the sale of grain crops, according to ABARES (Valle, 2014). However, farmers that choose to sell water through the MDBA's water buyback scheme are more likely to do so if they value of the water they sell is higher than the agricultural production that they would yield from that water. This suggests that the most productive agricultural producers are unlikely to sell their water rights, because they will gain higher net returns on their agricultural production compared to selling water. In other words, the water buy-backs that underpin SDLs are likely to come from marginally profitable agricultural producers, for whom production costs are higher than the 2013 average of 78 per cent of total revenues from the sale of agricultural products. Assuming that marginal agricultural producers are earning half the returns of the nation-wide average, meaning that these marginal producers only earn an 11 per cent return on agricultural products sold, ABARES' estimate of $542 million in lost agricultural production net of production costs comes down to $59.6 million in net lost annual agricultural production. To convert this annual cost into net present value terms, in order to make it comparable with the benefits discussed in the section above, we apply a standard multiplier of 8 to arrive at roughly $477 million in lost agricultural production in present value terms, significantly lower than estimated environmental PV benefits equal to $3-8 billion.

$15-61 million: our lower and upper-bound estimates of the short-to-medium-term costs delivered by CSIRO's MDBSY through the imposition of sustainable diversion limits

As CSIRO's MDBSY has contributed to the benefits of returning 2,750 GL/year of environmental flows to the Murray Darling Basin through SDLs, it has also contributed to the costs in terms of lost agricultural production, at least over the short-to-medium term. Using the same attribution rates (70 per cent of 5 per cent for a lower bound, and 70 per cent of 20 per cent for a higher estimate), we estimate that CSIRO's work in the MDBSY is responsible for $15 million present value in lost agricultural production, as a lower bound estimate, and $61 million present value in lost agricultural production as a higher estimate.

In reality, the trade-offs between increasing environmental flows and losing agricultural production in the Murray-Darling Basin exist only in the short-to-medium term. Over the longer-term, higher water prices will drive innovation in agricultural production, forcing the

[19] Again, actual benefits may be slightly lower due to the 1.8 per cent discrepancy between the volume of returned environmental water underpinning CSIRO's benefits estimates and the eventual agreed SDL for the Murray-Darling Basin.

agricultural sector to become more water efficient. In addition, increased sustainability of water flows in the Murray-Darling Basin, healthier ecosystems and more resilient water supply will also bring long-term benefits to agricultural production in the form of greater water supply security. Incorporating improved understanding of the limits of water extraction, beyond which the risk of serious damage of ecosystems rises dramatically, decreases the likelihood that the Murray-Darling Basin will enter its next drought with an ecosystem that is already heavily damaged by long-term low environmental water flows. In turn, this will ensure that agricultural production in all parts of the Basin, particularly in the lower reaches of major rivers, will be more sustainable and profitable over the long-term, and less exposed to large losses as a result of catastrophic environmental damage.

The identified benefits more than cover the total program cost of all WRAs

Our lower-bound, mid-point and upper-bound benefits estimates of the environmental delivered by CSIRO's MDBSY through the imposition of SDLs more than cover total program costs for all seven WRAs in this case study of $54.2 million.

Implications for the broader environmental value of CSIRO's WRAs

Given that this evaluation has only examined the benefits associated with one WRA (MDBSY) and one decision (SDLs), it can be assumed that CSIRO's WRAs have delivered environmental benefits in excess of our mid-point estimate of $600-700 million because they have also delivered environmental benefits in other regions and through other water management decisions. This is based on three considerations.

In reality, environmental benefits delivered by all the seven WRAs are likely to be well in excess of $600-700 million

One consideration relates to the fact that uptake of WRAs delivers increased environmental efficiency. Many of CSIRO's WRAs have assessed areas with high levels of ecological degradation and reduced environmental flows. In the Murray-Darling Basin itself and in other areas of Victoria, both the MDBSY and SEACI have influenced a broad range of water management and investment decisions, not just the decision to impose SDLs. While these decision are not always associated with the return of environmental flows per se, they are associated with long-term water use that is less likely to exceed the sustainable limits of water extraction in each area. Given that the MDB and Victoria have been characterised by high levels of water extraction, the marginal benefits of more sustainable water management over the long-term for the environment can be expected to be large. Similarly, in areas such as south-west Western Australia, which has a 35 year declining trend in runoff and consequently decreased environmental flows, the marginal benefits of water management decisions that take account of the natural limits of sustainable water extraction can be expected to be significant.

A second consideration is the avoidance of large future environmental costs. In particular, both Tasmania and Northern Australia have in the past been subject to speculation as to how Australia can harness high levels of local water yield for increased agricultural production. In the case of Tasmania, this ambition has translated a large irrigation-building scheme. In the case of Northern Australia, there have been repeated calls to introduce large-scale irrigation in the region and turn it into a 'food bowl' to meet the growing food demand from Asia. In both of these cases, better understanding of the sustainable limits of water extraction provided by CSIRO's WRAs enables water managers to take sustainable environmental flows into account in their decision-making, potentially avoiding investments that carry large future environmental costs. In Tasmania, this meant proceeding only with irrigation schemes that were shown under CSIRO methods to have sustainable streamflow into the future. In northern Australia, CSIRO effectively busted the 'food bowl' myth, although it has highlighted the potential for smaller scale irrigation in some discrete areas of the north.

A third consideration is that the MDBSY accounted for only 22 per cent of the total input costs of the WRAs covered in this case study. This 22 per cent of total research expenditure has delivered at least $600-700 million in environmental benefits (remember that only one decision arising out of the MDBSY has been costed), but many other areas covered by the WRAs face widespread environmental problems due to water over-extraction, while other areas have faced the prospect of large-scale water infrastructure development. The small share of the MDBSY in overall inputs compared to the large benefits it has delivered supports the conclusion that the environmental benefits delivered by CSIRO's WRAs are likely much higher than $600-700 million identified in this case study.

Economic benefits delivered by the WRAs: irrigation in Tasmania

ACIL Allen has chosen to use the expected economic benefits of irrigation schemes in Tasmania to illustrate the economic benefits that the WRAs deliver, because this is one of the few WRA-influenced investment decision for which a publicly available economic impact study has been conducted.

Estimate of economic impacts

Tasmanian Irrigation has identified economic benefits equal to $858 million for tranches one and two of Tasmania's irrigation schemes

Tasmania has embarked on a large expansion of irrigation infrastructure that has been co-funded by the federal and Tasmanian state governments, and private investment. In total, Tasmanian Irrigation, the state-owned company responsible for implementing the irrigation schemes, has estimated that the first tranche of ten irrigation schemes in Tasmania will deliver $192 million in direct farm-gate economic benefits and further additional economic value of $384 million, while the second tranche of an additional five irrigation schemes will deliver $282 million in national economic benefits, or $858 million in net present value economic benefits (Tasmanian Irrigation, 2012). All of these figures are net present value calculated over a projection period of 40 years, under a standard six per cent discount rate.

Attribution of benefits to CSIRO's Tasmania SY

How much of these estimated economic benefits are attributable to CSIRO, and specifically, to the role CSIRO played in the Tasmania Sustainable Yield project? ACIL Allen assumed that Tasmania SY resulted in water management and usage that delivers a 10-to-20 per cent increase in overall economic value compared to the counterfactual, i.e. the decision that would have been made absent the rigorous information base that the Tasmania SY provided. ACIL Allen believes that applying the same lower- and upper-bound attribution rate of 10-to-20 per cent that was applied to the Murray-Darling Basin example above is justified, because there is a clear and direct line of sight between Tasmania SY and how that study influenced the decision to invest in large irrigation schemes in Tasmania, and the siting of each individual scheme:

- Tasmania SY techniques, such as land suitability mapping and future water supply mapping, were crucial in demonstrating the economic and ecological sustainability of expanded irrigation in Tasmania, providing the scientific information needed to underpin the then-Premier David Bartlett's announcement of the first tranche of the irrigation scheme in 2010 (The Australian, 2010).
- It is a condition of both Federal government co-investment and investment by Tasmanian Irrigation that all irrigation schemes must demonstrate 95 per cent water supply reliability for 100 years. The research and methodologies underpinning this requirement were first developed and supplied by CSIRO through the Tasmania Sustainable Yields project and then subsequently further developed by CSIRO in partnership with the State government (Tasmanian Irrigation, n.d.; Department of the Environment, n.d.).

$60-120 million: our lower- and upper-bound estimates of the benefits attributable to CSIRO's Tasmania SY project

Based on Tasmanian Irrigation's identification of economic benefits, ACIL Allen estimates lower- and upper-bound benefits from Tasmania's irrigation schemes that are attributable to Tasmania SY of $85.8 million to $172 million in present value terms (i.e. 10 per cent and 20 per cent of total benefits of $858 million respectively). Remembering that this study attributed 70 per cent of the research outputs of the WRAs to CSIRO, the total economic benefits attributable to CSIRO's role in Tasmania SY are equal between $60 million and $120 million in present value terms.

Both this lower and upper bound estimate covers total program costs of $54.2 million for the seven WRAs.

Implications for the broader economic value of CSIRO's WRAs

In reality, the economic benefits of CSIRO's WRAs are likely to be well in excess of $60-120 million

CSIRO's WRAs can be expected to result in water investments that are more economically efficient compared to the counterfactual, in which investment decisions would be made without the rigorous information base the WRAs provide. The type of economic benefits derived from greenfield water infrastructure development, as seen in the example of Tasmania's irrigation schemes can be expected to also occur in other areas where CSIRO has conducted its WRAs. In particular, economic benefits of a similar order of magnitude to those identified in Tasmania could emerge as a result of CSIRO's study of the Flinders and Gilbert Catchment, which suggested that the two rivers can support up to 95,000 hectares or irrigated agriculture. While the recent release of the report in December 2013 means that CSIRO's FGARA has yet to lead to investments on the scale of those in Tasmania, the study has led to increased confidence in the ability of the area to support small-to-medium sized irrigated farms (Tapp, 2014). This can be expected to yield significant economic benefits, particularly for local communities.

In areas that have already seen significant development of water irrigation and storage infrastructure, and where the sustainable limits of water extraction have already been tested, these economic benefits will be dominated by avoidance of large future economic loss, and greater economic viability of future additional water infrastructure development. This is because these additional investment can take place with the benefit of a better understanding of natural limits of sustainable water extraction. The scale of avoided economic losses from investment decisions that later prove to be unprofitable or unfeasible due to changing water supply patterns could be considerable, given that water infrastructure investments can often run into hundreds of millions of dollars for only one project.

Tasmania Sustainable Yield accounted for only 7.7 per cent of total financial inputs into the seven WRAs surveyed in this case study. If 7.7 per cent of CSIRO's WRA budget yielded $60-120 million in economic benefits, it can be expected that the total economic benefits delivered by all seven of the WRAs are likely much higher than this. These economic benefits will continue to grow as WRAs are incorporated into a wider array of investment decisions, particularly in places that have been proven to have significant greenfield development potential, such as the Flinders and Gilbert Catchments.

Overall aggregation of benefits

As a lower estimate, CSIRO's WRAs have delivered approximately $685-795 million in economic and environmental benefits in present value terms. This is based upon the mid-point estimate of benefits delivered by SDLs in the Murray-Darling Basin that are attributable to CSIRO's MDBSY ($600-700 million) and a mid-point estimate of benefits delivered by Tasmania's Tranche 1 and 2 irrigation projects that are attributable to CSIRO's Tasmania SY (i.e. the mid-point between $60 million and $120 million in benefits, which is $85-$95 million). It should be emphasised that these are approximate estimates, due to methodological differences between CSIRO's estimation of benefits in its 2012 report on returning environmental water to the Murray-Darling Basin and Tasmanian Irrigation's estimate of economic benefits from Tranche 1 and 2 irrigation schemes. Nonetheless these estimates provide an indication of the lower bound of benefits delivered by all of the WRAs. Moreover, the higher estimates of benefits from these two examples – $1.12 billion from SDLs in the Murray-Darling and $120 million from irrigation schemes in Tasmania – suggests that benefits from all seven of the WRAs could be much higher still. This is particularly the case given that Tasmania SY and MDBSY accounted for only 29.7 per cent of the total research budget of all seven WRAs.

The following table presents a summary of the costs and benefits of CSIRO's WRAs and the investment decisions that the WRAs have influenced so far:

Table H5 **Costs and benefits of WRA impacts and activities**

Activity/impact	Benefit	Cost
CSIRO research	Nationally-consistent water resource assessment framework.	$54.2 million
Environmental impacts	$600-700 million (possibly as high as $1.12 million) from analysis of MDBSY influence on imposition of SDLs. — This represent the outputs of only 22 per cent of total research budget, and only one of many decisions influenced by WRAs. — Therefore environmental impacts of all WRAs is likely to be substantially higher than $600-700 million, and potentially above $1.12 billion.	$15-61 million in lost agricultural production as a result of MDBSY influence on imposition of SDLs. — This is a short-to-medium term cost that will dissipate over time due to positive economic influence of increased water supply security and increased incentive to improve the water efficiency of agricultural production.
Economic impacts	$60-120 million from analysis of Tasmania SY influence of Tasmanian irrigation schemes. — This represent the outputs of only 7.7 per cent of total research budget, and only one of many decisions influenced by WRAs. — Therefore economic impacts of all WRAs is likely to be substantially higher than $60-120 million.	
Capital expenditure on infrastructure construction	Additional economic benefits flowing from construction of improved water storage and consumption infrastructure.	$310 million – Tranche 1 Tasmanian irrigation schemes $363 million – Cotter Dam extension Additional capital spending in Victoria as a result of government and corporate water strategy planning.

Source: ACIL Allen Consulting

H.5.4 Impact pathway diagram

Figure H2 **CSIRO Integrated Water Assessments - impact**

INPUTS

- Funding from CSIRO
- Funding from Federal, State and Territory governments

ACTIVITIES

- Integration of pre-existing data and models to provide a consistent picture over time of water resources
- Characterising and quantifying climate and hydrologic variability
- Estimating climate change impacts on water
- Hydrological modelling
- Developing measurement and modelling techniques to assess surface-groundwater interactions
- Tailoring water resource assessments to water planning needs
- Developing techniques to characterise aquifer and aquitarf propertoes using isotopic and geophysical techniques

OUTPUTS

- Publically accessible modelling and databases that allow detailed understanding of water and soil resources in each region.
- Water resource assessment reports. These include a range of summary reports and technical report to inform policy making, investment decisions, stakeholders and the general public
- Provision of CSIRO skilled staff to train and collaborate with key regional organisation (such as the Murray-Darling Basin Authority) to transfer knowledge and technology
- Journal and conference publications

OUTCOMES

- Greater understanding of water sector adaptation to climate change variability
- Incorporation of WRAs into private sector and government water management and investment decision-making.

IMPACTS

Economic impacts

- Allocation of water resources to highest value users
- ‘Insurance value’ of avoiding high-cost or highly damaging investments
- Optimisation of cropping choices, higher agricultural productivity
- Reduced economic cost of flooding and drought
- Greater resilience to climatic and water supply uncertainty
- Reduced water availability for some users

Environmental impacts

- Increased ecological health of river and groundwater systems
- Reduced likelihood of serious environmental damage

Social impacts

- Increased sustainability of agricultural communities

Source: ACIL Allen Consulting

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