Development of an agreed set of climate projections for South Australia
Final Report

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Disclaimer

The Participants advise that the information contained in this publication comprises general statements based on scientific research and does not warrant or represent the completeness of any information or material in this publication.

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Glossary

AMDR	Annual Maximum Daily Rainfall
APET	Areal Potential Evapotranspiration
AR4	Fourth Assessment Report of the IPCC
AR5	Fifth Assessment Report of the IPCC
AWQC	Australian Water Quality Centre
BoM	Australian Bureau of Meteorology
CCAM	Conformal Cubic Atmospheric Model
CMIP5	Coupled Model Intercomparison Project Phase 5
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEWNR	Department of Environment, Water and Natural Resources (SA)
DMI	Dipole Mode Index
ENSO	El Niño Southern Oscillation
Flinders	Flinders University of South Australia
GCM	General Circulation Model
GIWR	Goyder Institute for Water Research
GLIMCLIM	Generalized Linear Modelling for Daily Climate Time Series
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IWA	International Water Association
MDB	Murray-Darling Basin
NCCARF	National Climate Change Adaptation Research Facility
NCEP	National Centers for Environmental Prediction
NHMM	Non-homogeneous Hidden Markov Model
NRM regions	Natural Resource Management regions
RCP	Representative Concentration Pathway

SA	South Australia
SARDI	South Australian Research and Development Institute
SEACI	South East Australia Climate Initiative
SOI	Southern Oscillation Index
UniSA	University of South Australia
UoA	University of Adelaide
VPD	Vapour pressure deficit

Contents

Background

Climate change will bring about significant changes to the capacity of, and the demand on, South Australia's water resources. As the future changes to these water resources cannot be measured in the present, hydrological models are critical in the planning required to adapt our water resource management strategies to future climate conditions. Such models include catchment runoff models, reservoir management models, flood prediction models, groundwater recharge and flow models, and crop water balance models.

This issue was highlighted in the State Government 2010 document Water for Good - *A plan to ensure our water future to 2050*. We can no longer assume that the recent change in rainfall patterns is a temporary situation – that the drought will end, and the rains we have relied on in the past will return. Managing our water supply in a variable climate requires adaptive and innovative solutions. An important part of the Water for Good document is the series of actions designed to ensure a secure and reliable supply of water for the state to support economic, social and cultural development. One of these actions (43) is "to commission, where required, regional scale studies on the impacts of climate change on water resources". This Goyder Institute Climate Projections project has addressed this action and builds on previous commissioned work on climate change projections for the South Australian government based on global climate models from the third assessment round of IPCC.

Past and ongoing hydrological modelling efforts within the South Australian State Government departments, universities and research organisations have individually converted some regional climate projections into the downscaled daily time-step weather variable time series that are required for specific hydrological models. However, the various methods by which this has been achieved have typically not been coordinated across organisations. Furthermore, some organisations have achieved this with greater levels of expertise than others.

This lack of an agreed set of downscaled time series creates a number of problems. Firstly, there is a considerable duplication of effort across organisations in what is a time consuming and highly expertise-driven task. Secondly, the variation in the methods and quality with which this task has been carried out creates many limitations to the application of hydrological model results to resource management and policy. For example, model outputs cannot be compared across organisations, and some organisations may be reluctant to adopt the results of others, where a different quality of downscaling and time series generation has been applied.

Hence, an essential first step in the adaptation of all aspects of water management under future climate conditions is to generate a set of agreed daily time-step downscaled climate variable time series, for all regions of South Australia, to be used for hydrological modelling across all State Government departments and research organisations. It is essential in the development of these time series that they match with the specific requirements of the various hydrological models used within the State Government departments and research organisations in South Australia.

In response to this issue, the Goyder Institute for Water Research proposed, in close consultation with end users, the development an agreed set of downscaled climate projections for South

Australia to support proactive responses to climate change in water resource planning and management.

Development of an agreed set of downscaled climate projections for South Australia was the largest funded climate change project in South Australia. The focus of the Climate Change priority project was the development of a benchmark suite of downscaled climate projections and climate variable time series for South Australia. End users include the three other themes in the Goyder Institute, and a range of stakeholders in SA government and the wider community. This project will contribute significantly to making South Australia a leader in climate change adaptation. The three characteristics that distinguish this important project are:

- the latest CMIP5 GCM models were used to generate the large scale projections
- the GCM models selected were those that accurately picked up the climate drivers that specifically affect the SA climate
- the latest downscaling techniques were adapted for application in SA

This priority project involved four major Tasks. The four specific tasks detailed in this project directly address the research priorities and knowledge gaps articulated in South Australia's Strategic Plan: Attaining Sustainability, the Tackling Climate Change Strategy, the Water for Good Plan, the SA Water Climate Change Strategy and Regional NRM Plans. This is consistent with the Australian national climate change program and the National Climate Change Adaptation Research Facility (NCCARF).

Task 1: Understanding the key drivers of climate change in South Australia

Professor Simon Beecham (UniSA; Project Leader and Task 1 Leader)

The objective of Task 1 was to understand the key drivers of climate change in South Australia. In this task it was necessary to explore the causes of non-stationarity in our environmental time series. This needed to allow for seasonal variations and the influences of climate drivers such as the Indian Ocean Dipole (IOD) and the Southern Oscillation Index (SOI), including assessment of statistical significances. The environmental time series were decomposed into random variations about an underlying level, trend, and additive seasonal effects and then these levels, trends and seasonal effects were tracked over time.

Task 2: Selection of GCMs for regional downscaling and projection

Dr Wenju Cai (CSIRO; Task 2 Leader)

The objective of this task was to develop an approach for model selection that is consistent with both the IPCC framework and national climate change initiatives. The selection was based on a set of climatic criteria that are relevant to both SA current climate and future climate changes. In terms of relevance to the SA current climate, this necessarily involved testing the realism of model simulation of SA climate drivers and their impacts. This built on the outputs from Task 1.

Task 3: Downscaling and climate change projections for South Australia

Dr Steve Charles (CSIRO; Task 3 Leader)

This objective of Task 3 was to deliver ensembles of stochastic daily time-series of precipitation and other variables for use in hydrological modelling for the South Australian NRM regions. This allows for scenario planning of water management adaptation for the projected range of future climates. Statistical downscaling was applied to produce projections for the SA NRM regions that are presented probabilistically enabling assessment of projection uncertainty associated with selection of emissions scenarios, GCM ensembles and downscaling techniques.

Task 4: Development of an application test bed

Dr Graham Green (DEWNR; Task 4 Leader)

The objective of Task 4 was that a test bed of modelling applications be developed collaboratively between the research partners and the key State Government agencies. These applications included models of catchment surface water runoff, a reservoir management model, and an irrigated crop water balance model. The applications test bed was not intended as a substitute for detailed catchment hydrology or groundwater projects. Instead this test bed of application models helped ensure that the downscaled projections were ready for wider end user applications in South Australia. The relationship to the other three tasks in this project is shown in Figure 1. The inclusion of key personnel from State Government agencies ensured links to activities in the SA Government and built capacity within its agencies. A full list of project team personnel including SA Government officers who actively participated in the project is provided in Table 1.

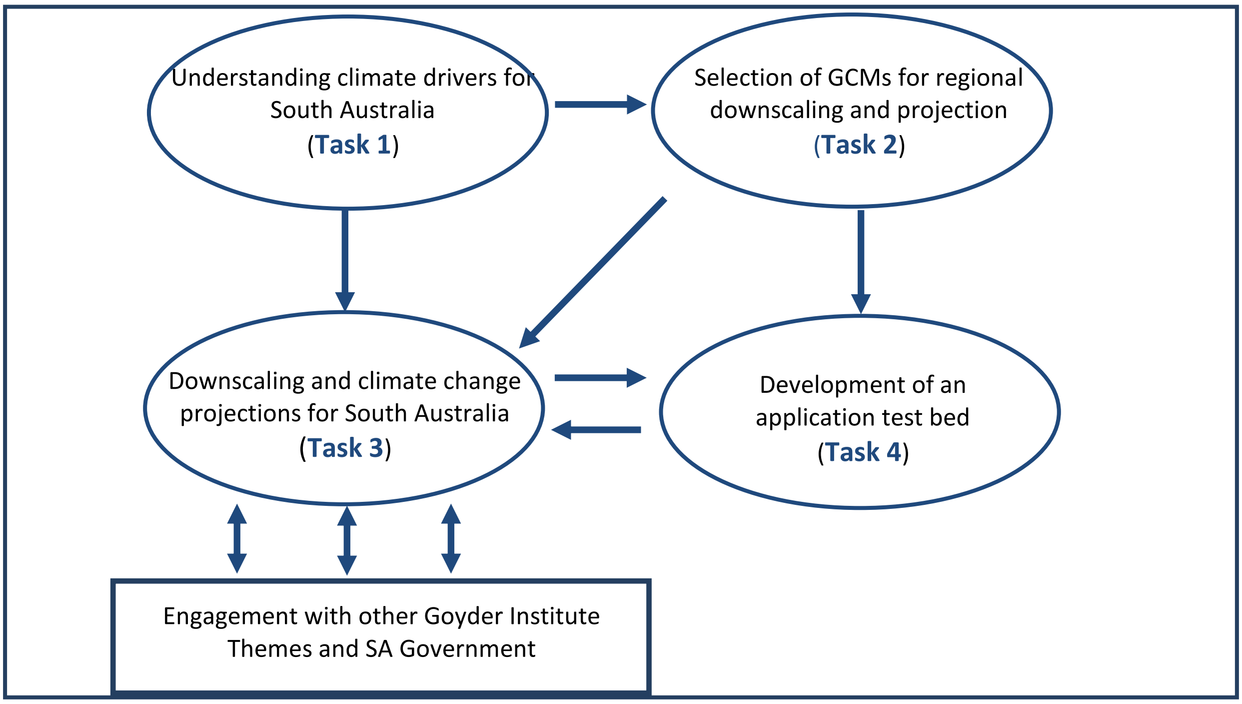

Figure 1: Interrelationship between the four project tasks

Distributions of environmental time series, including rainfall, temperature and potential evapotranspiration were first developed from a suite of agreed GCM downscaled projections for the Onkaparinga catchment, which also accounted for current climate variability (including trend and seasonality) and the influence of known climate drivers. Once the methodology on the Onkaparinga case study catchment was validated, the work was then expanded to provide downscaled climate projections for all eight South Australian NRM Board areas, using the most up-to-date (AR5) climate information from the IPCC and Australian climate initiatives.

Project Team

Throughout the project there were 24 Research Staff, 6 SA Government officers and 2 PhD students actively participating in the project.

Table 1. Project Team members and affiliations

Research staff	
Name	**Affiliation**
Simon Beecham (Project Leader, Task 1 Leader)	UniSA
John Boland	UniSA
Julia Piantadosi	UniSA
Mohammad Kamruzzaman	UniSA
Manju Agrawal	UniSA
Wenju Cai (Task 2 Leader)	CSIRO
Lu Zhang	CSIRO
Evan Weller	CSIRO
Tim Cowan	CSIRO
Steve Charles (Task 3 Leader)	CSIRO
Guobin Fu	CSIRO
Freddie Mpelasoka	CSIRO
Jin Teng	CSIRO
Martin Lambert	U Adelaide
Mark Thyer	U Adelaide
Seth Westra	U Adelaide
Michael Leonard	U Adelaide
Danica Jakovovic	Flinders U
Adrian Werner	Flinders U
Juliette Woods	Flinders U
Jim Cox	SARDI
Nigel Fleming	SARDI
Bronya Alexander	SARDI
Peter Hayman	SARDI
Mike Burch	SA Water
Leon van der Linden	SA Water
SA Government officers actively participating in project	
Name	**Affiliation**
Graham Green (Task 4 Leader)	DEWNR
Matt Gibbs	DEWNR
Darren Alcoe	DEWNR
Leike van Roosmalen	DEWNR
PhD students in research team	
Name	**Affiliation**
Sherin Ahamed	UniSA
Rashid Md. Mamunur	UniSA
PhD students associated with research but not in research team	
Name	**Affiliation**
Mostafa Razzaghmanesh	UniSA

Report Outline

This report is the final report for the Project *Development of an agreed set of climate projections for South Australia*. The report provides a synthesis and summary of the key outcomes from the investigations and is structured as follows:

- Contribution to Goyder Institute Strategic Objectives
- Delivery Against Objectives
- Summary and Conclusions
- Key Findings and Recommendations
- Knowledge Transfer and Capacity Projects

Throughout the project, there has been a dialogue between climate modellers, downscalers and end-users in order to ensure that adequate guidance is provided on the application of the climate projections and downscaled products. The details of stakeholder workshops and meetings are described in the Section *Knowledge Transfer and Capacity Projects*. The scientific research has been peer reviewed in leading international journals, and this report includes a complete list of publications in Appendix A. The Project Team members have been actively contributing to national/international conferences and giving seminars and invited addresses. A list of public presentations is given in Appendix B. Three fact sheets describing the outputs of this project in simple terms were prepared by the Team members (refer to Appendix C for further details). Metadata templates and simulation file details are presented in Appendices D and E, respectively. Details of the milestones and project management throughout the project are presented in Appendices F and G, respectively.

Contributions to Goyder Institute Strategic Objectives

The downscaled projections resulting from this Project will be used by State Government agencies in their modelling and assessment work to provide evidence-based advice to feed into a number of current and future State Government Policies, including:

- South Australia's Strategic Plan: Target 3.9 Sustainable water supply) which requires that "South Australia's water resources are managed within sustainable limits by 2018".
- South Australia's State Infrastructure Plan: Sustainable water supplies; increase the stability of the State's water supply; successful management and effective allocation of water resources.
- Tackling Climate Change - South Australia's Greenhouse Strategy (2007-2020): the need to reduce greenhouse emissions; the need to adapt to climate change; and the need to innovate in markets, technologies, institutions, and the way we live.

In terms of the Goyder Institute's specific Policy Objectives, this project has contributed to:

- reliable and resilient urban water supplies that meet future needs through its provision of future downscaled climate projections;
- provision of environmental water to support ecological objectives, through its contribution to understanding climate change scenarios in all 8 South Australian NRM regions;
- proactive responses to climate change in water resource management, through its provision of climate scenarios for all 8 NRM regions.

In terms of the Goyder Institute's specific Capacity Objectives, this project has contributed to integrated water management through:

- Adaptive management systems and tools that can be picked up and used by policy makers within state government through the projects development of a model test-bed for the Onkaparinga catchment. These models can now be applied more broadly to other SA catchments subject to a successful catchment-specific calibration and validation;
- Develop capacity through support for postgraduate and research positions to build local capacity across all four research themes; through its employment of four post-doctoral researchers and two Goyder scholarship-funded PhD students.
- Develop synergies across Institutions that build greater local capacity, through GIWR's collaboration with all three SA universities, DEWNR, CSIRO, SARDI and SA Water.

In terms of the Goyder Institute's specific Research Activity Objectives, this project has:

- included team members from seven different research partners.
- produced several major achievements including seven papers in Nature publications, two scholarly books, 42 scientific journal papers and several keynote and invited presentations at international conferences. These research outputs have considerably raised the international profile of South Australian water research.

Delivering Against Objectives

The Project involved a number of milestones (Refer to Appendix F for a complete list), and these combine to address the main four Project Tasks. In broad terms, the project delivered against the objectives:

Task 1: Understanding the key drivers of climate change in South Australia

Climate change will bring about significant changes to the capacity of, and the demand on, South Australia's water resources. Rainfall is the key hydro-climatic variable that plays a vital role in the development of regional water management policies. Assessment of the spatial and temporal influences of climate drivers SOI, DMI and Niño3.4 on South Australian rainfall is therefore important for climate change adaptation measures.

Underpinning all climate-related projects within the Goyder Institute is the identification of the key drivers affecting the South Australian climate. We also need to understand the fundamental processes through which these drivers exert their influence.

Little is known about the factors that affect the South Australian climate and even less about the causes of the observed changes. The concept of "drivers" of climate variability is useful and widespread in similar studies overseas (Chowdhury and Beecham, 2010). However, there needs to be a clear distinction between what are useful, but nonetheless simple indices of the state of the climate system, and the true physical influences on that system. Also, indices that have predictive power in the current climate may have lesser influence in a changed climate.

In broad terms, the project aimed to develop a clear agreement on the definition of climate drivers for South Australia. Overall, the research focused on the critical areas: Understanding SA climate, including the impacts of the El Niño-Southern Oscillation (ENSO) cycle, the Pacific Decadal Oscillation (PDO), the Indian Ocean Dipole (IOD), and the Southern Annular Mode (SAM) on rainfall and other hydro-climatic variables.

In terms of significance for the project, this knowledge was essential for a quantification of the relative importance of climate change and variability in historical observations. It was also required for the selection of models for climate downscaling and for developing projections, including quantification of their associated uncertainty. Finally, it was important for understanding the projected changes and their implications. Throughout the project, there was ongoing communication with Tasks 2 and 3 to assist with climate downscaling projections.

The environmental time series were decomposed into random variations about an underlying level, trend, and additive seasonal effects and then these changes in the level, trend and seasonal effects were tracked over time. A key output from the Task was the statistical analysis of 53 stations across the eight SA Natural Resource Management (NRM) regions. The SA NRM regions: (0) SA Arid Lands, (1) Alinytjara Wilurara, (2) SA Murray Darling Basin, (3) Northern and Yorke, (4) Eyre Peninsula, (5) Kangaroo Island, (6) Adelaide and Mount Lofty Ranges and (7) South East. The main outcomes are listed in the Section *Key Findings and Recommendations*.

Task 2: Selection of GCMs for regional downscaling and projection

The objective of this task was to develop an approach for model selection that is consistent with both the IPCC framework and national climate change initiatives and built on outputs from Task 1. It is important to note that the selection should be based on a set of climatic criteria that are relevant to both SA current climate and future climate changes. In terms of relevance to the SA current climate, this will necessarily involve testing the realism of model simulation of SA climate drivers and their impacts.

Benchmarking and selecting models, in particular Coupled Model Intercomparison Project Phase 5 (CMIP5)-generation models on the basis that they can simulate climate processes such as El Nino Southern Oscillation (ENSO) and Indian Ocean dipole (IOD) that drive variability and changes in

South Australia's climate. The selected models were used for statistical downscaling in Task 3. The highlights are presented in the Section *Key Findings and Recommendations*.

Task 3: Downscaling and climate change projections for South Australia

Statistically downscaled projections produced for South Australian stations, on a natural resource management (NRM) region basis, have been delivered by Task 3 of the Goyder Institute of Water Research Project '*Development of an agreed set of climate projections for South Australia*'. There are eight NRM regions across South Australia: (1) Adelaide and Mt Lofty Ranges; (2) Alinytjara Wilurara; (3) Eyre Peninsula; (4) Kangaroo Island; (5) Northern and Yorke; (6) SA Arid Lands; (7) SA Murray-Darling Basin; and (8) South East. Statistical downscaling models have been calibrated on a seasonal basis to each NRM region individually, with the exception of the Alinytjara Wilurara NRM as there is a lack of stations with sufficient data in this region. The seasonal partitioning used is summer as December-January-February (DJF), autumn as March-April-May (MAM), winter as June-July-August (JJA), and spring as September-October-November (SON). The key outcomes from Task 3 are presented in the Section *Key Findings and Recommendations*.

Task 4: Development of an application test bed

The emphasis of the work conducted for the applications test bed was to provide feedback to the developers of the climate change projections and downscaling, in addition to developing application modelling examples. The Onkaparinga River catchment (Figures 2 and 3) was identified by the Goyder Institute as the primary case study location for this project. Where required for this task, new models were developed that represent the case study catchment or its sub-catchments, such as the Cox Creek catchment. The modelling applications test bed was developed to ensure that the research project outputs comply with the specific needs of end users by ensuring an active technical engagement was established between the research team and key state government agencies, including Department of Environment, Water and Natural Resources (DEWNR), South Australian Research and Development Institute (SARDI) and SA Water. This activity has delivered on the project objectives and has helped to build capacity in end user agencies and is an important step towards the overall goal of developing an agreed set of climate projections for South Australia, ensuring the downscaled climate projection data sets are suitable for use in resource management modelling applications. The involvement of natural resource management scientists in SA government agencies also aimed to foster a working knowledge of the data sets, including the conditions and qualifiers that are required when applying and interpreting the datasets. The key findings of the test bed applications are presented in the Section *Key Findings and Recommendations*.

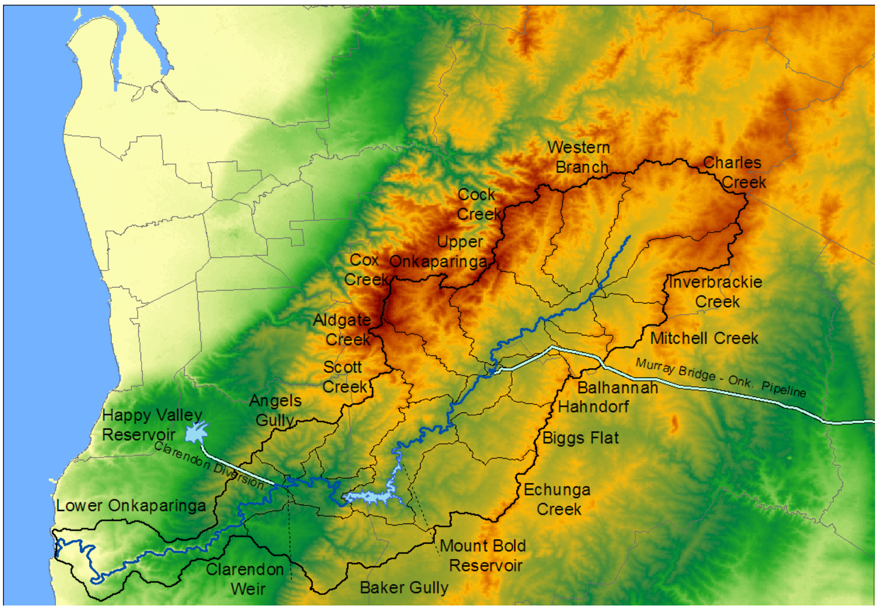

Figure 2. Onkaparinga catchment – test case study area including Cox Creek sub-catchment

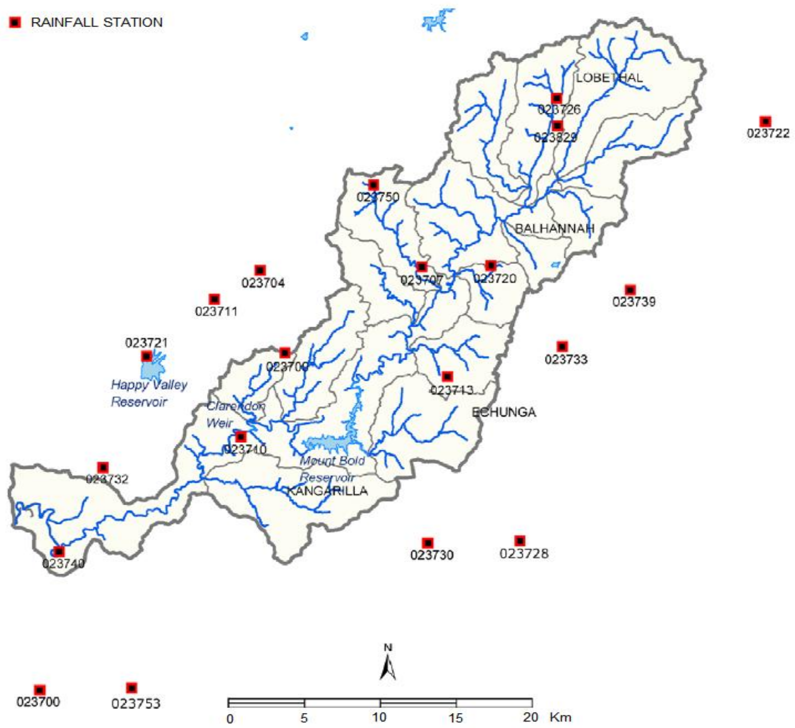

Figure 3. Rainfall stations in the Onkaparinga catchment

Summary and Conclusions

The Climate Projections Project has delivered on its objectives and has contributed significantly to the Goyder Institute's Strategic objectives as outlined in the previous Section. The project has delivered *an agreed set of climate projections for South Australia*, and using a range of scientific methods has advanced our understanding of key climate drivers in South Australia. The application of an applications test bed has ensured that the research project outputs comply with the specific needs of end users. The downscaled projections resulting from this project will be used by State Government agencies in their modelling and assessment work to provide evidence-based advice to feed into a number of current and future State Government Policies and to support proactive responses to climate change in water resource planning and management.

The project team was closely engaged with SA Government departments, agencies and corporations including DEWNR, SARDI and SA Water. Five Coupled Model Intercomparison Project Phase 5 (CMIP5) GCMs have been downscaled for a defined historical period. A Stakeholder Workshop was held in September 2013 where we released our interim projections to various State Government agencies. We have advanced our understanding of how the El Niño-Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and the subtropical-dry zone expansion influence the South Australian climate. Our results on how ENSO and the IOD impact on southern Australia is already being used by the Australian Bureau of Meteorology (BOM) in their assessment of the performance of the BOM's prediction models and models operated by other international bodies.

The project has also delivered easily implemented guidelines and software tools that translate these projections into interpretable inputs for regional demand-supply planning and other water management related studies. For example, a risk assessment framework was used to identify the risk of climate change to Middlepoint Swamp, a groundwater dependent ecosystem in the Lower South East region of South Australia. The study investigated the effects of historic groundwater level decline and the predicted impacts of additional climate induced groundwater decline. It was found that by 2030, the maximum surface water level in Middlepoint Swamp was predicted to fall by up to 1 m, almost completely drying the wetland. Consequently, the risk assessment found that the wetland ecosystem at Middlepoint Swamp was at moderate risk of not existing by 2030. Vegetation with the highest water requirements were no longer predicted to occur in any of the 2030 scenarios, being replaced by brackish herbland and exotic pasture grasses. The scale of predicted change was shown to have significant negative impacts for wetlands dependent on regional groundwater in the South East.

The benchmark suite of downscaled climate projections and climate variable time series will have tremendous benefits for South Australia's efforts to adapt the management of its water resources to future climate conditions. This will become a major asset for all climate change adaptation activities in South Australia. Furthermore, the involvement of key State Government departments in the operation of the proposed applications test bed will result in a markedly enhanced capability to apply climate projections and climate data to water resource management projects. Collectively, the outcomes of this research program will place South Australia firmly in the global forefront of climate change adaptation.

This project has produced far more than simply a set of environmental data. It also developed a robust fit for purpose framework that will allow the projections downscaled from IPCC CMIP5 models to be readily updated with future GCM modelling results as they are released. In addition, this project will lead to greatly increased levels of confidence in State Government policy decisions since they will always be based on the most reliable scientific evidence about both climate change and the localised climate variability caused by seasonality, trends and identified climate drivers for South Australia.

The key findings and recommendations are presented in the following Section.

Key findings and recommendations

Task 1: Understanding the key drivers of climate change in South Australia

Our major findings are:

- Recent records on monthly rainfall and climate driver index values from 1981 to 2010 were analysed for 53 stations across eight SA Natural Resource Management (NRM) regions. The SA NRM regions: (0) SA Arid Lands, (1) Alinytjara Wilurara, (2) SA Murray Darling Basin, (3) Northern and Yorke, (4) Eyre Peninsula, (5) Kangaroo Island, (6) Adelaide and Mount Lofty Ranges and (7) South East.
- A number of statistical techniques were applied to identify statistical significant correlation between rainfall and climate indices SOI, Niño3.4 and DMI and between the climate drivers themselves. The investigation provided an overall spatial view of influence of climate indices on SA rainfalls.
- It was found that SA summer (December to February) rainfall is influenced by SOI in the south east SA region, particularly in December and January.
- Some influences of Niño3.4 in the Arid Lands NRM region are also evident.
- In autumn (March to May), the influences of both SOI and DMI are evident in the Arid Lands NRM region in May. DMI influence in autumn is confined to the south east part of SA.
- Winter rainfall in the south and east parts of SA is heavily influenced by both SOI and DMI. Both SOI and DMI are correlated in winter.
- Spring rainfall is influenced by DMI in the southern and eastern parts of SA, particularly in September and October.
- In terms of ENSO phenomena, whilst both SOI and Niño3.4 are correlated, SOI is found to be more influential than Niño3.4 for SA rainfall.
- This study has shown that autumn rainfalls have exhibited downward trends in the south-east part of the Murray Darling Basin region, in the Northern and Yorke region and in the South East region. This is consistent with the outputs of the SEACI project, even though different methodologies have been used.
- Hydrological modellers in DEWNR, SA Water and SARDI need to carefully consider these findings as they have significance in terms of groundwater recharge/storage, surface runoff, decreased catchment wetting during the lead up to higher rainfall winter periods.

- More broadly these modellers have begun using preliminary projections in their surface and groundwater models in the Onkaparinga catchment. They have also analysed the uncertainty associated with this modelling work. When using non-stationary models for developing streamflow projections for a future climate, scientific judgement is still required to estimate how the identified parameter trends might continue over time. For example, in this study, the identified trend of increasing model storage capacity could be tentatively explained by an increase in farm dams within the catchment, although other hypotheses such as changes in vegetation dynamics or groundwater extractions cannot be excluded. Given this uncertainty, projections should be made available using an ensemble of possible models, encompassing a range of possible future changes to catchment stores. This offers the best chance to adequately capture the uncertainty in future catchment behaviour.

We refer the reader to Beecham and Chowdhury (2012, 2013, 2015), Williams *et al* (2012), Loch *et al* (2013), Boland (2014), Kumruzzaman *et al* (2014) Rashid *et al* (2015) for further details and applications.

Task 2: Selection of GCMs for regional downscaling and projection

Highlights include:

- The work done on extreme ENSO, which shows that extreme El Nino events, associated with drought conditions in southern Australia, will likely double in the future from one event every 20-years to one event every 10-years (Cai et al. 2013).
- Likewise, the CMIP5 models also project that the frequency of extreme positive IOD events, that often drive spring drying, and precondition severe bushfires in southeast Australia will increase by around a factor of three so that one event could occur every 7 years over the 21st century (Cai et al. 2014).
- The models also project a greater warming in the northern part of the eastern Indian Ocean, which will increase the likelihood of positive IOD-like mean-state in the future (Weller & Cai 2014).
- The ability of climate models to also simulate the frequency and strength of extreme summer heat waves and winter warm spells over southern Australia was also assessed.
- It was found that while models only weakly capture of the observed frequency and duration of heat waves, they perform well at capturing the observed amplitude (i.e., maximum temperature of heat waves) (Cowan et al. 2014).
- Climate models project an almost 3°C increase in the maximum temperature of the hottest southern Australian heat waves by the end of the 21st century, mostly because central Australia will warm faster than coastal regions, allowing weaker systems to advect this warmer air south (Purich et al. 2014).
- In summary, Tasks 1 and 2 have enabled the proper selection of global climate models that can capture important climate processes that influence the climate of South Australia, including extreme events (El Nino, positive IOD and heat waves).

Refer to Cai *et al* (2012a, 2012b, 2013a, 2013b, 2014) and Weller and Cai (2014) for further details.

Task 3: Downscaling and climate change projections for South Australia

The key findings include:

- Precipitation is projected to decrease in all regions and seasons, with the largest relative decreases for spring.
- Maximum temperature is projected to increase in all regions and seasons, and corresponding with the projected precipitation changes the maximum increases are for the spring season (followed by summer).
- There is also greater increase inland and further north, predominantly reflecting the moderating effect of the oceans, in contrast to the larger continental heating.
- Minimum temperatures are projected to increase less than maximum temperatures, and the largest increases in minimum temperature are projected to occur in autumn.
- Solar radiation changes are surmised to be related to changes in cloud cover and thus highly correlated with the precipitation projections.
- The largest relative changes are increases in winter and spring. VPD also increases in response to the temperature increase and the reduced precipitation. These combine to increase estimated APET, with again the largest relative increases in spring.
- One identified shortcoming of NHMM simulations of relevance to hydrological modelling, as noted by the Task 4 case study of hydrological simulation in the Onkaparinga catchment, is the underestimation of extreme multi-day precipitation events. Thus whilst the NHMM can reproduce the probability distribution of station precipitation amounts, its simulation of consecutive days of high amounts does not sufficiently reproduce the extreme multi-day event totals as seen in the observed record.
- Because of the above limitation, the project's alternative downscaling model, GLIMCLIM was successfully adapted for extreme rainfall analysis. To this end, the performance of the Generalized Linear Modelling of daily Climate sequence statistical downscaling model (GLIMCLIM) was assessed to simulate extreme rainfall indices and Annual Maximum Daily Rainfall (AMDR) when downscaled daily rainfall from NCEP reanalysis and CMIP5 GCM (four GCMs and two scenarios) output datasets and then their changes were estimated for the future period 2041 – 2060. Overall South Australia will experience drier conditions due to an increase in consecutive dry days coinciding with decreases in heavy (>long term 90th percentile) rainfall days, Empirical 90th quantile of rainfall and maximum 5 day consecutive total rainfall for the future period (2041 – 2060) compared to the base period (1961 – 2000).
- The magnitude and range of change from an ensemble of six better performing GCMs are consistently less than that from an ensemble of six poorer performing GCMs.
- This suggests that the selection of GCMs for downscaling based on their performance in terms of the large-scale drivers is important for regional climate variability, as assessed by Task 2, has significant merit.
- Correspondingly, this also implies that the use of all available GCMs may produce unrealistically large uncertainties that obscure robust regional climate change signals.

- Given the differences between the ensembles, it is concluded that the downscaled series obtained from the six better GCMs provide more realistic inputs for impacts and adaptation assessment than those from the six poorer GCMs.
- However, the user also needs to be mindful that the range of possible future climate change is larger than that obtained from only using the downscaled results from the six better GCMs.
- It is advisable to consider multiple sources of climate projection information, e.g. more than one downscaling technique, as different techniques have different strengths and weaknesses (Ekström et al., Accepted; Haylock et al., 2006).

For further details refer to Goyder Institute Technical Report 15/1 that summarises the statistically downscaled projections produced for South Australian stations, on a natural resource management (NRM) region basis.

Task 4: Development of an application test bed

The fourth task involved the development of a suite of hydrological models to serve as a test bed for the downscaled climate change projections. The Onkaparinga River catchment was identified as the primary case study area for hydrological modelling. The key findings are presented in 3 sub-tasks:

Application of downscaled climate data for South Australia using the agricultural model APSIM (Agricultural Production Systems Simulator).

The key findings from this experience are as follows:

- There are advantages of including an application test bed in such a project in order to test the consistency of climate change projections. Conducting applied research in parallel with data production enables two way flow of information between the data providers and data users.
- Although the time allocation was modest, SARDI Climate Applications benefited from the engagement with climate science and interdisciplinary work with hydrologists.
- It has been clearly demonstrated that the cropping simulation model APSIM can be run with the data from this Climate Projections Project.
- We found that there was no simple approach to subsampling ensembles by identifying a dry (10^{th} percentile), mid-range (50^{th} percentile) and wet (90^{th} percentile). We also found that taking a year in the future and running the 100 ensembles was problematic as some years have almost all ensembles wetter or drier than the average.
- The projection data from the Climate Projections Project is substantial (100 ensembles for 94 years from 2006 to 2100). This data set presents information technology challenges, many of which have been solved during the life of the project. Skills in using the modelling program R will benefit SARDI Climate Applications.
- It is likely that agricultural applications will want to subsample the large amount of climate data. This is partly due to the processing time required for 9400 yearly simulations for each climate model and projection pathway. The main reason is that adaptation research involves the use of many options such as fertiliser rates, or choice of crop and variety.

- One of the key recommendations is that future research be conducted to develop improved downscaling techniques that can reproduce multi-day rainfall amounts, and that these approaches are evaluated using a split-sample procedure.

Further details are available in the Goyder Institute Technical Report 15/2.

Impacts of Climate Change on Surface Water in the Onkaparinga Catchment

We refer to three technical reports Goyder Institute Technical Reports 14-22, 14-23, 14-27 for the key outcomes and recommendations from the University of Adelaide component of *Task 4: Application Test Bed.* The development and evaluation of the hydrological models and sources of uncertainty is presented in Report 1 and Hydrological Evaluation of the CMIP3 and CMIP5 GCMs and the Non-homogenous Hidden Markov Model (NHMM) is presented in Report 2. The third report, which builds on Reports 1 and 2, provides flow projections for three sub-catchments of the Onkaparinga catchment (Scott Creek, Echunga Creek and Houlgrave Weir), based on non-homogenous hidden Markov model (NHMM) simulations of rainfall and potential evapotranspiration from 15 global climate models (GCMs) and two representative concentration pathways (RCPs) that describe possible future atmospheric greenhouse gas emission and concentration scenarios. The results were assessed using the following flow metrics: (a) mean annual flows; (b) low annual flows (lowest 10th percentile annual flows); (c) low daily flows (lowest 10th percentile daily flows); and (d) high daily flows (95th and 99th percentile daily and annual maximum flows).

Developing an Application Test Bed for Hydrological Modelling of Climate Change Impacts: Cox Creek Catchment, Mount Lofty Ranges

This report outlines the construction of three hydrological models of the northern 15.6 km^2 of the Cox Creek sub-catchment, including: (1) a MODFLOW groundwater model, (2) a LEACHM recharge model, and (3) a SOURCE (GR4J) catchment runoff model. The models were develop through a collaborative effort involving Flinders University, the Department of Environment, Water and Natural Resources (DEWNR), and the South Australian Research and Development Institute (SARDI), who each led the construction of the groundwater, recharge and runoff models, respectively.

Key findings:

- Individual models of surface water runoff, groundwater recharge and groundwater flow have been developed to assess climate change impacts for the Cox Creek catchment in the Mount Lofty Ranges of South Australia.
- The selected models were able to reproduce adequate matches to the field observations. Firstly, the MODFLOW model provided a reasonable reproduction of groundwater levels, in terms of both the spatial and temporal water level trends. The lower calibration weighting of single-measurement heads is the reason that these are not as closely matched to the averages from monitoring wells. Secondly, the LEACHM model adequately reproduced both an approximate value for total pumping, and an estimate of recharge obtained from the chloride mass balance (CMB) approach.

- The application of the models to four scenarios of future climate indicates reduced groundwater recharge, enhanced evapotranspiration, largely similar surface runoff, a higher agricultural water demand, and falling groundwater levels. Given that the four climate change scenarios represent lower future precipitation and higher potential evapotranspiration relative to historical conditions, this is somewhat unsurprising. However, the magnitude of future climate change impacts was marked, and considerably larger than the rainfall decline, at least in terms of the recharge reduction.
- The results indicate that significant decreases in flows are likely during the 21st century, with larger decreases for RCP 8.5 compared to RCP 4.5, and for late 21st century projections compared to early 21st century projections. Averaging across GCMs, RCPs and hydrological models, the median percentage change for the four time slices analysed at Houlgrave Weir are: -14% (2016-2045), -24% (2036-2065), -33% (2056-2085) and -37% (2071-2100).
- Uncertainty is large, particularly for the late 21st century projections, however confidence about the direction of change is high: by 2071-2100, 98% of simulations show that the mean annual flow will decrease.

Recommendations:

- There are several areas in which the current work can be extended to produce improved simulation of climate change impacts on the Cox Creek catchment.

Further details are available in the Goyder Institute Technical Report 14/28.

Knowledge Transfer and Capacity Projects

Throughout the project, there has been a dialogue between climate modellers, downscalers and end-users in order to ensure that adequate guidance is provided on the application of the climate projections and downscaled products. Communication activities include a number of joint meetings and stakeholder workshops. We highlight a number of activities below.

Stakeholder Workshops

The Stage 1 Stakeholder Workshop was held on the 19th September 2013 in the DEWNR Offices at 25 Grenfell Street, Adelaide. This was a pre-cursor to a broader Stakeholder Workshop that was held in November where we released our interim projections to various State Government agencies. The September workshop was attended by the four Task Leaders, Peter Hayman and Bronya Alexander from SARDI, Neil Power from DEWNR and Julia Piantadosi from UniSA. At this Stakeholder Workshop we discussed the nature and format of the downscaled products that our project will deliver to the State Government.

The Stage 2 Stakeholder Workshop was held on 27 November 2013. It is intended that the climate projections will be used across government for development of climate adaption policy and strategies. To help formulate the most informative way to present the climate projections, the

Goyder Institute conducted this workshop to brief State agencies, natural resources management staff and local government involved in climate adaption projects on the project and to obtain feedback on the best options to present the climate projections so they are most useful to policy makers and planners. The workshop consisted of two sessions: A general session in the morning on the climate projections project and presentation of the climate projection data; and a technical session including details of the climate data sets. At this workshop Professor Steve Rayner from Oxford University in the UK contributed his expertise on stakeholder engagement. Professor Rayner has served on various US, UK, and international bodies addressing science, technology and the environment, including Britain's Royal Commission on Environmental Pollution, the Intergovernmental Panel on Climate Change and the Royal Society's Working Group on Climate Geoengineering. His current research focuses on the future of cities, alternative policy frameworks for climate change, and the emergence of novel technologies, especially climate geoengineering.

Project Mid-Term Review

The Mid-Term Review of the Project was held in conjunction with the project's Annual Workshop on 3-4 October 2012. The review was attended by the Task Leaders, The Goyder Institute Director, members of the Scientific Advisory Committee (SAC) and by several State Government representatives. A number of presentations and detailed discussions took place around the review panel's terms of reference, uptake and implementation of project outcomes, translating outcomes to State Government and other external communications relating to the project.

Climate Change Projections Annual Workshop / Joint SEACI Workshop

A joint Goyder Institute for Water Research Climate Change Projections Annual workshop and South Eastern Australian Climate Initiative (SEACI) Workshop was held on Tuesday 15 and Wednesday 16 November 2011. David Post introduced the South East Australian Climate Initiative (SEACI). One of the aims was to Review the SEACI/Goyder interrelationship and identify synergies and overlaps between the Goyder and SEACI projects.

The second Climate Projections Project Annual meeting was held on October 3, 2012. Graeme Pearman presented on SEACI outcomes and benefits for Goyder Projects.

Establishment of linkages to the national NRM Project

The CSIRO and BoM next generation of national projections will be delivered through a recently commenced 'NRM projections project'. This project aims to include all appropriate downscaled information in its delivery of a new suite of regional climate projections to all NRM groups by mid-2014. CSIRO Task 3 researchers are involved in this project. Thus we were well placed to promote synergies and leverage output so as to maximise outcomes for the Goyder Institute.

Task 3 Leader Steve Charles and Freddie Mpelosoka participated in a CSIRO NRM Projections Workshop 4-6 February 2013, Melbourne.

The GIWR Climate Projections Project Stakeholder Engagement Teleconference Meeting was held on 20 March 2014. Attendees included: Tina Brew (representing Rohan Hamden, DEWNR) Leanne Webb (CSIRO), Graham Green (DEWNR), Zafi Bachar (DEWNR), Peter Hayman (SARDI) and Simon Beecham (UniSA). Leanne Webb gave an overview of the *Projections for Australia's NRM Regions* project (southern and south-west flatlands region). Discussion then was around how the GIWR datasets are probably most useful for hydrological modellers but that overall, the two data products will be very complementary. The *Projections for Australia's NRM Regions* project products are more geared towards NRM users, but both types of users are recommended to look at both products.

Engagement with the Australian Bureau of Meteorology

Project Leader Simon Beecham met in Canberra with Dr Janice Green, Head of the IFD Revision Project Unit, Bureau of Meteorology regarding:

- Bureau continuous rainfall stations
- Bureau daily read rainfall stations and
- Stations operated by DEWNR and whose data are provided to the Bureau under the Water Regulations.

BoM is using the new understanding of ENSO's impact on the Australian climate to improve their seasonal predictions**.**

Goyder Institute Activities

Project Leader Simon Beecham gave a presentation titled "What is South Australia's Climate future" as part of the Goyder Institute for Water Research Seminar Series to present research findings in a public forum.

Goyder Institute Science Retreat for Project Leaders and Project Teams was held on June 3-4, 2013. Project Leader Simon Beecham attended the retreat. One of the aims of the retreat was to discuss how we can integrate this work into the other three Goyder Institute research themes.

Task Leader meetings / workshops

A successful half day workshop was held at the DEWNR which brought together representatives of all State Agencies and Project Tasks to discuss GCM selection and downscaling performance and output requirements. Four project workshops have been held throughout 2011-12 including Joint Task workshops to maximise synergies between the Tasks.

Task Leader 2-day meeting/workshop was held in Adelaide, 1-2 May 2013. This included a meeting of the four task leaders is to discuss the requirements of the interim set of projections and to decide an appropriate content and format for them; technical discussions will be held between all Tasks; and a meeting between four task leaders and representatives of end-user organisations from water and other sectors.

Goyder Institute Model Stock Take

Task 4 Leader Graham Green presented on behalf of the Climate Change Team. The Goyder Institute Model Stock Take was held on 20 November 2014 at SA Water House. Attendees included representatives from all Goyder Institute projects that were involved with developing/optimising emodels; DEWNR staff; Goyder Institute staff; representatives of other State agencies. The objectives were to obtain agreement about the minimum requirements for metadata summaries of the models; to obtain agreement about storage of the models and understand the issues and requirements around the storage; and to develop a plan or work flow to ensure that the models developed from Goyder Institute projects are available/ discoverable for future use and development.

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The following Goyder Institute Technical Reports are available on the Goyder Institute Website: www.goyderinstitute.org

Goyder Institute Technical Report 14-22

Westra, S., Thyer, M., Leonard, M., Kavetski, D. & Lambert, M. (2014) Impacts of Climate Change on Surface Water in the Onkaparinga Catchment – Volume 1: Hydrological Model Development and Sources of Uncertainty

Goyder Institute Technical Report 14-23

Westra, S., Thyer, M., Leonard, M. & Lambert, M. (2014) Impacts of Climate Change on Surface Water in the Onkaparinga Catchment – Volume 2: Hydrological Evaluation of the CMIP3 and CMIP5 GCMs and the Non-homogenous Hidden Markov Model (NHMM)

Goyder Institute Technical Report 14-27

Westra, S., Thyer, M., Leonard, M. & Lambert, M. (2014) Impacts of Climate Change on Surface Water in the Onkaparinga Catchment – Volume 3: Impacts of climate change on runoff

Goyder Institute Technical Report 14-28

Werner AD, Jakovovic D, Ordens CM, Green G, Woods J, Fleming N, Alcoe D (2014) Developing an Application Test Bed for Hydrological Modelling of Climate Change Impacts: Cox Creek Catchment, Mount Lofty Ranges

Goyder Institute Technical Report 15/1

Stephen P. Charles and Guobin Fu (2015) Statistically Downscaled Climate Change Projections for South Australia

Goyder Institute Technical Report 15/2

Peter Hayman and Bronya Alexander (2015) Application of downscaled climate data for South Australia using the cropping simulation model APSIM

Appendix A - Reports and Publications

The scientific research underpinning the first two tasks has been peer reviewed in leading international journals. A list of the 42 journal papers, 2 books and 17 conference papers is provided below. Additional research outputs are presented in Technical Reports which are now available on the Goyder CSIRO SharePoint at: http://teams.csiro.au/sites/GoyderInstitute.

Scholarly Books

1. Willems, P., Olsson, J., Arnbjerg-Nielsen, K., Beecham, S., Pathirana, A., Bülow Gregersen, I., Madsen, H. and Nguyen, V.T.V. (2012), Impacts of Climate Change on Rainfall Extremes and Urban Drainage Systems, IWA Publishing, 226 pages, ISBN: 9781780401256 (paperback), ISBN: 9781780401263 (eBook).
2. Loch, A., Wheeler, S., Bjornlund, H., Beecham, S., Edwards, J., Zuo, A. and Shanahan, M. (2013), The Role of Water Markets in Climate Change Adaptation, National Climate Change Adaptation Research Facility, Gold Coast, 142 pages, ISBN: 978-1-925039-01-6

Highlighted papers

1. Cai, W., Cowan T., Thatcher, M. (2012a), Rainfall reductions over Southern Hemisphere semi-arid regions, including southeast Australia: the role of subtropical dry zone expansion, Nature Scientific Reports, 2:702, doi: 10.1038/srep00702.
2. Cai, W., Zheng, X.T., Weller, E., Collins, M., Cowan, T., Lengaigne, M., Yu. W. and Yamagata, T. (2013a), Projected response of the Indian Ocean Dipole to greenhouse warming, Nature Geoscience, 6, 999–1007 doi: 10.1038/ngeo2009
3. Cai, W., S. Borlace, M. Lengaigne, P. van Rensch, M. Collins, G. Vecchi, A. Timmermann, A. Santoso, M. J. McPhaden, L. Wu, M. H. England, G. Wang, E. Guilyardi, and F.-F. Jin (2013b) Increasing frequency of extreme El Niño events due to greenhouse warming. Nature Climate Change, 4, 111-116, 2014 | doi: 10.1038/nclimate2100.
4. Weller, E., W. Cai, S-K, Min, L. Wu, K. Ashok, & T. Yamagata (2014), More-frequent extreme northward shifts of eastern Indian Ocean tropical convergence under greenhouse warming, Nature Sci. Rep. Scientific Reports, 4, 6087; doi: 10.1038/srep06087.
5. Cai, W., A. Santoso, G. Wang, E. Weller, L. Wu, K. Ashok, Y. Masumoto, and T. Yamagata (2014) Increased frequency of extreme Indian Ocean Dipole events due to greenhouse warming. Nature, 510, 254-258, doi: 10.1038/nature13327.
6. Weller, E., Cai, W. (2014) Meridional variability of atmospheric convection associated with the Indian Ocean Zonal Dipole Mode. Nature Scientific Reports 4, 3590, doi: 10.1038/srep03590.
7. Cai, W., Lengaigne, M., Borlace, S., Collins, M., Cowan, T., McPhaden, M.J., Timmermann, A., Power, S., Brown, J., Menkes, C., Ngari, A., Vincent, E.M., Widlansky, M.J. (2012b) More extreme swings of the South Pacific convergence zone due to greenhouse warming. Nature 488 365-369.

An article "Indian Ocean linked to bushfires and drought in Australia" has been published in The Conversation. Here is the link:

http://theconversation.com/indian-ocean-linked-to-bushfires-and-drought-in-australia-20893

Invited Report

MDB Plan Science Review Assessing South Australia's environmental water requirements and the implications of the Murray-Darling Basin Plan March 2011 Report prepared by Simon Beecham (Project Leader) with assistance from team members.
The report is available: http://teams.csiro.au/sites/GoyderInstitute.

Invited Special Issue of the Journal: *Water*

Project Leader Simon Beecham and his colleague Julia Piantadosi were invited to be guest Editors of a special issue of the journal *Water*, titled *Water Resources in a Variable and Changing Climate*. Water (ISSN 2073-4441; CODEN: WATEGH) is an open access journal on water science and technology, including the ecology and management of water resources, and is published quarterly online by MDPI. The journal, which is quite new, has one of the fastest growing impact factors (currently 1.291). Further details can be found here:
http://www.mdpi.com/journal/water/special_issues/water_climate

Invited Special Issue Synopsis: Climate change will bring about significant changes to the capacity of, and the demand on, water resources. The resulting changes include increasing climate variability that is expected to affect hydrologic conditions. The effects of climate variability on various meteorological variables have been extensively observed in many regions around the world. Atmospheric circulation, topography, land use and other regional features modify global changes to produce unique patterns of change at the regional scale. As the future changes to these water resources cannot be measured in the present, hydrological models are critical in the planning required to adapt our water resource management strategies to future climate conditions. Such models include catchment runoff models, reservoir management models, flood prediction models, groundwater recharge and flow models, and crop water balance models. In water-scarce regions such as Australia, urban water systems are particularly vulnerable to rapid population growth and climate change. In the presence of climate change induced uncertainty, urban water systems need to be more resilient and multi-sourced. Decreasing volumetric rainfall trends have an effect on reservoir yield and operation practices. Severe intensity rainfall events can cause failure of drainage system capacity and subsequent urban flood inundation problems. Policy makers, end users and leading researchers need to work together to develop a consistent approach to interpreting the effects of climate variability and change on water resources.

This Special Edition includes papers by international experts who have investigated climate change impacts on a variety of systems including irrigation and water markets, land use changes and vegetation growth, lake water levels and quality and sea level rises. These investigations have been conducted in many regions of the world including the USA, China, East Africa, Australia, Taiwan and the Sultanate of Oman.

Refereed Journal Publications

Arnbjerg-Nielsen, K., Willems, P., Olsson, J., Beecham, S., Pathirana, A., Bulow Gregersen, I., Madsen, H. and Nguyen, V.T.V. 2013. Impacts of climate change on rainfall extremes and urban drainage systems: a review. Water Science and Technology 68, 16-28 http://www.iwaponline.com/wst/06801/0016/068010016.pdf

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Appendix B - Public Presentations

The Project Team members have been actively contributing to national/international conferences and giving seminars and invited addresses. A list of public presentations is given in Table 2.

Table B1. Public Presentations by Project Team Members

Date	Presenter	Topic	Audience/Location
28 June – 8 July 2011	Wenju Cai (Task 2 Leader)	Tropical variability and change in recent decades	**IUGG Congress, Melbourne Australia**
02 August 2011	Mike Burch Simon Beecham (Project Leader / Task 1 Leader) **Invited Presentation**	Climate Change and Water Quality	**Researchers and leaders from water utilities and universities from around Australia and overseas gathered in Adelaide in August to discuss climate change and water quality.**
14 August 2011	Wenju Cai (Task 2 Leader) **Invited Presentation**	Understanding Australian Climate drivers and rainfall trend	**DCCEE, Canberra Australia**
22 August 2011	Simon Beecham (Project Leader / Task 1 Leader) **Invited Presentation**	Climate Change and Water Quality	**WQRA members from all around Australia gathered in Darwin in August to talk water quality**
4-7 December 2011	Simon Beecham (Project Leader / Task 1 Leader) **Keynote paper**	Effects of climate change on integrated water management	10th Engineering Mathematics and Applications Conference (EMAC) in 2011 at the University of Technology Sydney
12-16 December 2011	Steve Charles (Task 3 Leader) **Invited Presentation**	Projections of Climate Change: from modelling to application	International Congress on Modelling and Simulation (MODSIM 2011), Perth, WA.
12-16 December 2011	Julia Piantadosi	Rainfall Modelling at Various timescales	International Congress on Modelling and Simulation (MODSIM 2011), Perth, WA.
31 Jan to 3 Feb 2012	Evan Weller	CMIP3 representation of the IOD rainfall teleconnection to Australia and its asymmetry	Australian Meteorological & Oceanographic Society (AMOS) annual conference, Sydney
31 Jan to 3 Feb 2012	Tim Cowan	Do we really know the cause of the recent southeast Australian autumn rainfall reduction?	Australian Meteorological & Oceanographic Society (AMOS) annual conference, Sydney
5 – 9 March 2012	Tim Cowan	Climate change and its impact on the Indian Ocean dipole: a CMIP5 model perspective	WCRP Workshop on Coupled Model Intercomparison Project Phase 5 (CMIP5) Model Analysis, Honolulu, Hawaii, USA
5 – 9 March 2012	Evan Weller	CMIP5 IOD and its rainfall teleconnection: Amplitude, Rainfall teleconnection & its Asymmetry	WCRP Workshop on Coupled Model Intercomparison Project Phase 5 (CMIP5) Model Analysis, Honolulu, Hawaii, USA

Date	Presenter	Topic	Audience/Location
26 – 29 March 2012	Steve Charles (Task 3 Leader) **Invited Presentation**	Downscaling and climate change projections for South Australia	Planet Under Pressure 2012 Conference, London, UK
11-13 April 2012	Wenju Cai (Task 2 Leader) **Invited Presentation**	Drought in Australasia	WCRP Workshop on the Development of an Experimental Global Drought Information System (GDIS), Frascati, Italy
12 April 2012	Seung-Ki Min	Understanding and projecting changes in climate extremes	Meeting of Extremes Research Program of the ARC Centre of Excellence for Climate System Science, Melbourne
23 to 27 April 2012	Tim Cowan	Southeast Australian autumn rainfall reduction: a climate-change induced poleward expansion of atmospheric circulation	10th International Conference on Southern Hemisphere Meteorology and Oceanography, Noumea, New Caledonia
23 to 27 April 2012	Wenju Cai (Task 2 Leader) **Invited Presentation**	Teleconnection of ENSO and the IOD and the mechanism for impact on Australia rainfall	10th International Conference on Southern Hemisphere Meteorology and Oceanography, Noumea, New Caledonia
27 April 2012	Freddie Mpelasoka	Assessment of CMIP5 GCM daily predictor variables for statistical downscaling	European Geosciences General Assembly, Vienna, Austria
28-29 April, 2012	Wenju Cai (Task 2 Leader) **Invited Presentation**	An early look at ENSO in CMIP5	7th session of the WCRP CLIVAR Pacific Panel meeting, Noumea
1-3 May 2012	Simon Beecham (Project Leader / Task 1 Leader) **Invited Presentation**	South Australian Rainfall – Trends, Step changes and climate drivers / Wavelet based assessment of relationship between hydrological time series in South East Australia / Climate Change impacts on the hydrology of Aldgate and Inverbrakie creeks in South Australia.	2nd 'Practical Responses to Climate Change' conference to be held in Canberra, Australia The theme for 2012 is **'Water and Climate: Policy Implementation Challenges'**
7 to 8 May 2012	Tim Cowan	Midlatitude and tropical processes influencing rainfall across southern Australia	CSIRO-Chinese Academy of Sciences Inaugural Workshop, Beijing, China
9 May 2012	Tim Cowan	Midlatitude and tropical processes influencing rainfall across southern Australia	Third Institute of Oceanography, State Oceanic Administration, Xiamen, China.
9 May 2012	Wenju Cai (Task 2 Leader) **Invited presentation**	Presentation title: Midlatitude and tropical processes influencing rainfall across southern Australia	The Third Institute of Oceanography, State Oceanic Administration, in Xiamen, China
14 to 15 May 2012	Tim Cowan	Climate change and its impact on the Indian Ocean dipole: a CMIP5 model perspective	CAWCR Coupled Model Intercomparison Project Phase 5 (CMIP5) Model Intercomparison Workshop

Date	Presenter	Topic	Audience/Location
			Hobart
14 to 15 May 2012	Evan Weller	CMIP5 IOD and its rainfall teleconnection: Amplitude, Rainfall teleconnection & its Asymmetry	CAWCR Coupled Model Intercomparison Project Phase 5 (CMIP5) Model Intercomparison Workshop Hobart
14 to 15 May 2012	Seung-Ki Min	Attribution of Hadley Cell expansion	CAWCR Coupled Model Intercomparison Project Phase 5 (CMIP5) Model Intercomparison Workshop Hobart
24 May 2012	John Boland	Reconciling rainfall on differing time scales	Statistics and Actuarial Science Mathematics University of Waterloo
28-29 May 2012	Simon Beecham (Project Leader / Task 1 Leader)	Climate Change Projections for South Australia	Goyder Institute Annual Water Forum 2012 Adelaide
28-29 May 2012	Wenju Cai (Task 2 Leader)	The three-headed dog of Australian climate (the IOD, ENSO, and the SAM), its tail (the subtropicalridge), and the elephant in the room (autumn rainfall reduction)	Goyder Institute Annual Water Forum 2012, Adelaide
29 May 2012	Freddie Mpelasoka	Climate Change *Development of an agreed set of climate projections for South Australia*	Regional Climate Programs Workshop in Canberra
26-28 June, 2012	Simon Beecham (Project Leader / Task 1 Leader)	Analysis of Spatial Rainfall Patterns in South Australia (SA) Between 2000 and 2010	NCCARF Climate Adaptation in Action Conference – Sharing knowledge to adapt, Melbourne
8-11 July 2012	John Boland	Reconciling rainfall modelling on differing timescales	25th European conference on Operational Research, 8-11 July 2012, Vilnius, Lithuania.
8-11 July 2012	Julia Piantadosi	Mathematical methods for rainfall modelling	25th European conference on Operational Research, 8-11 July 2012, Vilnius, Lithuania.
10-12 July, 2012	Simon Beecham (Project Leader / Task 1 Leader) **Keynote Paper**	Water Sensitive Urban Design for Today's and Future Climates,	5th ENCON: Engineering Towards Change - Empowering Green Solutions, Kuching, Malaysia
10-12 July, 2012	Simon Beecham (Project Leader / Task 1 Leader) **Invited Presentation**	Assessing the evidence of climate change in South Australia (SA) from 1950 to 2010	5th ENCON: Engineering Towards Change - Empowering Green Solutions, Kuching, Malaysia

Date	Presenter	Topic	Audience/Location
13-17 August 2012	Evan Weller	Performance of the CMIP5 Models in Representing the IOD Precipitation Teleconnection to Australia and Its Asymmetry: Implications for Future Climate Changes	AOGS - AGU (WPGM) Joint Assembly 2012, Singapore
13-17 August 2012	Tim Cowan	Teleconnection Pathways of ENSO and the IOD: the driver of cool season variations in extratropical Australian rainfall	AOGS - AGU (WPGM) Joint Assembly 2012, Singapore
3-7 September, 2012	Wenju Cai (Task 2 Leader)	Modulation of the Pacific Decadal Oscillation on the nonlinearity of an ENSO-rainfall teleconnection	Qingdao, China
11 September 2012	Mark Thyer	Towards Robust Predictions of Hydrological Impacts of Climate Change: The Bayesian Total Error Approach.	International Conference on Climate, Water and Policy (ICCWP) 2012, Busan, Republic of Korea 11-13 Sep 2012
25-27 September, 2012	Seung-Ki Min	Influence of climate variability on seasonal extremes over Australia	ARC Centre of Excellence Climate System Science Annual Workshop, Hobart
29 September, 2012	Wenju Cai (Task 2 Leader)	Argo profiles nonlinear feedback processes associated with the Indian Ocean Dipole	4th Argo Science Workshop Venice
3-7 December 2012	Seung-Ki Min	Multi-model attribution of the Southern Hemisphere Hadley cell widening: CMIP3 and CMIP5 models.	AGU Fall Meeting, San Francisco, USA
3-7 December 2012	Evan Weller	Realism of the Indian Ocean Dipole in CMIP5 models: the implication for climate projections	AGU Fall Meeting, San Francisco, USA
6-9 December 2012	Simon Beecham (Project Leader / Task 1 Leader) **Invited Presentation**	Analysis of extreme rainfall intensities in South Australia / Evidence for changes in daily rainfall extremes in South Australia	UrbanRain12: 9th International Workshop on Precipitation in Urban Areas
6 February 2013	Shern Ahamed	Rainfall modelling	Australian and New Zealand Industrial and Applied Mathematics ANZIAM Conference, Newcastle, NSW
13 February 2013	Ariaan Purich	Weather from ozone hole variations	AMOS National Conference
1 March 2013	Ariaan Purich	Weather from ozone hole variations	WCRP workshop on ozone and climate, Argentina
6 March	Tim Cowan	Atmospheric blocking and impacts on Southern Australian climate	Second Chinese Academy of Sciences-CSIRO joint meeting, Canberra, ACT

Date	Presenter	Topic	Audience/Location
23 March 2013	Tim Cowan **Invited Presentation**	Weather Systems - Impacts on the Australian Agricultural Industry	API Rural Queensland Conference, Toowoomba, Qld
20 April 2013	Mohammad Kamruzzaman	Community based adaptation to Climate Change	Panel list- water session "Community based adaptation to Climate Change conference, 18-25th April 2013, Dhaka, Bangladesh
26 June 2013	Evan Weller	IOD teleconnection in CMIP5	AOGS2013 conference, Brisbane
25 June 2013	Mohammad Kamruzzaman	Analysis of trends in rainfall extremes in South Australia	10th Asia Oceania Geosciences Society (AOGS) conference, 24-28th June 2013, Brisbane, Australia
01-04 July 2013	John Boland	Rainfall modelling	26th EURO – INFORMS Joint International Conference
01-04 July 2013	Julia Piantadosi **Invited Special Stream**	Special Stream – Decision Making under Uncertainty and Environmental Applications	26th EURO – INFORMS Joint International Conference
8-12 July 2013	Julia Piantadosi **Invited Special Session**	Special Session – Environmental Modelling (ANZIAM)	Mathematics for Planet Earth Conference 2013 with a focus on understanding Climate variability and change and the challenges of communicating the reality of climate change.
9 July, 2013	Graham Green (Task 4 Leader) **Invited presentation**	Climate Change Project and about the integration of the results into Government policy	Sri Lankan delegation, Adelaide SA
1-6 December 2013	Mohammad Kamruzzaman	Atmospheric PM10 dispersion in the South Australian region / Quantify the rainfall extremes in the South Australia	**20th International Congress on Modelling and Simulation** (**MODSIM2013**) Adelaide, SA
1-6 December 2013	Evan Weller	Realism of Climate Modes in CMIP5 models: the implication for climate projections	**MODSIM 2013,** Adelaide, SA
1-6 December 2013	Ariaan Purich	Autumn precipitation trends over southern Australia and other Southern Hemisphere midlatitude regions as simulated by CMIP5 models	**MODSIM 2013,** Adelaide, SA
1-6 December 2013	Simon Beecham (Project Leader / Task 1 Leader) **Invited Session**	Modelling of extreme rainfall in South Australia using a generalized linear model.	**MODSIM 2013,** Adelaide, SA

Date	Presenter	Topic	Audience/Location
1-6 December 2013	Shern Ahamed	Generating synthetic rainfall using a disaggregation model	**MODSIM 2013,** Adelaide, SA
1-6 December 2013	John Boland	The Interplay Between Rainfall and Vegetation**.**	**MODSIM 2013,** Adelaide, SA
1-6 December 2013	Graham Green (Task 4 Leader)	Reconciling surface and groundwater models in a climate change context	**MODSIM 2013,** Adelaide, SA
1-6 December 2013	Leon van der Linden	Suitability of a coupled hydrodynamic water quality model to predict changes in water quality from altered meteorological boundary conditions	**MODSIM 2013,** Adelaide, SA
1-6 December 2013	Seth Westra	A strategy for diagnosing and interpreting hydrologic non-stationarity / Quantifying the uncertainty of streamflow projections under a future climate	**MODSIM 2013,** Adelaide, SA
13-14 February 2014	Simon Beecham (Project Leader / Task 1 Leader)	Climate Change	South Australian Climate Change Adaptation Showcase 2014, RiAUS, Exchange Place, Adelaide, SA
5 May 2014	Tim Cowan	Future projections (of heat waves) from the CMIP5 models – can we prepare for the very long-term future	Australian Heat wave workshop, UNSW, Sydney
8 September 2014	Simon Beecham (Project Leader / Task 1 Leader) **Keynote Paper**	Developing Resilient Green Infrastructure for Urban Environments	13th International Conference on Urban Drainage (13ICUD), Kuching, Malaysia
23 September 2014	Simon Beecham (Project Leader / Task 1 Leader) **Invited Presentation**	Assessing Changes in Daily Rainfall Extremes in South Australia	19th IAHR-APD Congress 2014, Hanoi, Vietnam
3 September 2015	Simon Beecham (Project Leader / Task 1 Leader) **Inaugural Bob Such Keynote Address**	Climate Resilient Street Trees – Green Infrastructure of the Future	15th Australian National Street Tree Symposium, Adelaide

Appendix C – Project Fact Sheets

The following three fact sheets describing the outputs of this project in simple terms are provided at the end of this report.

1. Accounting for Climate Change in water management practices in South Australia
2. Understanding the key drivers of climate change in South Australia: Influence of SOI, DMI and Niño3.4 on South Australian Rainfall
3. Rainfall reductions over Southern Hemisphere semi-arid regions, including southeast Australia: the role of subtropical dry zone expansion.

Additional fact sheets are currently being prepared by the Goyder Institute for Water Research.

Appendix D – Model Metadata Templates

A number of Goyder Institute projects have used or modified or developed models. In order to maximise their use by future users, Model Metadata Templates have been developed to: provide an overview of the model, list the model owner and team members, provide details of the storage of the model and associated data identify any dependencies (i.e. other models or essential data), permission requirements or licenses that may be needed to use the model.

For further information on any of the models listed refer to the owner's contact details on the Templates.

Climate Projections Project

The following Climate Projections Project Model Metadata Templates are available on the Goyder Institute for Water Research website: www.goyderinstitute.org

- Regional Climate Change Downscaling
- Onkaparinga Runoff Model
- Agricultural Production Systems Simulator (APSIM) Model
- Cox Creek Groundwater Model
- Multi-Variate Non-homogeneous Hidden Markov Model (MVNHMM)
- Multivariate Daily Weather (non-rainfall) Generator

Appendix E – Simulation files

All of the simulation files used to produce the projection results are freely available, unsupported, for further use by others. Currently they are available via a (temporary) ftp repository, and access details can be obtained from the first author. Note that the observed weather data used in downscaling model calibration cannot be provided as the PPD is a commercial, licensed product (https://www.longpaddock.qld.gov.au/silo/ppd/index.php). A more permanent home for the projection files is to be determined, either hosted by the CSIRO Data Access Portal (https://data.csiro.au/dap/) or the Goyder Institute for Water Research (http://goyderinstitute.org).

Appendix F – Milestones

Table F1. Climate Projections Project Milestones for each Task

Task	Milestone Number	Milestone Description	Participant Recipient	Start Date	Delivery Date
Task 5	5.1.a	Project Management (upfront payment)	Uni of SA	Jan-11	Jan-11
Task 1	1.1.a	Understanding SA Climate (commencement)	Uni of SA	Mar-11	Mar-11
Task 1	1.1.b	Understanding SA Climate (completion)	Uni of SA	Mar-11	Aug-11
Task 1	1.1.a	Understanding SA Climate (commencement)	CSIRO	Mar-11	Mar-11
Task 1	1.1.b	Understanding SA Climate (completion)	CSIRO	Mar-11	Aug-11
Task 1	1.1.a	Understanding SA Climate (commencement)	Flinders	Mar-11	Mar-11
Task 1	1.1.b	Understanding SA Climate (completion)	Flinders	Mar-11	Aug-11
Task 1	1.2.a	Detecting and attributing SA climate changes (commencement)	Uni of SA	Jul-11	Jul-11
Task 1	1.2.b	Detecting and attributing SA climate changes (completion)	Uni of SA	Jul-11	Jun-12
Task 1	1.2.a	Detecting and attributing SA climate changes (commencement)	CSIRO	Jul-11	Jul-11
Task 1	1.2.b	Detecting and attributing SA climate changes (completion)	CSIRO	Jul-11	Jun-12
Task 1	1.3.a	Benchmarking models for projecting SA Climate (commencement)	Uni of SA	Jul-12	Jul-12
Task 1	1.3.b	Benchmarking models for projecting SA Climate (completion)	Uni of SA	Jul-12	Oct-14
Task 1	1.3.a	Benchmarking models for projecting SA Climate (commencement)	CSIRO	Jul-12	Jul-12
Task 1	1.3.b	Benchmarking models for projecting SA Climate (completion)	CSIRO	Jul-12	Jun-14
Task 3	3.1.a	Evaluate/benchmark the downscaling techniques (commencement)	Uni of SA	Jan-11	Jan-11
Task 3	3.1.b	Evaluate/benchmark the downscaling techniques (completion)	Uni of SA	Jan-11	Jun-12
Task 3	3.2.a	Select GCMs for use in statistical downscaling (commencement)	Uni of SA	Jul-11	Jul-11
Task 3	3.2.b	Select GCMs for use in statistical downscaling (completion)	Uni of SA	Jul-11	Jun-12
Task 3	3.3.a	Improve the downscaling techniques (commencement)	Uni of SA	Jan-12	Jan-12
Task 3	3.3.b	Improve the downscaling techniques (completion)	Uni of SA	Jan-12	Oct-14
Task 3	3.1.a	Evaluate/benchmark the downscaling techniques (commencement)	CSIRO	Jan-11	Jan-11
Task 3	3.1.b	Evaluate/benchmark the downscaling techniques (completion)	CSIRO	Jan-11	Jun-12
Task 3	3.2.a	Select GCMs for use in statistical downscaling (commencement)	CSIRO	Jul-11	Jul-11
Task 3	3.2.b	Select GCMs for use in statistical downscaling (completion)	CSIRO	Jul-11	Jun-12
Task 3	3.3.a	Improve the downscaling techniques (commencement)	CSIRO	Jul-12	Jul-12
Task 3	3.3.b	Improve the downscaling techniques (completion)	CSIRO	Jul-12	Sep-14
Task 2	2.1.a	Develop system for benchmarking climate models (commencement)	CSIRO	Jan-11	Jan-11
Task 2	2.1.b	Develop system for benchmarking climate models (completion)	CSIRO	Jan-11	Jun-12
Task 2	2.2.a	AR5 models most suitable for downscaling & projection (commencement)	CSIRO	Jul-12	Jul-12
Task 2	2.2.b	AR5 models most suitable for downscaling & projection (completion)	CSIRO	Jul-12	Jun-13
Task 2	2.3.a	Examine mean climate change over SA (commencement)	CSIRO	Jul-13	Jul-13
Task 2	2.3.b	Examine mean climate change over SA (completion)	CSIRO	Jul-13	Jun-14
Task 2	2.4.a	Interpret modelled climate conditions (commencement)	CSIRO	Jul-13	Jul-13
Task 2	2.4.b	Interpret modelled climate conditions (completion)	CSIRO	Jul-13	Jun-14
Task 4	4.1.a	Review/selection of models for case study catchments (commencement)	Uni of Adelaide	Jan-11	Jan-11
Task 4	4.1.b	Review/selection of models for case study catchments (completion)	Uni of Adelaide	Jan-11	Dec-11
Task 4	4.1.a	Review/selection of models for case study catchments (commencement)	AWQ	Jan-11	Jan-11
Task 4	4.1.b	Review/selection of models for case study catchments (completion)	AWQ	Jan-11	Dec-11

Task 4	4.1.a	Review/selection of models for case study catchments (commencement)	SARDI	Jan-11	Jan-11
Task 4	4.1.b	Review/selection of models for case study catchments (completion)	SARDI	Jan-11	Dec-11
Task 4	4.1.a	Review/selection of models for case study catchments (commencement)	Flinders	Jan-11	Jan-11
Task 4	4.1.b	Review/selection of models for case study catchments (completion)	Flinders	Jan-11	Dec-11
Task 4	4.2.a	Develop processes to evaluate parameter consistency (commencement)	Uni of Adelaide	Jul-11	Jul-11
Task 4	4.2.b	Develop processes to evaluate parameter consistency (completion)	Uni of Adelaide	Jul-11	Jun-12
Task 4	4.2.a	Develop processes to evaluate parameter consistency (commencement)	AWQ	Jul-11	Jul-11
Task 4	4.2.b	Develop processes to evaluate parameter consistency (completion)	AWQ	Jul-11	Jun-12
Task 4	4.2.a	Develop processes to evaluate parameter consistency (commencement)	SARDI	Jul-11	Jul-11
Task 4	4.2.b	Develop processes to evaluate parameter consistency (completion)	SARDI	Jul-11	Jun-12
Task 4	4.2.a	Develop processes to evaluate parameter consistency (commencement)	Flinders	Jul-11	Jul-11
Task 4	4.2.b	Develop processes to evaluate parameter consistency (completion)	Flinders	Jul-11	Jun-12
Task 4	4.3.a	Evaluate hydrological performance of the downscaling (commencement)	Uni of Adelaide	Jul-12	Jul-12
Task 4	4.3.b	Evaluate hydrological performance of the downscaling (completion)	Uni of Adelaide	Jul-12	Jun-13
Task 4	4.3.a	Evaluate hydrological performance of the downscaling (commencement)	AWQ	Jul-12	Jul-12
Task 4	4.3.b	Evaluate hydrological performance of the downscaling (completion)	AWQ	Jul-12	Jun-13
Task 4	4.3.a	Evaluate hydrological performance of the downscaling (commencement)	SARDI	Jul-12	Jul-12
Task 4	4.3.b	Evaluate hydrological performance of the downscaling (completion)	SARDI	Jul-12	Jun-13
Task 4	4.3.a	Evaluate hydrological performance of the downscaling (commencement)	Flinders	Jul-12	Jul-12
Task 4	4.3.b	Evaluate hydrological performance of the downscaling (completion)	Flinders	Jul-12	Jun-13
Task 4	4.4.a	Run the models for the case study catchments (commencement)	Uni of Adelaide	Jul-13	Jul-13
Task 4	4.4.b	Run the models for the case study catchments (completion)	Uni of Adelaide	Jul-13	Oct-14
Task 4	4.4.a	Run the models for the case study catchments (commencement)	AWQ	Jul-13	Jul-13
Task 4	4.4.b	Run the models for the case study catchments (completion)	AWQ	Jul-13	Oct-14
Task 4	4.4.a	Run the models for the case study catchments (commencement)	SARDI	Jul-13	Jul-13
Task 4	4.4.b	Run the models for the case study catchments (completion)	SARDI	Jul-13	Oct-14
Task 4	4.4.a	Run the models for the case study catchments (commencement)	Flinders	Jul-13	Jul-13
Task 4	4.4.b	Run the models for the case study catchments (completion)	Flinders	Jul-13	Oct-14

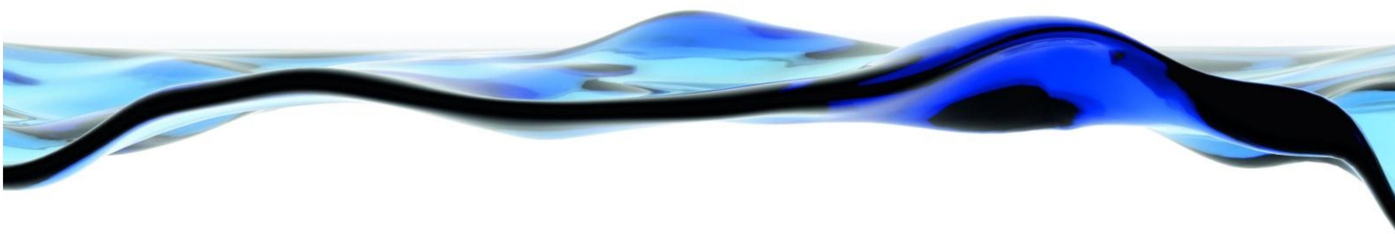
Appendix G – Project Management

Due to the large number of project partners located in various cities around Australia, it was necessary to implement a high level of overall project management and coordination within the Climate Projections Project Team (Refer to Table 1 in Section Project Team), as well as to the Goyder Institute for Water Research and the number of Stakeholders.

Through this project, the research team has developed a collaborative working arrangement involving consultative workshops and a strong interaction between State Government agencies and the partner research organisations including regular meetings, workshops, published update documents and formal progress reports.

The project management group consists of Simon Beecham and Julia Piantadosi from the University of South Australia. The project management group has assisted in preparing agenda, management reports and minutes for Steering and Technical Committees and have assembled financial reports to track progress of the project against expenditure, research effort logging and quarterly reporting. The progress meeting and workshop meeting minutes and presentation slides are available on the SharePoint. Goyder Institute Climate Projections Project Scientific Advisory Committee Members for 2013-2014 were: Graeme Pearman (Chair): Independent Advisor; Simon Beecham: Program Leader, Goyder Institute Climate Change Program; David Post: Program Director, South East Australia Climate Initiative; Darren Ray: Bureau of Meteorology, South Australian Regional Office.

There was a small increase in project funds for Project Management to support the activities that were identified in the Mid-term Review. The funds were expended on meetings and workshops with State Government; expansion of the current communications plan with advice from communications experts and policy officers; development of a risk management framework to relate the outcomes of this project to adaptation strategies in the State; faster delivery of a set of interim climate projections; and identification of leading stories and preparation of fact sheets.



The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.