IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES

PHASE 3 VOLUME 4

SOUTH AUSTRALIAN ARID LANDS NATURAL RESOURCES MANAGEMENT REGION

2013/06

Government of South Australia
Department of Environment, Water and Natural Resources

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Matt Gibbs, Darren Alcoe and Graham Green

Science, Monitoring and Knowledge Branch
Department of Environment, Water and Natural Resources

March 2013

DEWNR Technical Report 2013/06

Science, Monitoring and Knowledge Branch
Department of Environment, Water and Natural Resources
25 Grenfell Street, Adelaide
GPO Box 1047, Adelaide SA 5001

Telephone	National	(08) 8463 6946
	International	+61 8 8463 6946
Fax	National	(08) 8463 6999
	International	+61 8 8463 6999
Website	www.environment.sa.gov.au	

ISBN 978-1-921923-73-9

Preferred way to cite this publication
Gibbs, M, Alcoe, D, and Green, G, 2012, *Impacts of Climate Change on Water Resources Phase 3 Volume 4: South Australian Arid Lands Natural Resources Management Region,* DEWNR Technical Report 2013/06, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide

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FOREWORD

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector and that the best skills and expertise are used to inform decision making.

Allan Holmes
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES

ACKNOWLEDGEMENTS

The authors would like to thank Dr Justin Costelloe of the University of Melbourne, for making his model of the Neales-Peake catchment available for use in this study, and for his assistance in running the model scenarios.

CONTENTS

CONTENTS

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The Department for Water's *Impacts of Climate Change on Water Resources* (ICCWR) project has undertaken an analysis of groundwater recharge, surface water runoff and rainfall intensity data in the South Australian Arid Lands Natural Resources Management (SAALNRM) Region to determine the potential impact of climate change on the principal water resources of the region.

This report is presented as Volume 4 of Phase 3 of the ICCWR project, with the intention that reports of similar analyses of other natural resource management regions in South Australia will comprise further volumes as the project progresses. Phases 1 and 2 of the ICCWR project reported on precursors to the detailed data-analysis phase, respectively the first-order risk assessment and prioritisation of South Australia's water resources for climate change impact assessment and the selection of future climate change projections and downscaling methodology.

While the climate downscaling methodology is retained in the SAALNRM Region study, a new approach for selecting a suite of Global Climate Models (GCMs) has been adopted that is based on CSIRO's Climate Futures Framework (Clarke *et al*., 2011). Suppiah *et al*. (2006) identified 11 GCMs that were best suited to projections of South Australian climate and these were used, in addition to the CSIRO Mark 3.5 GCM, in the Climate Futures analysis for the SAALNRM Region. The Climate Futures analysis aided in identifying the 'most-likely', 'best' and 'worst-case' projections. From the analysis of 12 GCMs, three were selected to represent these cases.

The climate and groundwater recharge processes of the arid areas of the SAALNRM Region differ from the semi-arid and temperate areas of South Australia. Furthermore, limited rainfall and groundwater level data are available across the non-prescribed areas of the SAALNRM Region. Consequently, an analysis of rainfall metrics was adopted to determine the potential impact of climate change on the capacity of the region's groundwater resources. This approach is markedly different to the application of numerical hydrological models of groundwater processes, which was undertaken in earlier ICCWR assessments of the more southerly regions of South Australia.

The rainfall metrics selected for the SAALNRM Region assessment were the change in:

- annual average rainfall, as an indicator of the overall projected change
- the first percentile daily rainfall, as an indicator of the change in the intensity of extreme rainfall events
- the frequency of rainfall events of greater than 100mm/month, as an indicator of episodic large rainfall events that generate groundwater recharge in the arid north of the region.

Regional climate data for the period 1975–2004 were used as the historic climate baseline for the downscaling of projections of climate variables. Projected changes in annual average rainfall, first percentile rainfall and frequency of months with greater than 100 mm rainfall compared to the baseline period were calculated for each cell on a regular grid across the study area. This process was undertaken for climate change scenarios for projected climates of 2030, 2050 and 2070 with high (A2) and low (B1) emission cases. Results of the analysis indicate the likely changes in each rainfall metric, for each future scenario.

When results are averaged across the whole SAALNRM Region, the GCM selected to represent the 'most-likely' future climate case projected that decreases in average annual rainfall are likely to range from 5–6% in a 2030 climate with either high or low emissions scenarios, and up to 15% in a 2070 climate with a high-emission scenario.

SUMMARY

Reductions in the magnitude of extreme rainfall events (i.e. the first percentile daily rainfall), compared to the 1990 historic baseline period, are projected for both the 'worst' and 'most-likely' future climate cases for both high and low emissions scenarios. However, the 'best' future climate case indicates small increases in annual average and first percentile rainfall, for both high and low-emissions scenarios. Similarly, a reduction in the frequency of rainfall events that are expected to lead to recharge (months of rainfall greater than 100 mm) is projected for the 'most-likely' and 'worst' futures climate cases, whilst the 'best' case suggests that there may be an increase. However, these projected increases and reductions are highly variable spatially due to the very low frequency of months with rainfall greater than 100 mm in much of the region – in some cases less than once every 10 years on average. In the north of the region, where these large, recharge-generating rainfall events are the most frequent, the frequency of these events is projected (using the 'most-likely' GCM climate projection) to decrease by 21% under a low-emissions scenario for 2030 and by 47% under a high-emissions scenario for 2070.

Numerical modelling of the impacts of these future climate scenarios on flows in the Neales river catchment indicates an approximately 2:1 relationship between the changes in annual average surface water runoff rates compared to changes annual rainfall. For the episodic flow events typical of the Neales River catchment, the average annual runoff is not a particularly informative measure of changes in the catchments. Rather, it is the time between these episodic events that is important for the ecological health of waterholes. Further surface water modelling results suggest that the relationship between rainfall and dry periods is close to one-to-one, where a 1% reduction in rainfall leads to an increase in the average length of dry periods by approximately 1%.

It is unlikely that climate change impacts on groundwater recharge occurring to the Great Artesian Basin (GAB) in South Australia will cause a reduction in availability of GAB groundwater, however an increase is possible if the wetter or 'best-case' future climate scenarios eventuate. The impacts of climate change on recharge that occurs at the eastern side of the GAB, primarily in Queensland, may result in significant positive or negative impacts on aquifer pressures in the western GAB in South Australia.

1. INTRODUCTION

1.1. PROJECT BACKGROUND

Climate change is acknowledged as a potential threat to the future of South Australia's water security. The State's Water for Good plan identifies climate change as a major challenge to water resources in most of South Australia's Natural Resources Management (NRM) regions.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology (BoM) have previously undertaken investigations which project the likely impacts of climate change on South Australia (Suppiah et al., 2006; CSIRO & BoM, 2007). Their projections indicate that through the 21st century, South Australia may be subject to:

- increased temperatures
- reduced rainfall
- increased rainfall variability
- increased evaporation
- significantly increased frequency and severity of drought
- changes in the frequency of extreme weather events, including flooding.

Of immediate concern to South Australia will be the impacts of decreased rainfall and its increased variability. Along with higher temperatures, which increase potential evaporation, the combined impacts may have significant consequences for the State's natural water resources. With projected impacts of climate change leading to a generally drier outlook, the State may face reduced availability and increased risk to water resources that are of strategic and economic importance.

The Department for Environment, Water and Natural Resources (DEWNR) project *Impacts of Climate Change on Water Resources* (ICCWR) was established in 2010 under the New Knowledge for the Future component of DEWNR's Groundwater Program. The Groundwater Program addresses Target 75 of South Australia's Strategic Plan 2011 which requires that "South Australia's water resources are managed within sustainable limits by 2018".

The studies conducted by the ICCWR project will ultimately fulfil Action 43 of the Water for Good plan: "Commission, where required, regional scale studies on the Impacts of Climate Change on Water Resources".

The NRM Plan of the SAALNRM Region (SAALNRMB, 2010) identifies impacts of climate change as a key risk factor to surface water and groundwater resources and to the biodiversity of the region. Some pest species may also be advantaged by the impacts of climate change. One of the SAALNRM Board's strategic directions is to "…investigate potential implications of climate change for water resources management in the SAAL NRM Region". The NRM Plan suggests that adaptive management strategies and risk assessment processes are approaches that might aid in water resources management under a variable or changing climate.

1.2. PREVIOUS WORK

This report is preceded by five related reports that have been completed by the ICCWR project. To enable the evaluation of climate change impacts on groundwater resources, a key foundation task was to identify the most appropriate climate change projections for use in these studies and to develop a method to downscale these projections to create 'future climate' data sets that are representative of each study area location. This task was undertaken by the ICCWR project team and is described in the report *Impacts of Climate Change on Water Resources, Phase 2: Selection of Future Climate Projections and Downscaling Methodology* (Gibbs et al., 2011). However, while the downscaling methodology is retained in this study, a different approach for selecting a suite of Global Climate Models (GCMs) has been adopted that is based on CSIRO's Climate Futures Framework (Clarke et al., 2011), which is discussed in Sect.3.1.

Two earlier reports on the impacts of climate change on water resources in the Northern and Yorke NRM region (Green *et al*., 2011) and the Eyre Peninsula NRM Region (Green *et al*., 2012) presented the results of numerical modelling of groundwater recharge and surface water runoff under a range of future regional climate scenarios. The report *Impacts of Climate Change on Water Resources Phase 3 Volume 3: Alinytjara Wilur̲ara Natural Resources Management Region* (Alcoe *et al*., 2012), published in July 2012, followed a similar structure, with the same climate downscaling methods applied to the region. However, numerical models of recharge were not developed in this study due to a paucity of the field data required for model calibration. Instead, this study focussed on identifying changes in the frequency and magnitude of extreme rainfall events, which are understood to govern groundwater recharge in the arid areas of the Alinytjara Wilur̲ara Natural Resources Management (AWNRM) Region. The current study adopts the same modelling approach as used in the AWNRM Region, using climate metrics to infer likely changes in groundwater recharge. This climate metrics approach is based on evidence that in areas with an arid climate similar to the SAALNRM and AWNRM Regions (e.g. central Australia's Ti Tree Basin (Harrington, Cook & Herczeg, 2002) and Lake Eyre (Tweed et al., 2011)), groundwater recharge occurs only after periods of extreme local rainfall, typically of greater than 100–200 mm/month.

1.3. AIMS AND OBJECTIVES

The objective of the SAALNRM Region study is to provide, for water planning and adaptation policy purposes, an understanding of the likely changes to groundwater resource capacity specific to the region under a range of possible future climate scenarios. With some exceptions, the amount of water that is available from groundwater resources for cultural and environmental water provisions and human water uses is dictated by the volume of runoff and groundwater recharge. This study was focussed on (1) the intensity and frequency of extreme rainfall events as these are likely to be the principal drivers of recharge and therefore determine the capacity of the groundwater resources; and (2) climate change impacts on runoff in the Neales-Peake catchment.

It is not the intention of this study to provide a guide to the most likely climate change scenarios, nor to predict what changes in climate will occur. Rather, the intention has been to adopt an approach wherein the climate change projections of a range of existing GCMs are applied to (1) rainfall intensity and frequency analyses that indicate possible changes in the frequency and magnitude of recharge events; and (2) a distributed runoff model, implemented over a 5 km x 5 km grid, which uses daily rainfall and evaporation inputs and simulates runoff across the catchment.

The objective of the study was achieved by completing five key activities:

1. Review water resources studies conducted in the SAALNRM Region and also in similar arid environments.
2. Identify the 'most-likely', 'best' and 'worst' case climate projections and the selection of a suite of GCMs to represent each of these cases using the Climate Futures Framework.
3. Conduct downscaling of climate data to produce region-specific projections of changes in daily rainfall.

4. Analyse the changes in the frequency and magnitude of extreme rainfall events in projected future climate scenarios to provide a guide to potential future changes to the capacity of groundwater resources of the region.
5. Conduct modelling to project the potential changes in average annual and summer rainfall and runoff for the Neales-Peake catchment.
6. Develop projections of changes in the elapsed time between episodic rainfall-runoff events for the Neales-Peake catchment, which is likely to have impact on waterhole water levels and the biota that rely on them.

A large part of the north of the SAAL NRM region is occupied by the Far North Prescribed Wells Area (FNPWA). This area is a prescribed primarily for the purpose of managing the groundwater resources of the confined aquifers within the South Australian part of the Great Artesian Basin (GAB).

The GAB aquifer system is of very large extent, occurring across four states, with recharge occurring mainly at its eastern and north eastern margins in Queensland and New South Wales. The capacity of the GAB as a water resource is largely dependent on the amount of groundwater in storage in the system and flowing across the state border from the east, rather than on recharge occurring in South Australia. It is beyond the scope of this study to make quantitative projections of the impacts of 21st century climate change on recharge occurring in Queensland and New South Wales. However, a discussion is provided within this report of the GAB in South Australia, including its likely vulnerability to 21st century climate change, and recent research efforts to understand these possible changes.

2. THE SOUTH AUSTRALIAN ARID LANDS NATURAL RESOURCES MANAGEMENT REGION

The areal extent of the SAALNRM Region is greater than 520 000 km^2 and accounts more than 50% of the area of South Australia (Fig. 1). The Far North Prescribed Wells Area (FNPWA) was prescribed in 2003 in response to the need to eliminate wasteful water-use practices and to arrest decreasing water pressure in the Great Artesian Basin (GAB). The FNPWA covers around 315 000 km^2 of the SAALNRM Region.

The SAALNRM Region encompasses diverse arid landscapes. Granitic intrusions that form the rounded domes of the Gawler Ranges occur to the west, while the folded, faulted and uplifted mountain chains of the Flinders Ranges are found toward the east. Sandy and gibber stone deserts dominate the north.

2.1. SURFACE GEOLOGY

The surficial geology of the SAALNRM Region is diverse and includes dome-shaped granitic exposures and outcrop of Precambrian rock, gibber plains, tablelands, sandy plains and desert dunefields (Fig 2). In the early Cenozoic (~60–25 ma), the climate was far wetter than that of today, which led to the formation of extensive endorheic basins such as Lake Eyre in central northern South Australia. The Flinders Ranges is the largest mountain range in the state.

2.2. CLIMATE

The SAALNRM Region can be broadly described as having an arid climate. However, there are three distinct climate sub-zones within this broader arid zone (Fig. 3). Along the southern boundary of the study area, the climate is described as 'Arid Steppe Cold' (i.e. semi-arid). Further north, the climate shifts to 'Arid Desert Cold' and then to 'Arid Desert Hot'. These sub-zones have been delineated using the Köppen-Geiger climate classification system (Kottek *et al*., 2006), which is based on landscape signals of climate (particularly vegetation) and threshold values of mean annual precipitation and mean annual temperature.

Rainfall in the SAALNRM is typically less than 250 mm/y while evaporation may exceed 3500 mm/y (Fig. 4), resulting in the rapid evaporation of surface runoff. Consequently, heavy rainfall events are required for water to infiltrate the ground surface. Importantly, rain may not fall for several years in arid areas but intense rainfall can deliver total annual rainfall in a single event. Consequently, mean rainfall statistics are often misleading and care should be taken in their interpretation.

Climate statistics (Table 1) show that rainfall in the 'cold steppe' climate zone (e.g. Kimba and Yunta) is winter dominant, whereas rainfall in the 'hot desert' climate zone (e.g. Andamooka and Arkaroola) is summer dominant. Rainfall in the 'hot desert' zone becomes increasingly episodic and unpredictable with decreasing latitude.

Mean summer maximum temperatures across the SAAL Region range between 31–35°C (Table 1). Mean winter maximum temperatures range between 16–19°C, while sub-zero winter minima in the Arid Lands are common (Watt, Berens & Magarey, 2011).

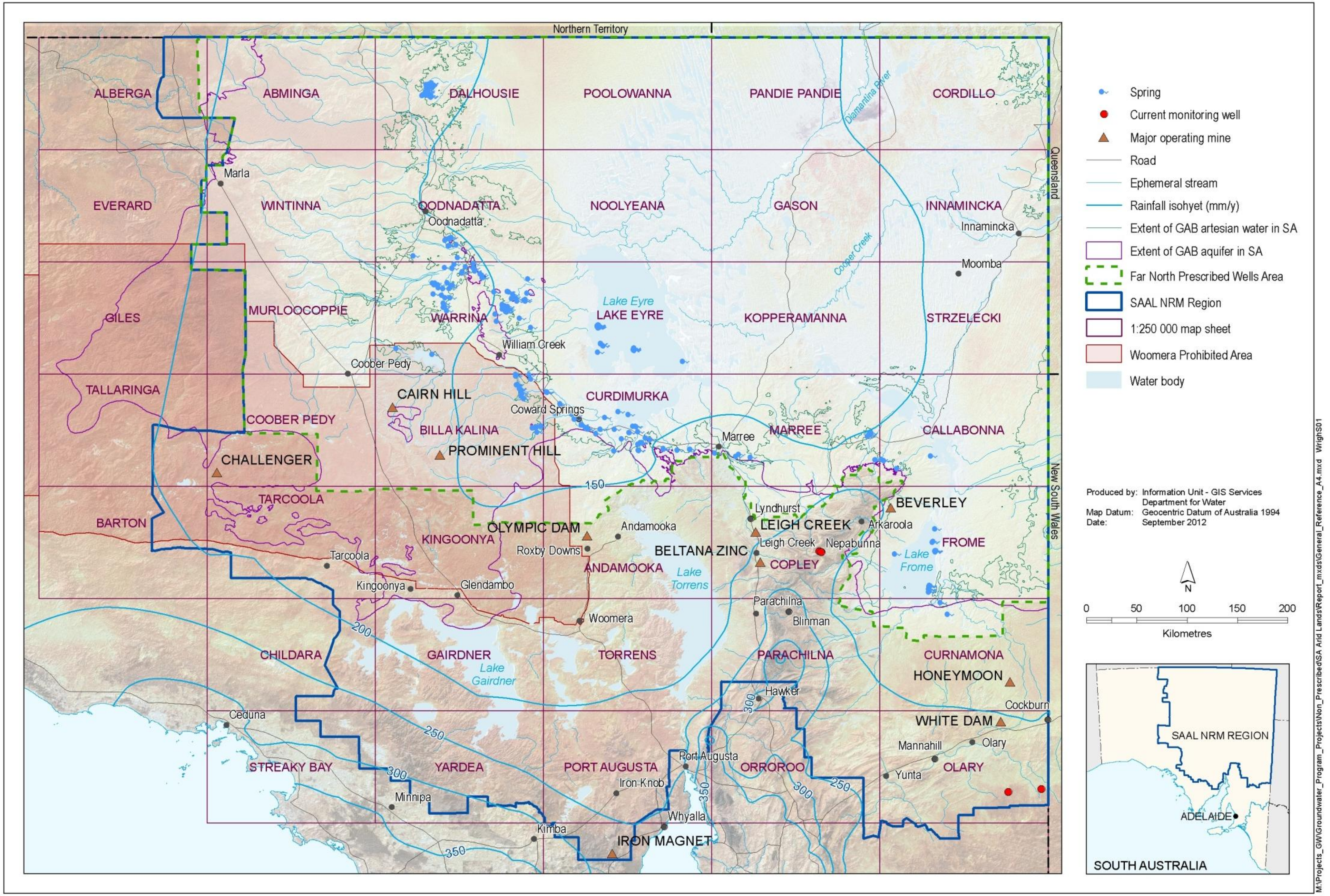

Figure 1. The South Australian Arid Lands Natural Resources Mannagement Region (Watt, Berens and Magarey, 2012)

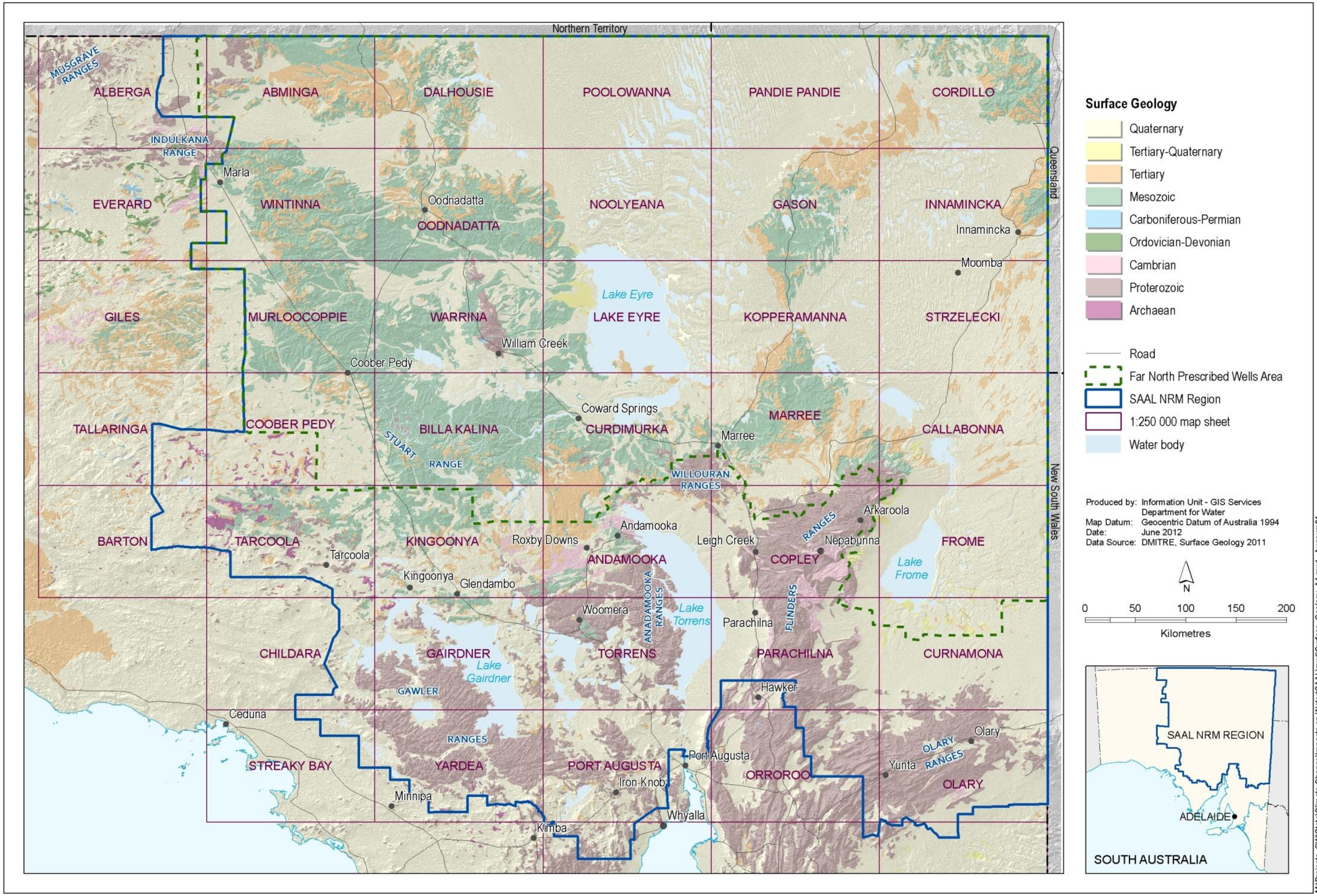

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Figure 2. Surface geology of the South Australian Arid Lands Natural Resources Mannagement Region (Watt, Berens and Magarey, 2012)

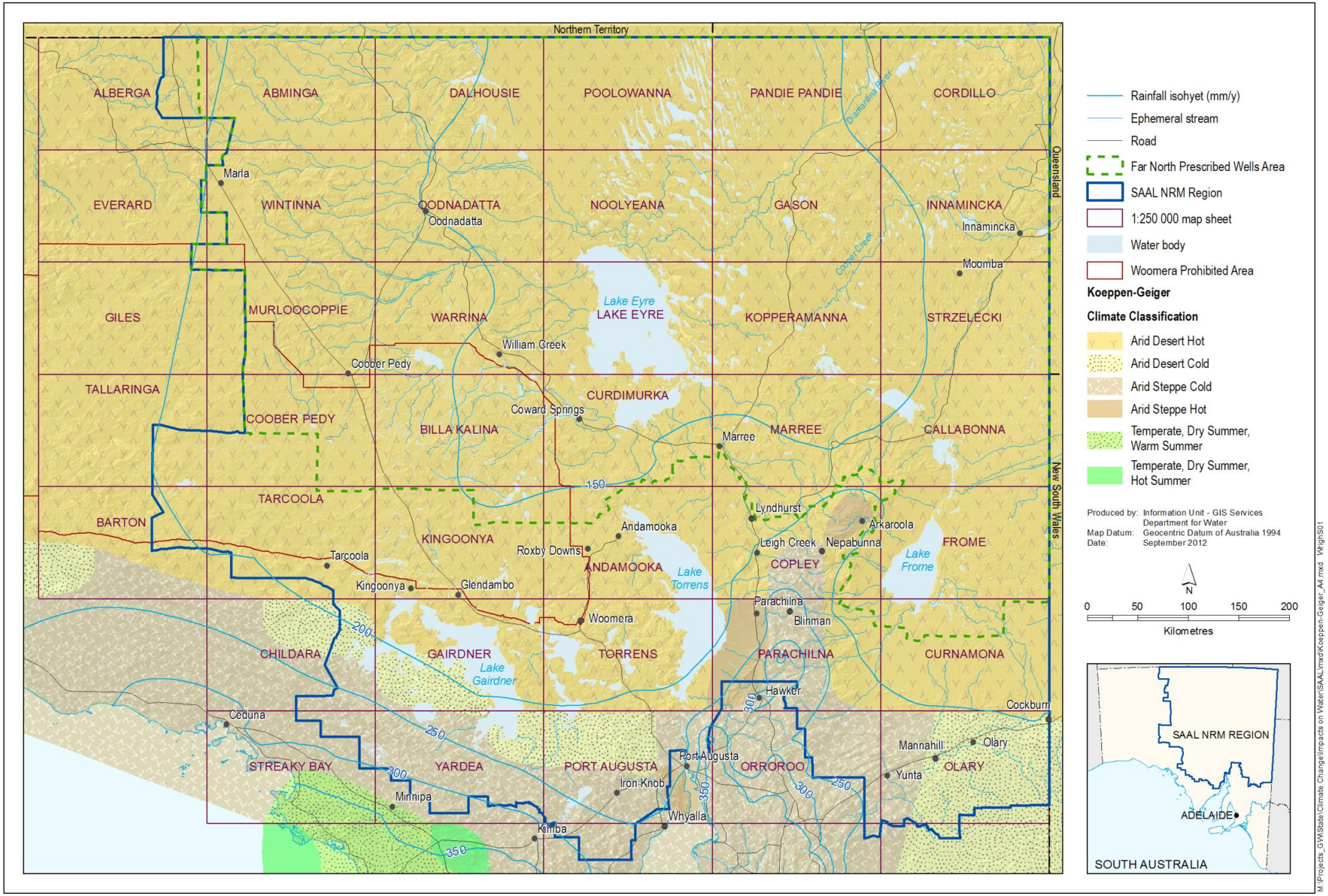


Figure 3. Climate zones based on the Koppen-Geiger climate classification system (Kottek *et al.*, 2006)

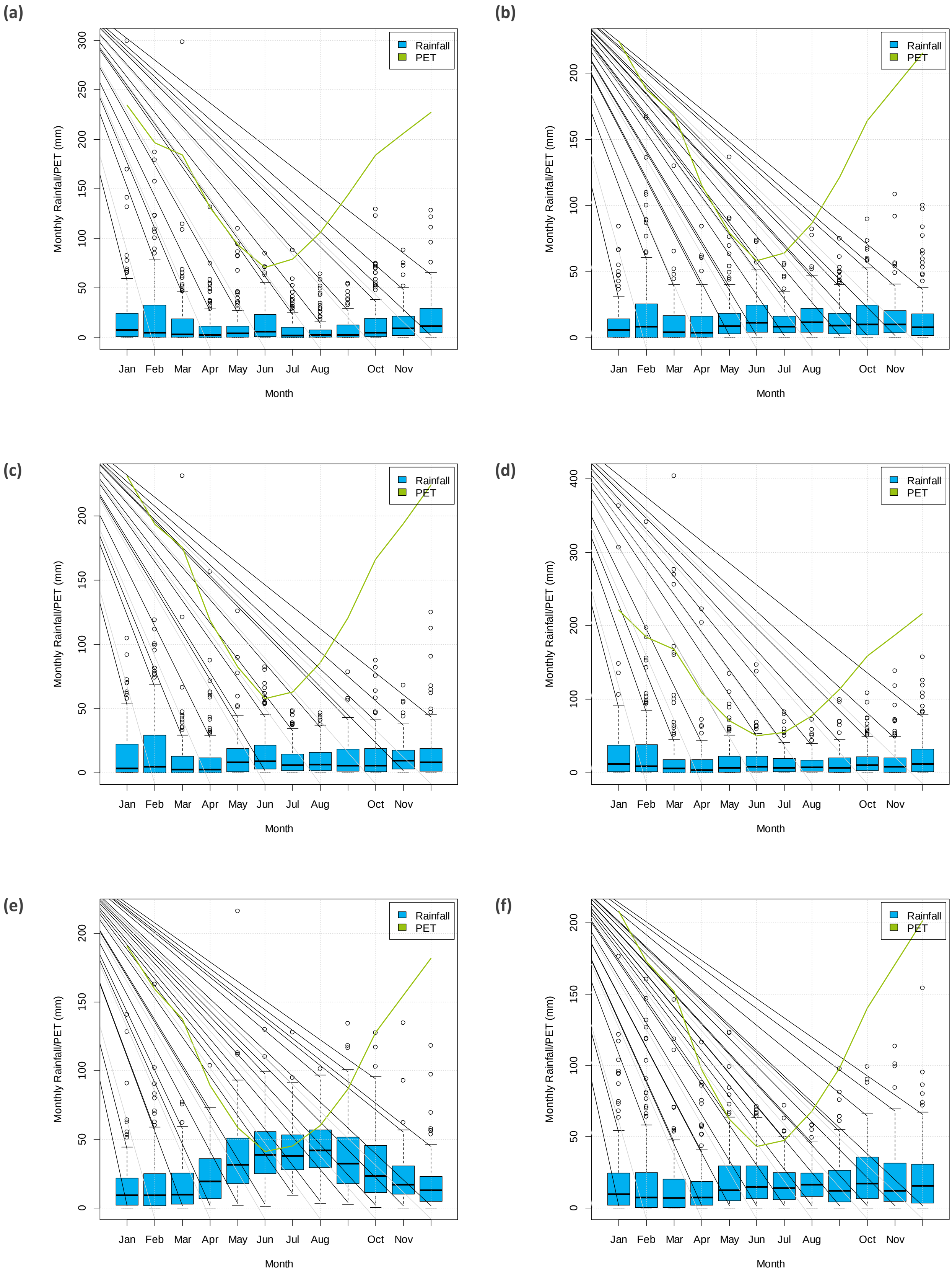


Figure 4. Monthly rainfall and potential evapotranspiration (PET) at the BoM rainfall stations (a) Marla; (b) Tarcoola; (c) Andamooka; (d) Arkaroola; (e) Kimba; and (f) Yunta (Jeffrey 2001). Note the different scales on the vertical axes. The whiskers extending beyond each box represent 1.5 times the range of rainfall within the box and circles represent historic monthly rainfall totals that fall outside this range, which can be considered extreme events.

Table 1. Monthly climate statistics for the non-prescribed area of the SAALNRM Region (BoM 2012)

Locality	Mean annual maximum temp (^{0}C)	Mean annual minimum temp (^{0}C)	Mean summer maximum temp (^{0}C)	Mean summer minimum temp (^{0}C)	Mean winter maximum temp (^{0}C)	Mean winter minimum temp (^{0}C)	Period of record
Coober Pedy (Stn. 16007)	27.7	13.7	35.6	20.2	19.3	7.0	1965–1994
Andamooka (Stn. 16065)	27.5	13.7	35.5	19.1	20.6	6.8	1969–2012
Kimba (Stn. 18040)	23.5	10.3	30.5	16.1	15.2	5.6	1967–2012
Arkaroola (Stn. 17099)	25.6	11.5	33.3	17.3	19.0	4.2	1977–2012
Yunta (Stn. 20024)	24.3	9.0	31.9	16.1	14.5	3.6	1951–1994
Locality	**Mean annual rainfall (mm)**	**Mean summer# rainfall (mm)**	**Highest summer# rainfall (mm/ month)**	**Lowest summer# rainfall (mm)**	**Mean winter^ rainfall (mm)**	**Highest winter^ rainfall (mm/ month)**	**Lowest winter^ rainfall (mm)**	**Period of record**
Coober Pedy (Stn. 16027)	157.0	52.0	132.1	0	35.5	74.2	0	1909–2012
Andamooka (Stn. 16065)	194.1	62.0	125.1	0	40.5	79.9	0	1965–2012
Kimba (Stn. 18040)	346.8	57.8	162.9	0	122.6	129.6	1.3	1920–2012
Arkaroola (Stn. 17099)	257.0	97.8	403.8	0	44.0	138.0	0	1938–2012
Yunta (Stn. 20024)	224.6	60.1	176.5	0	54.6	71.9	0	1888–2012

Summer months: December, January and February
^ Winter months: June, July and August

2.3. LAND USE

The dominant land use across the SAALNRM Region—by areal extent—is pastoralism, covering an area of around 409 000 km^2 (SAALNRMB 2010). A large proportion of the region is recognised as Aboriginal Managed Lands, which hosts a mixture of land uses, or has been set aside for conservation purposes under the auspices of the *National Parks and Wildlife Act 1972* and through reserves under private management. The Flinders Ranges/South Australian Outback tourism region is also an important regional-scale economic driver.

The mining and petroleum industries have experienced considerable growth in recent times. Mineral and petroleum production across the SAALNRM Region accounts around 70% of the State's total mining outputs (SAALNRMB 2010). These industries are anticipated to further develop in the region in coming decades.

2.4. DEMAND FOR GROUNDWATER

2.4.1. TOWN WATER SUPPLY

Groundwater is the principal source of town water supplies for townships located within the Far North PWA. The demand for groundwater from Coober Pedy, Marla, Oodnadatta and Roxby Downs totals around 1.4 GL/y (SAALNRMB, 2009). The townships of Parachilna, Blinman, Cockburn, Mannahill, Yunta and Olary are all located outside the Far North PWA and source their town water supplies from shallow aquifers outside the GAB (Watt, Berens & Magarey, 2012). Smaller townships in the western Flinders Ranges also rely on groundwater for town water supplies. The total demand for groundwater across the non-prescribed area of the SAALNRM Region has not been estimated.

Tourism has been identified as a growth industry across the region and special events often cause stress on water delivery infrastructure. Demand from tourism is seasonal and has been estimated to be around 0.7 GL/y (SAALNRMB, 2009).

2.4.2. MINING AND PASTORAL SECTORS

The Olympic Dam mine (including the township of Roxby Downs) is the largest user of groundwater in the SAALNRM Region. The principal source of water for current mining operations is a well field in the GAB aquifer, located 120–200 km north of the mine site. The rate of extraction from the well field is around 13.5 GL/y (BHP Billiton, 2009). Water for the proposed expansion of Olympic Dam will be sourced mainly from seawater desalination, although the use of some high-salinity groundwater has been proposed for the purpose of dust suppression (BHP Billiton, 2009).

Coal, natural gas and oil production and exploration have been pivotal to the economic prosperity of the SAALNRM Region for over three decades. Co-produced water from petroleum exploration and production (i.e. formation water mixed with petroleum) is estimated to be around 6.2 GL/y. Investment in hot-dry-rock geothermal energy has focussed on the Cooper–Eromanga Basin due to high temperatures that are associated with thick sedimentary basin cover and the inferred presence of high-heat granites (DMITRE, 2011). Water requirements for two proposed geothermal energy schemes located near Moomba and Innamincka are estimated to be in the order of 7.3 GL/y (SAALNRMB, 2009).

There are 328 pastoral leases across the SAALNRM Region (SAALNRMB, 2010). The SAALNRMB (2009) estimate the demand for groundwater for stock and domestic purposes within the Far North PWA is around 12.3 GL/y. The Far North PWA WAP requires that by 2019, all water used for stock and domestic purposes must be taken through a maintained, watertight reticulation system (SAALNRMB, 2009) and the resulting increased efficiencies are expected to reduce the demand for groundwater. Demand for groundwater that is used for stock and domestic purposes across the non-prescribed area of SAALNRM Region has not yet been estimated.

2.5. GROUNDWATER RECHARGE IN ARID ENVIRONMENTS

Groundwater recharge to unconfined aquifers is primarily a function of rainfall duration and intensity, and is also controlled by topography, the type of vegetation and its extent, the nature of the soil profile and the underlying geology. In arid areas, climate variables have the greatest influence on groundwater recharge. The estimation of recharge rates to unconfined aquifers in arid environments can be especially challenging due to the episodic nature of rainfall and low fluxes to the water table.

Many arid-zone groundwater systems host groundwater that is very old and may have been recharged under a different climate to today's (Clarke *et al.*, 1987). These systems may contain 'fossil' water and some may not receive recharge from present-day rainfall. However, some groundwater systems in arid regions show water level responses to local rainfall events.

Many techniques are available to estimate contemporary rainfall recharge. However, the choice of technique is often difficult because the timing and location of recharge is variable (Scanlon, Healy & Cook, 2002). The hydrograph (or water table fluctuation) method is commonly used to estimate recharge rates due to its simplicity and because *a priori* knowledge of mechanisms by which water moves through the vadose zone is not required (Healy & Cook, 2002). This method is best applied to groundwater systems with shallow water tables which show sharp water level rises and recessions (e.g. ICCWR assessments of the Northern and Yorke and Eyre Peninsula NRM Regions). However, in arid areas, water fluxes are usually low and the water table deep. Consequently, the hydrograph technique is often not useful in these environments (Herczeg & Love, 2007). Instead, environmental tracer methods are often used.

Recharge rates have been estimated in the arid Ti-Tree Basin in central Australia using two environmental tracer methods—modelling and isotopic dating of groundwater by ^{36}Cl and ^{14}C (Harrington, Cook & Herczeg, 2002). Recharge from floodouts of ephemeral rivers in the region was found to be an important recharge mechanism. Recharge to fresh groundwater (salinity less than 1000 mg/L) via streambed floodout reportedly occurred at a mean rate of ~1.9 mm/y compared with a mean recharge rate of ~0.2 mm/y for the rest of the basin. Importantly, recharge appeared to occur rarely and only after the most intense rainfall events of greater than 150–200 mm/month. It is thought that water levels today are still responding to an extreme rainfall event that occurred in 1974.

Major-ion chemistry, stable isotopes, radiogenic isotopes and remote sensing data have been used to investigate groundwater recharge and salinisation processes in the Lake Eyre Basin in arid central Australia (Tweed *et al.,* 2011). A large and intense local rainfall event occurred in January 2007 that resulted in the flooding of the usually-dry Lake Eyre. Results from groundwater chemistry analysis showed no evidence of recharge from the floodwaters or the local rainfall, but recharge may not have yet been detected due to low transit times and low infiltrating volumes. The stable-isotope chemistry results derived from this study indicate that groundwater in this area is mainly recharged diffusely following local heavy rainfall events of 100–150 mm/month.

2.6. GROUNDWATER RESOURCES OF THE SAALNRM REGION

Across the SAALNRM Region, a diversity of geological environments has resulted in complex groundwater systems and consequently, groundwater quality and storages are highly variable. Groundwater typically resides within four aquifer types (AACWMB, 2006):

- fractured rock aquifers
- sedimentary basins
- surficial aquifers
- palaeochannels.

Shallow, fresh groundwater systems across the SAALNRM Region are generally recharged by localised incident rainfall. These groundwater systems are located in fractured rock aquifers around the Olary and Flinders Ranges, in shallow unconsolidated sediments (e.g. alluvial fans and streambeds) and within some palaeovalleys. Recharge rates tend to be greatest in high-rainfall areas (e.g. the Flinders Ranges) and these shallow aquifers are commonly used for stock watering (AACWMB, 2006). Lower rainfall in arid areas typically results in low sustainable yields (e.g. Pleistocene-age palaeovalley groundwater systems located around Kingoonya and Tarcoola). Outside of the GAB, groundwater occurring at depth in the region typically show high salinities.

2.6.1. NON-PRESCRIBED GROUNDWATER RESOURCES

Non-prescribed groundwater resources of the SAALNRM Region have been described in detail by Watt, Berens and Magarey (2012). Those groundwater resources that may have economic, social or environmental significance and may also be vulnerable to the impacts of climate change in the short to medium term (i.e. shallow or unconfined aquifers that are likely to respond to contemporary rainfall) have been summarised in Table 2.

Table 2. Economically and/or socially significant groundwater systems that are likely to respond to impacts from climate change

Region	Aquifer type(s)	Comment	Reference
Poontana Trough (Callabona Sub-basin) (Fig. 5)	Alluvium	East and north of the Northern Flinders Ranges, creek catchments recharge shallow Tertiary / Quarternary aquifers. The Willawortina Formation being an important aquifer	Heathgate Resources (2008)
		Electromagnetic surveys conducted by Geoscience Australia / DMITRE (and validated by water bore salinity) confirm the Hamilton, Arkaroola and Four Mile Creek as significant contributors of shallow recharge to Poontana Trough sediments.	Michaelsen *et al.* (2012).
Olary Spur	Alluvium	Freshwater can be obtained from sediment filled watercourses and valleys (TDS < 5000 mg/L).	SAALNRMB (2006)
Torrens Basin	Alluvium	Shallow Quaternary sediments recharged by surface water runoff from Ranges to the east. Parachilna town water supply sourced from these sediments.	AGT (2010) Costar and Howles (2012)
Northern Flinders Ranges	Fractured Rock	Fractured rock aquifers are present in the Northern Flinders Ranges, with highest yields occurring near faults, where most springs occur. Recharge is via direct infiltration from rainfall. Discharge from fractured rock aquifers occurs in numerous ephemeral creeks and along the range front at springs.	SAALNRMB (2006)
Far North Prescribed Wells Area	Great Artesian Basin confined sandstone	The economically significant confined aquifers of the western GAB receive minimal recharge within South Australia, however aquifer pressure levels in the GAB in SA are sensitive to changes in recharge that may occur at the eastern side of the basin in Queensland and New South Wales.	Smerdon *et al.* (2012) Love *et al.* (2013)

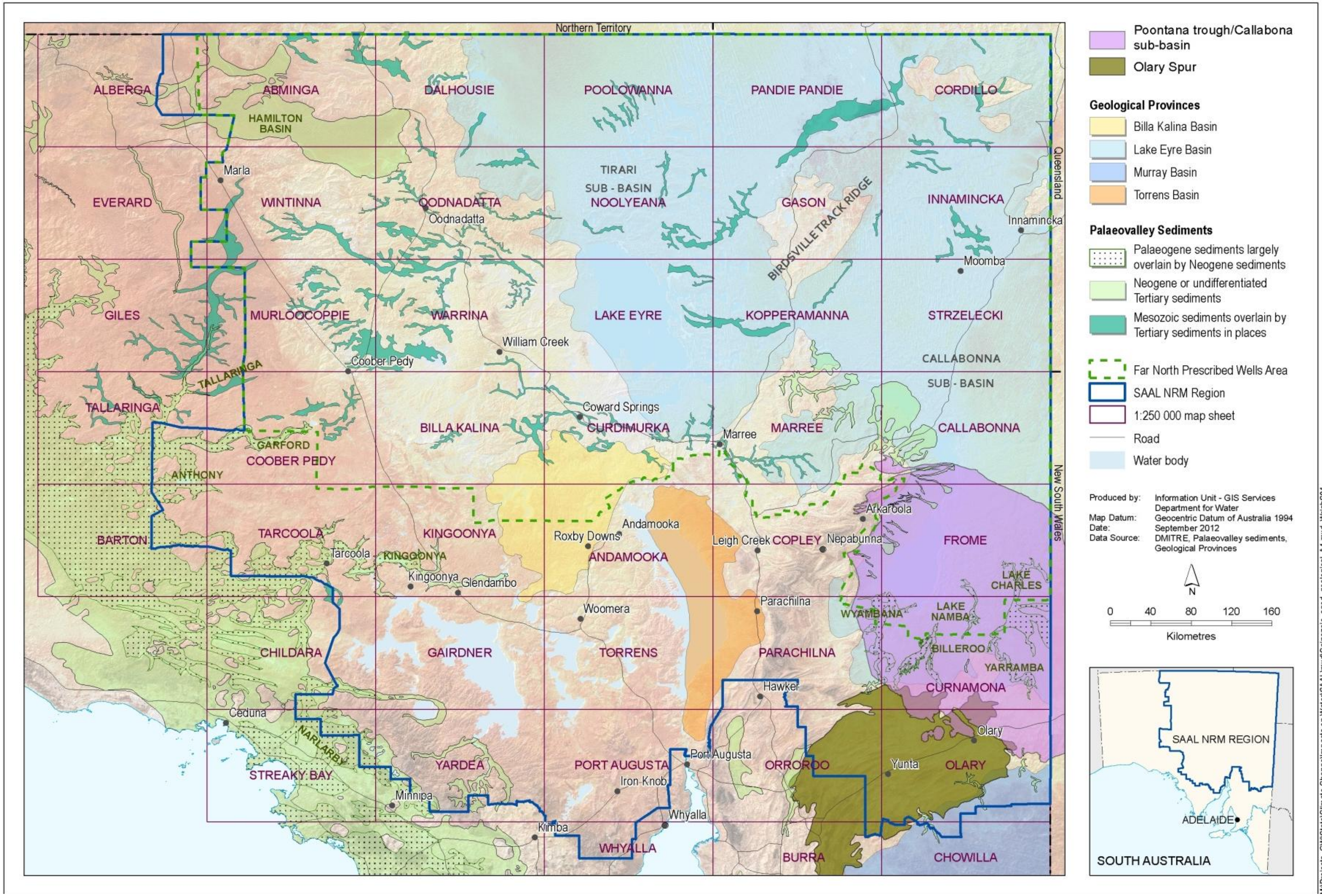


Figure 5. Groundwater basins of the SAAL NRM Region

2.6.2. FAR NORTH PRESCRIBED WELLS AREA GROUNDWATER RESOURCES

The Far North Prescribed Wells Area (FNPWA) covers an area of ~315 000 km^2 in the northeast corner of the SAAL NRM Region and includes the towns and settlements of Coober Pedy, Oodnadatta, William Creek, Marla and Innamincka. The FNPWA is located in the arid zone of South Australia where rainfall is infrequent, erratic and low, averaging 100–200 mm/y with high annual variability. Evaporation is extremely high, ranging from 2400 to over 3700 mm/y, and significantly exceeds rainfall. Underground water, particularly from the GAB, is therefore critical to the health of ecological communities and the viability of the pastoral, mining and tourist industries in the region (SAALNRMB, 2009). The FNPWA is largely aligned with the margins of the part of the GAB that lies within South Australia.

The GAB is a multi-aquifer system comprising Jurassic and Cretaceous sediments of the geological Eromanga, Surat and Carpentaria Basins. In South Australia, the GAB sequence is composed entirely of Eromanga Basin sediments, which comprise two major confined aquifers:

i) the lower confined, predominantly artesian Cadna-Owie Formation and Algebuckina Sandstone aquifer, and

ii) the upper confined, non-artesian Winton and Mackunda Formations aquifer.

In the South Australian context, the Cadna-Owie–Algebuckina aquifer is known as the GAB aquifer, providing a source for most of the water demand in the FNPWA and supporting the ecologically significant GAB spring ecosystems (SAAL NRMB, 2009).

Most of the recharge to the GAB aquifers occurs along the elevated eastern margin of the basin, on the western slopes of the Great Dividing Ranges. In South Australia, some recharge occurs along the western edge of the Eromanga Basin, where the aquifer becomes unconfined and may outcrop at the surface or be overlain by sandy sediments. Seasonal recharge along main drainage systems such as the Finke River is considered to be significant, not only over aquifer outcrop but also through the highly fractured Bulldog Shale aquitard into the underlying Algebuckina Sandstone aquifer (SAALNRMB, 2009).

2.7. EVALUATING THE IMPACTS OF CLIMATE CHANGE

Previous DFW ICCWR projects have used daily time step rainfall–runoff–recharge models to assess the impacts of climate change projections on water availability (e.g. Green *et al*., 2011; Green *et al*., 2012). Construction and calibration of models such as these requires detailed information on surface water flows or groundwater levels and their variations over time.

Limited surface water monitoring data are available for parts of the SAALNRM Region and these have been used to develop distributed rainfall-runoff models for some of the region. One of these models, of the Neales-Peake catchment, has been used in this work to investigate the impacts of climate change on the river systems in the region (Sect.3.3).

However, few groundwater observation wells exist in the SAAL NRM region outside the boundaries of the FNPWA, resulting in a paucity of groundwater level data across the non-prescribed areas of the region. The groundwater level data that exist are sourced from six town water supply wells that provide potable water to the township of Marla, which is located in the arid north west of the region (Fig.1). All of these wells indicate that recharge to the unconfined, shallow aquifer occurs following intense rainfall events (Figs A1 and A2). Two months of high rainfall (111 mm in December 1988 and 298 mm in March 1989) resulted in water level rises of around 1.5–2 m.

Whilst these data indicate that shallow groundwater around Marla responds to contemporary rainfall events (and therefore may be vulnerable to the impacts of climate change), it is difficult to estimate the peak of the water table in response to rainfall because of the coarse temporal resolution of the water level data (some readings are monthly whilst others are six monthly). For this reason, quantification of potential reductions in recharge using a rainfall–recharge modelling approach was considered to be infeasible for the groundwater resources of the SAAL NRM region. Instead, the current study adopts an analysis of climate metrics that are likely to indicate a change in the occurrence of groundwater recharge, rather than a rainfall–recharge modelling approach.

2.7.1. METRICS OF CLIMATE CHANGE IMPACT

Measures of the frequency and magnitude of extreme rainfall events are likely to be the most important metrics in projecting changes in surface runoff and groundwater recharge due to the impacts of climate change in the SAALNRM Region.

Groundwater systems in arid and semi-arid areas are commonly recharged by flooding from intense, episodic rainfall events. For example, the groundwater levels around Marla typically show a marked rise following the largest rainfall events (more than 100 mm in a month). However, this analysis is valid only where recharge is contemporary with rainfall. In some groundwater systems, the relationship between rainfall and recharge may not be clear, while water levels in some deep and/or confined aquifers may be largely unresponsive to contemporary rainfall events.

Under the effects of climate change, South Australia is likely to be subject to changes in both average annual rainfall amounts and the frequency of extreme weather events, including flooding (Suppiah *et al.*, 2006; CSIRO and BoM, 2007). If the frequency of extreme rainfall events changes, the frequency of episodic recharge events that are driven by these rainfall events may be expected to change similarly.

Two rainfall metrics have been selected to provide an indication of the possible impacts of climate change on recharge. The first metric is the change in the magnitude of the first percentile daily rainfall, which is the amount of rainfall that is expected to fall in a day on the wettest days, occurring on only one in every 100 days, on average (i.e. the most intense *daily* rainfall events). Crosbie *et al*. (2012) found that episodic recharge in the Murray-Darling Basin was more strongly related to the change in first percentile rainfall compared to the change in total rainfall. Crosbie *et al*. (2012) also tested the threshold percentile to represent the extreme rainfall events and found that as the threshold was reduced to include more rainfall events, the discriminatory power of the rainfall metric to estimate change in recharge was reduced. As such, a first percentile (largest 1% of events) threshold was found to be appropriate (Crosbie *et al*., 2012).

The occurrence of rainfall events leading to recharge in the SAAL NRM Region is expected to be less frequent than one in every 100 days, as recharge events occur on average only once every few years, even in the areas in the SAALNRM Region that experience the most frequent events. However, it is difficult to quantify the changes in very rare events such as these, even over a number of decades. Hence, the one in 100 day occurrence has been selected as a trade-off between representing the very rare events, while still having enough events within the data to provide confidence in the results.

The second climate metric is the number of months over a 30-year period that recorded a large amount of rainfall. Stable-isotope chemistry suggests that over the long term, recharge occurs in arid areas predominantly after heavy local rainfall events of greater than 100–150 mm/month (Tweed *et al.,* 2011). Consequently, the number of months with rainfall greater than 100 mm/month has been identified for each scenario to provide an indication of the expected change in the frequency of recharge events, based on the different GCM projections. The analysis has been based on rainfall totals in a calendar month as the calculation is much more computationally efficient compared to using a metric such as a rolling total of rainfall over a 30-day period. Over 10 000 pixels of daily rainfall have been included in the analysis for each time period, emissions scenario and GCM considered, so there were considerable computational gains from using calendar-month totals. While there is the potential to miss recharge events that occur over the end of one month into the next month compared to using a

30-day rolling total, precursory data analyses suggested that the difference between the two approaches was negligible.

For consistency with previous ICCWR studies, projections of changes in average annual rainfall have also been generated. However, average rainfall data provides little insight into the important aspect of rainfall for water resources in the study region, as the monthly average potential evapotranspiration (PET) is greater than the monthly average rainfall in all months of the year (Fig. 4). Furthermore, there are distinct differences in rainfall patterns between the 'Arid Steppe Cold and 'Arid Desert Hot' climate sub-zones (Sect. 2.2).

3. CLIMATE CHANGE PROJECTIONS

The projections of climate change and their potential impacts on the water resources of the SAALNRM Region are presented in this section.

An analysis of the projections from a set of selected GCMs is presented, which includes maps representing the projected range of changes in rainfall and groundwater recharge across the whole SAALNRM Region. Finally, projected changes in rainfall and in evapotranspiration have been applied to a surface runoff model to investigate the impact of the projected changes on the simulated runoff for the Neales River, a tributary of Lake Eyre.

An approach called the "Climate Futures Framework" (Clarke *et al*., 2011) was applied to evaluate the range of climate change projections for the region. The framework provides a simplified representation of GCM projections, while still addressing uncertainty and maintaining internally consistent combinations of climate variables from the different models. This approach provides a mechanism to select the most appropriate GCMs to represent the 'most-likely', 'best' and 'worst' case projections for the future climate of the region.

3.1. *CLIMATE FUTURES FOR SAALNRM REGION*

Three study site locations have been selected for the Climate Futures analyses that span the extent of the SAALNRM Region. These sites are: (1) Oodnadatta in the North West; (2) Moomba in the North East; and (3) Woomera toward the South. The time horizon of 2050 has been used and both low (B1) and high (A2) emission scenarios have been investigated. Twelve GCMs that have been identified as suitable for South Australia (Suppiah *et al.* 2006) were selected. For each of the selected locations and emission scenarios, projections from each of the 12 GCMs for the variables of (1) change in mean annual temperature (degrees) and (2) change in mean annual rainfall (percentage) were obtained from the OzClim website (CSIRO, 2012). The projected changes were calculated relative to the historic baseline period of 1975–2004.

Temperature and rainfall projections from each of the 12 GCMs are plotted in graphs shown in Figure 7 to Figure 9. Each point represents a different GCM output and darker red colours are used to represent the 'most-likely' Climate Futures. Regular divisions of the different Climate Futures categories were adopted, every one degree of change, and every 10% change in rainfall, starting from a 'no change' category represented by a projected change in average annual rainfall less than ±5%.

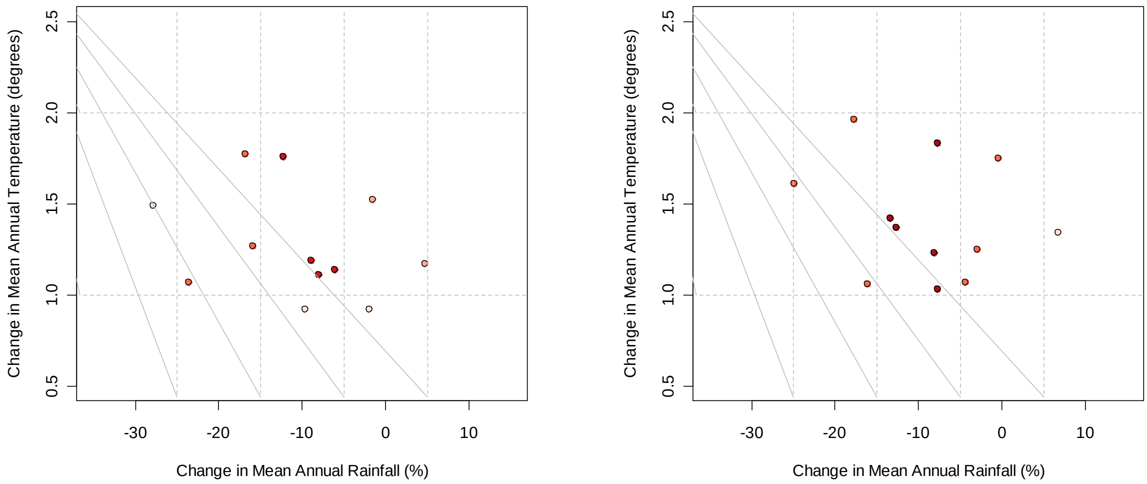
The names of the different Climate Futures are intended to provide some indication of the likely impacts of the climate change projections. However, the names and corresponding threshold values have been selected subjectively and qualitatively. Projections of (1) less than one degree of warming have been categorised as 'slightly warmer'; (2) between one and two degrees of warming have been defined as 'warmer'; and (3) two degrees of warming or more have been termed 'hotter'. Similarly for rainfall, a projection indicating (1) an increase in annual rainfall between 5 and 15% has been labelled 'slightly wetter', (2) less than 5% change in rainfall has been termed 'little change'; (2) up to a 15% reduction 'slightly drier'; (3) up to 25% reduction 'drier'; (4) and greater than 25% reduction 'much drier'.

For most Climate Futures cases, up to three of the 12 GCMs project a small increase in average annual rainfall (Figs 6–8). This is in contrast to climate change projections across the majority of South Australia, especially toward the south, where typically all GCMs project some reduction in average annual rainfall and the only variability is the magnitude of this reduction. However, a 'most-likely' case can be identified in all but one of the scenarios, with four or more GCMs falling into the slightly drier and warmer climate future. The variability in GCM projections is greater in the high-emissions scenario for the location of Moomba and consequently it is more difficult to identify a ‘most-likely’ case. However, the most populated and central climate future for the Moomba high emissions scenario is the slightly drier and warmer climate future, so this has again been selected as the ‘most-likely’ case.

For the low-emissions case, five of 12 GCMs in the South and two of 12 GCMs in the North project up to one degree of warming, while the remaining GCMs all project between one and two degrees of warming by 2050. For the high-emissions case, most GCMs project between one and two degrees of warming. There are no GCMs that project less than one degree of warming, while only two of 12 GCMs in the north of the region project an increase in average annual temperatures greater than two degrees.

An extended Climate Futures analysis, conducted at the same three locations and for high and low-emission scenarios at the time horizon of 2050, but derived from all 24 GCMs (herein termed the ’24-GCM analysis’) is shown in Appendix A. The inclusion of all 24 models in the 24-GCM analysis does little to influence the Climate Futures class boundaries compared to the 12-GCM analysis (i.e. the analysis based on 12 GCMs best suited to South Australian climate projections (Suppiah *et al.* 2006)). The greatest difference is that the ‘wettest’ GCMs (i.e. those that project a slight increase in average annual rainfall) tend to be absent from the 12-GCM analysis, whilst the ‘driest’ and ‘hottest’ GCMs remain in the Climate Futures analysis in both cases. Consequently, for the high emissions case , more GCMs fall into the ‘little change in rainfall’ Climate Future compared to the ‘slightly drier’ Climate Future for Moomba (eight GCMs in ‘little change’ compared to five in ‘slightly drier’) and also for Woomera (nine GCMs in ‘little change’ compared to eight in ‘slightly drier’).

Importantly, the individual GCM results each represent one simulation of a possible future climate. The GCMs attempt to replicate the long-term variability in the observed climate and, due to the architecture of the models, repeated simulations of a particular future climate scenario may produce different periods of wet and dry climates. This may result in inherent inconsistencies in changes projected by repeated simulations using a single GCM. The projections provided on the OzClim website are derived from a relationship between each variable (temperature and rainfall in this case) and the global change in temperature projected, which acts to ‘smooth out’ the impact of this inter-simulation variability on regional-scale climate projections (CSIRO, 2012).



Low Emissions High Emissions

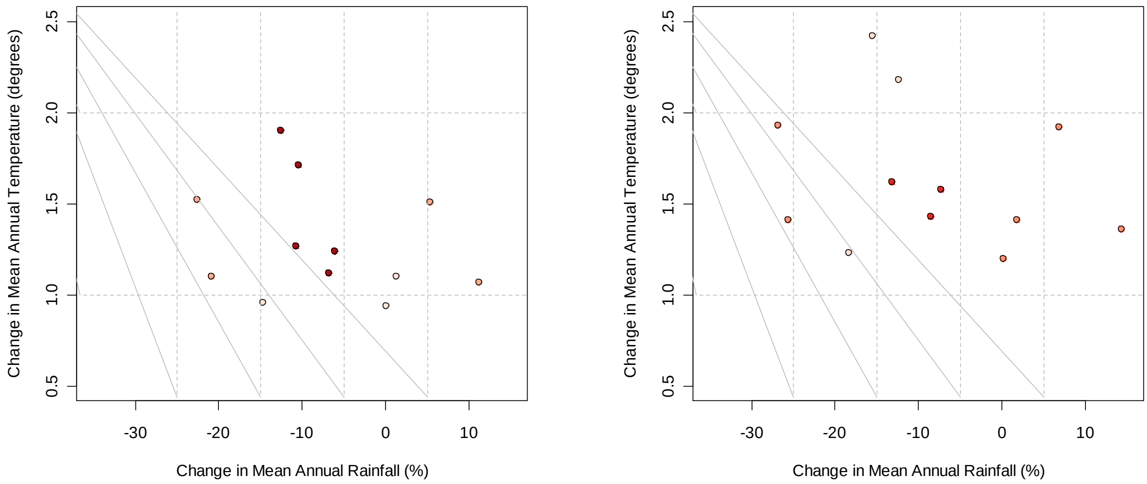
Figure 6. GCM Projections for Woomera for 2050

Table 3. Climate Future matrix for Woomera 2050 Low Emissions

		Mean Annual Temperature (°C)		
		Slightly Warmer	Warmer	Hotter
Annual Rainfall (%)		0.5 to 1	1 to 2	2 to 3
Much Drier	More than -25			
Drier	-15 to -25		1 of 12 models (8%)	
Slightly Drier	-5 to -15	3 of 12 models (25%)	4 of 12 models (42%)	
Little Change	-5 to 5	2 of 12 models (17%)	1 of 12 models (8%)	
Slightly Wetter	5 to 15		1 of 12 models (8%)	

Table 4. Climate Future matrix for Woomera 2050 High Emissions

		Mean Annual Temperature (°C)		
		Slightly Warmer	Warmer	Hotter
Annual Rainfall (%)		0.5 to 1	1 to 2	2 to 3
Much Drier	More than -25			
Drier	-15 to -25		3 of 12 models (25%)	
Slightly Drier	-5 to -15		5 of 12 models (42%)	
Little Change	-5 to 5		3 of 12 models (25%)	
Slightly Wetter	5 to 15		1 of 12 models (8%)	



Low Emissions High Emissions

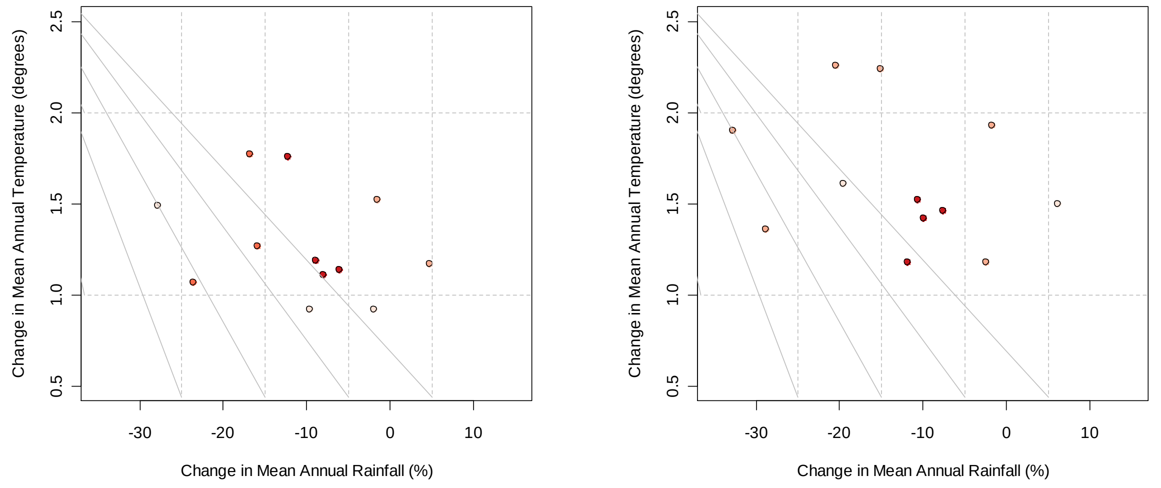
Figure 7. GCM Projections for Moomba for 2050

Table 5. Climate Future matrix for Moomba 2050 Low Emissions

		Mean Annual Temperature (°C)		
		Slightly Warmer	Warmer	Hotter
Annual Rainfall (%)		0.5 to 1	1 to 2	2 to 3
Much Drier	More than -25			
Drier	-15 to -25		2 of 12 models (17%)	
Slightly Drier	-5 to -15	1 of 12 models (8%)	5 of 12 models (42%)	
Little Change	-5 to 5	1 of 12 models (8%)	1 of 12 models (8%)	
Slightly Wetter	5 to 15		2 of 12 models (17%)	

Table 6. Climate Future matrix for Moomba 2050 High Emissions

		Mean Annual Temperature (°C)		
		Slightly Warmer	Warmer	Hotter
Annual Rainfall (%)		0.5 to 1	1 to 2	2 to 3
Much Drier	More than -25		2 of 12 models (17%)	
Drier	-15 to -25		1 of 12 models (8%)	1 of 12 models (8%)
Slightly Drier	-5 to -15		3 of 12 models (25%)	1 of 12 models (8%)
Little Change	-5 to 5		2 of 12 models (17%)	
Slightly Wetter	5 to 15		2 of 12 models (17%)	



Low Emissions High Emissions

Figure 8. GCM Projections for Oodnadatta for 2050

Table 7. Climate Future matrix for Oodnadatta 2050 Low Emissions

		Mean Annual Temperature (°C)		
		Slightly Warmer	Warmer	Hotter
Annual Rainfall (%)		0.5 to 1	1 to 2	2 to 3
Much Drier	More than -25		1 of 12 models (8%)	
Drier	-15 to -25		3 of 12 models (25%)	
Slightly Drier	-5 to -15	1 of 12 models (8%)	4 of 12 models (33%)	
Little Change	-5 to 5	1 of 12 models (8%)	2 of 12 models (17%)	
Slightly Wetter	5 to 15			

Table 8. Climate Future matrix for Oodnadatta 2050 High Emissions

		Mean Annual Temperature (°C)		
		Slightly Warmer	Warmer	Hotter
Annual Rainfall (%)		0.5 to 1	1 to 2	2 to 3
Much Drier	More than -25		2 of 12 models (17%)	
Drier	-15 to -25		1 of 12 models (8%)	2 of 12 models (17%)
Slightly Drier	-5 to -15		4 of 12 models (33%)	
Little Change	-5 to 5		2 of 12 models (17%)	
Slightly Wetter	5 to 15		1 of 12 models (8%)	

3.2. *CLIMATE CHANGE PROJECTIONS FOR SAALNRM REGION*

The Climate Futures Framework analysis has been used to select three GCMs that represent the (1) 'best'; (2) 'worst'; and (3) 'most-likely' cases of the future climate for both low and high-emission scenarios. The projections from these three GCMs have been downscaled to provide daily-time-step rainfall for the whole SAALNRM Region. The downscaled rainfall data have then been used in an analysis of climate metrics (Sect. 2.8.1) that provide an indication of the possible impacts of climate change on groundwater recharge and possible subsequent changes in the capacity of groundwater resources across the region.

3.2.1. SELECTION OF GLOBAL CLIMATE MODELS

Results of the Climate Futures Framework analysis (Sect. 3.1) provides an overview of the range of current projections for the SAALNRM Region. These projections are based on the GCMs that Suppiah *et al.* (2006) identified as best suited to modelling the climate in South Australia. To select a range of GCMs to infer the range of projected changes in water resources, the change in rainfall has been identified as the sole variable of interest because surface water runoff and groundwater recharge in the region are observed to be driven typically by infrequent large rainfall events, rather than by accumulated differences between successive daily rainfall and evapotranspiration totals.

In arid areas, the projected changes in the first percentile daily rainfall and the changes in the number of months with greater than 100 mm of rainfall are likely to be better indicators of climate change-induced changes in recharge, rather than the change in the average annual rainfall. Changes in average annual rainfall are readily available from the OzClim website (CSIRO, 2012), whereas changes in the first percentile daily rainfall and the changes in the number of months with greater than 100 mm of rainfall first require data to be downscaled to the daily time step for each GCM and across the whole study area. The rationale behind selecting a subset of GCMs is to represent the full range of changes projected by the various GCMs, while reducing the time required to complete the downscaling process to a minimum. The GCM selection process has been based on the OzClim-derived changes in average annual rainfall.

For the 'best-case' Climate Future, the Meteorological Institute of the University of Bonn, Meteorological Research Institute GCM (ECHO-G GCM) was the only GCM to project a small increase in rainfall (5–15% increase) for all three locations and emissions scenarios considered, except for Oodnadatta with high emissions. For the latter location and scenario, increases in rainfall were not projected by any the GCMs, however a total of three GCMs, including the ECHO-G GCM, projected little change in average annual rainfall. Hence the ECHO-G GCM was selected to represent the 'best-case' Climate Future.

The Climate Future Framework analysis showed that the two NOAA Geophysical Fluid Dynamics Laboratory GCMs (GFDL 2.0 and GFDL 2.1) and the CSIRO Mark 3.5 GCM lie within the 'worst' case category (i.e. the top left of the Climate Future plots (Figs 6–8), or top right cell of the tables (Tables 3–8)). Only the GFDL 2.0 GCM projected a much-drier climate for Oodnadatta and drier climate for Woomera (both for the high emissions case). The remaining GCMs projected a smaller reduction in average annual rainfall or, in the case of ECHO-G, an increase. Therefore, the GFDL-2.0 GCM was selected to represent the 'worst-case' Climate Future.

The LASG-IAP and HADGEM1 GCMs were always present in the most common classification for all locations and emission scenarios and consequently, represent the 'most-likely' Climate Future. The HADGEM1 GCM does not output rainfall at the daily time step and cannot be used with the ICCWR downscaling method. Therefore, the LASG-IAP GCM was selected to represent the 'most-likely' Climate Futures case.

3.2.2. DOWNSCALING OF CLIMATE PROJECTIONS

The daily scaling approach used for all previous ICCWR projects (Gibbs *et al.,* 2011) has also been used in this study. This approach adopts different scaling amounts for different seasons and for different rainfall percentiles and as such, provides a dataset in which the differences between the projected changes in the mean rainfall, as well as the first percentile rainfall can be analysed. However, as it is based on scaling observed data, the sequence of days during which rainfall occurs does not change for the future projection cases, only the amount of rainfall changes. It has been assumed that this will not have a large impact on the modelling results. More sophisticated downscaling approaches, such as statistical methods using Non-homogenous Hidden Markov Models, would be required to consider changes in the temporal pattern of daily rainfall amounts for a future climate. These methods are currently being applied to the development of climate change projections for South Australia as a part of the climate change project of the Goyder Institute for Water Research.

The daily-scaling approach adopted in this report requires projections of daily rainfall from the GCMs to calculate the different adjustment factors for the different rainfall percentiles (Gibbs *et al.,* 2011). All three of the GCMs selected in the previous section provide daily rainfall projections only for the future periods 2046–65 and 2081–2100, as well as the 1961–2000 historic (i.e. 1990 baseline) period. In order to use these GCMs for this study, the change in rainfall distribution for each season comparing the 1970–1999 and 2046–65 periods of GCM data has been used to generate rainfall distributions for both the 2030 and 2050 projections. Because the totals for each 5% percentile range in rainfall are compared, the 20-year period can be compared with the 30-year period. The adjustments were then scaled to ensure that the change in average rainfall for each time horizon and season corresponded with the seasonal changes projected by OzClim (CSIRO, 2012) for 2030 and 2050. Similarly, the change in rainfall distribution between 1970–1999 and the 2081–2100 that were projected by the BCCR GCM was used to generate rainfall distributions for 2070, which were again scaled to ensure the overall changes correspond to the seasonal change projections provided by OzClim for 2070. Further details on the downscaling approach can be found in Gibbs *et al.* (2011).

To provide a representation of the projected changes in the selected rainfall metrics, the downscaling method has been applied to the whole SAALNRM region. The Australia-wide SILO gridded daily rainfall product (Jeffrey *et al*., 2001) has been used as the historical rainfall input for the basis of the downscaling method. The data is provided as a grid of 0.05° by 0.05° grid cells (approximately 5 km by 5 km) for each day. Daily rainfall data for the period 1975–2004 has been used as the (1990) historic baseline for the daily-scaling approach. This is the same baseline period against which Ozclim compares projected percentage changes in seasonal rainfall. Historic baseline values for each cell were calculated for the rainfall metrics of annual average rainfall, first percentile rainfall and number of months with greater than 100mm rainfall. The daily scaling process has then been applied to rainfall data for this baseline period, for the time horizons of 2030, 2050 and 2070 and for a high (A2) and low (B1) emission cases (Nakicenovic and Swart, 2000). The resulting changes in each rainfall metric, for each future scenario considered, are presented in the following section.

3.2.3. PROJECTED CHANGES IN RAINFALL METRICS

In this section, the 'best' Climate Future case refers to the projections provided by the ECHO-G GCM, 'most-likely' case to the LASG-IAP GCM projections and 'worst' case to the projections provided by the GFDL-2.0 GCM; low emissions correspond to the B1 emissions case and high emissions to the A2 emission case. The resulting projections for each time horizon and emissions case have been averaged across the whole SAALNRM Region (Table 9). In general, across the three metrics, the descriptions given to the climate scenarios are reflected by the percentage changes calculated, with the 'best' case GCM producing the an increase in the rainfall metrics, with the 'most-likely' GCM projecting a small decrease in the rainfall metrics, and then the 'worst' case GCM producing larger reductions. For the 'most-likely' and 'worst' cases, and apart from some of the 2030 projections, the high-emission scenario also results in greater reductions in each rainfall metric when compared to the corresponding low-emission scenario. Interestingly, for the 'best-case' scenario, higher emissions generally resulted in a greater increase in the rainfall metrics.

For the 'most-likely' Climate Future, under a low-emissions scenario at 2030 and 2050, the reductions in the first percentile rainfall and average annual rainfall are comparable. For all remaining Climate Futures, emissions scenarios and time horizons considered, reductions in the first percentile rainfall are less than the corresponding reductions in average annual rainfall. This result suggests a likely increase in the magnitude of the more extreme events relative to the overall average, even though both metrics indicate reductions in rainfall for the 'most likely' and 'worst' cases. The percentage change in the number of months with greater than 100 mm rainfall is large compared to the changes in both annual average and first percentile daily rainfall. This is likely due to the small number of these events recorded over the 30-year period (4.4 months for the historical case, when averaged across the region). The percentage changes in the number of months with greater than 100 mm of rainfall is strongly correlated to the change in the average annual rainfall (R^2=0.95).

In the remainder of this section these results that have been averaged over the whole SAALNRM Region are investigated further by considering their spatial distribution.

Table 9. Change in rainfall metrics, averaged across the SAAL Region and expressed as a percentage compared to the 1990 historic baseline case

Case	Emissions	Change in Annual Average Rainfall (%)			Change in 1st Percentile Daily Rainfall (%)			Change in Number of Months > 100mm Rainfall (%)		
		2030	2050	2070	2030	2050	2070	2030	2050	2070
Best	Low	4	6	8	8	10	11	27	38	36
Best	High	4	7	11	9	12	14	24	42	53
Most Likely	Low	-5	-8	-10	-6	-8	-10	-21	-30	-35
Most Likely	High	-6	-10	-15	-4	-9	-14	-18	-33	-47
Worst	Low	-18	-25	-30	-5	-13	-22	-31	-47	-59
Worst	High	-19	-30	-39	-4	-17	-31	-37	-60	-71

'Best' case = ECHO-G GCM, 'most-likely' case = LASG-IAP GCM, 'worst' case = GFDL 2.0 GCM
Low Emissions = SRES B1, High Emissions = SRES A2

3.2.3.1. Average annual rainfall

The projected reductions in average annual rainfall are likely to have greater impact on groundwater resources that are recharged in the Arid Desert Cold and Arid Steppe Cold climate zones (Figs 9–14) because rainfall in these areas is winter dominant and less episodic relative to the north. In areas where rainfall is episodic (i.e. in the arid north), statistics of average rainfall are often misleading and care should be taken in interpreting how changes in average rainfall may affect the capacity of water resources (Sect. 2.2.).

The projections of change in average annual rainfall (Figs 9–14) display a general trend of greater reductions in toward the north of the SAALNRM Region relative to the south. This trend is most pronounced in the ‘worst’ Climate Futures case; in the high-emissions scenario at the 2070 time horizon, reductions of 35–50% are not limited to the north but widespread across most of the SAALNRM Region. Conversely, under the ‘best’ case Climate Future, for either low or high-emissions scenarios, increases of 0–5% are projected across most of the region, with the exception of the south-western boundary where reductions in average annual rainfall of up to around 5% are possible. Under the ‘most-likely’ Climate Future, average annual rainfall shows a general trend of lowest reductions toward the southeast and southwest. In the arid north, under a high-emissions scenario at the 2070 time horizon, reductions of up to 19% (compared to the 1990 baseline case) are projected.

3.2.3.2. First percentile rainfall

In general, the projected change in first percentile rainfall (Sect. 2.8.1) is less than the projected change in the average annual rainfall for a given future scenario (Figs 9–14) as most GCMs project an increase in the magnitude of extreme events while also projecting a reduction in mean annual rainfall for this region. For all Climate Futures cases and emissions scenarios, there are some cells where marginal increases are projected in the first percentile rainfall compared to the 1990 baseline case (light-blue shading). For the ‘best’ Climate Futures cases, under both low and high-emissions scenarios, most of the projected increases in the first percentile rainfall occur uniformly across the region (i.e. do not show any spatial trends). However, for the ‘most-likely’ and ‘worst’ Climate Futures case, under both low and high-emissions scenarios, varying degrees of decrease in first percentile rainfall are projected to occur throughout much of the region. Increases occur only toward the south and west of the region at the 2030 time horizon and only in the south at the 2050 and 2070 time horizons.

The first percentile rainfall data show:

- For the ‘best‘ Climate Futures case, under low and high-emissions scenarios (Figs 9 and 10), increases in first percentile rainfall of up to approximately 5%, compared to the 1990 baseline case, are projected ubiquitously across the region
- For the ‘most-likely’ Climate Futures case, under a low-emissions scenario by 2030–50 (Fig. 11), slight increases in first percentile rainfall are generally projected to the east of the longitude that aligns with the strike of the Flinders Ranges, while slight decreases are generally projected to the west. By 2070, decreases in first percentile rainfall are more widespread across the region and those decreases are greatest toward the west (up to 20% compared to the 1990 baseline case). For the high-emissions scenario (Fig. 12), a spatial trend in changes in the magnitude of the first percentile rainfall is not apparent at the 2030 time horizon, but reductions again appear to be greatest toward the west by the 2050 and 2070 time horizons (up to 17.4% and 26.6% reductions, respectively).
- For the ‘worst’ Climate Futures case, decreases in the magnitude of first percentile rainfall, relative to the 1990 baseline case, are most pronounced in the north of the region. Projections under the low-emission scenario (Fig. 13), at the 2030 time horizon, indicate that the magnitude of first percentile rainfall will increase by around 0–5% in the northern Flinders Ranges and to the west of the ranges, but will decrease by 5–10% in the Arid Desert Cold and Arid Steppe Cold climate zones between Port Augusta and Ceduna; by 2070 first percentile rainfall is projected to decrease by up to 37%. Projections of changes in first percentile rain under the high-emissions scenario (Fig. 14) show spatial trends that are similar to the low-emissions case, but greater in magnitude, with up to a 50% reduction compared to the 1990 baseline case.

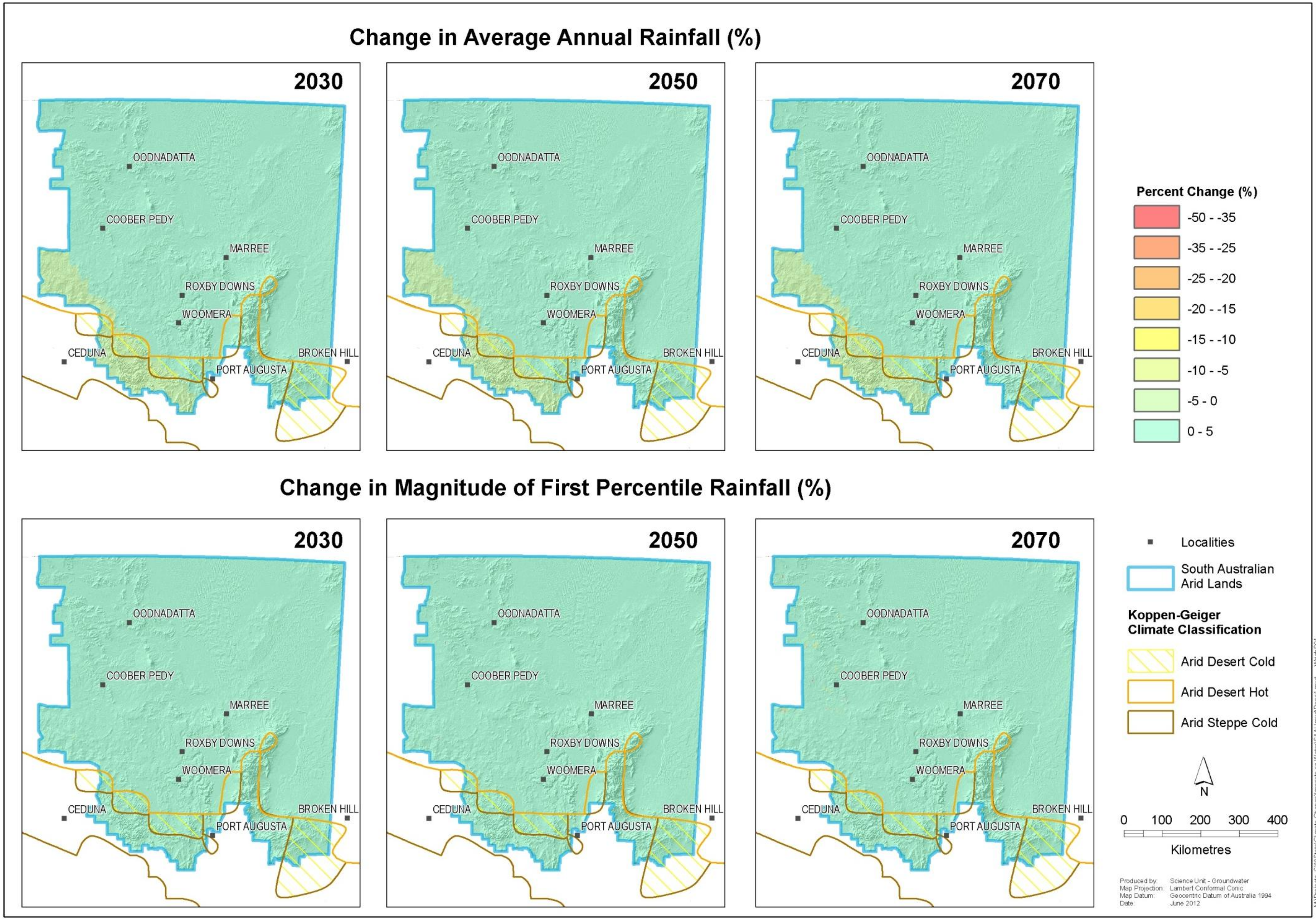


Figure 9 Change in average annual and first percentile rainfall for the 'best' case projections (ECHO-G GCM) and low emissions

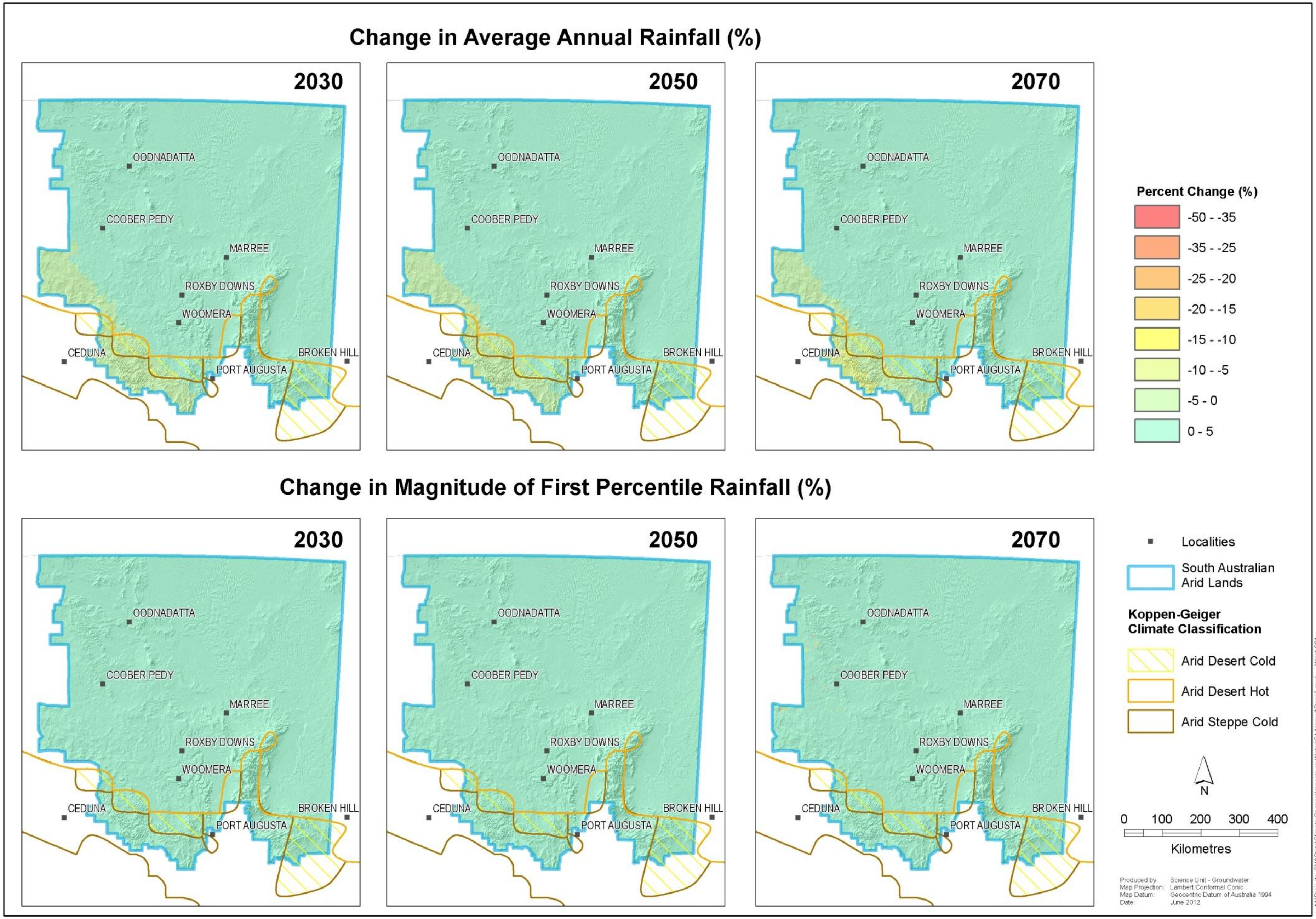


Figure 10. Change in average annual and first percentile rainfall for the 'best' case projections (ECHO-G GCM) and high emissions

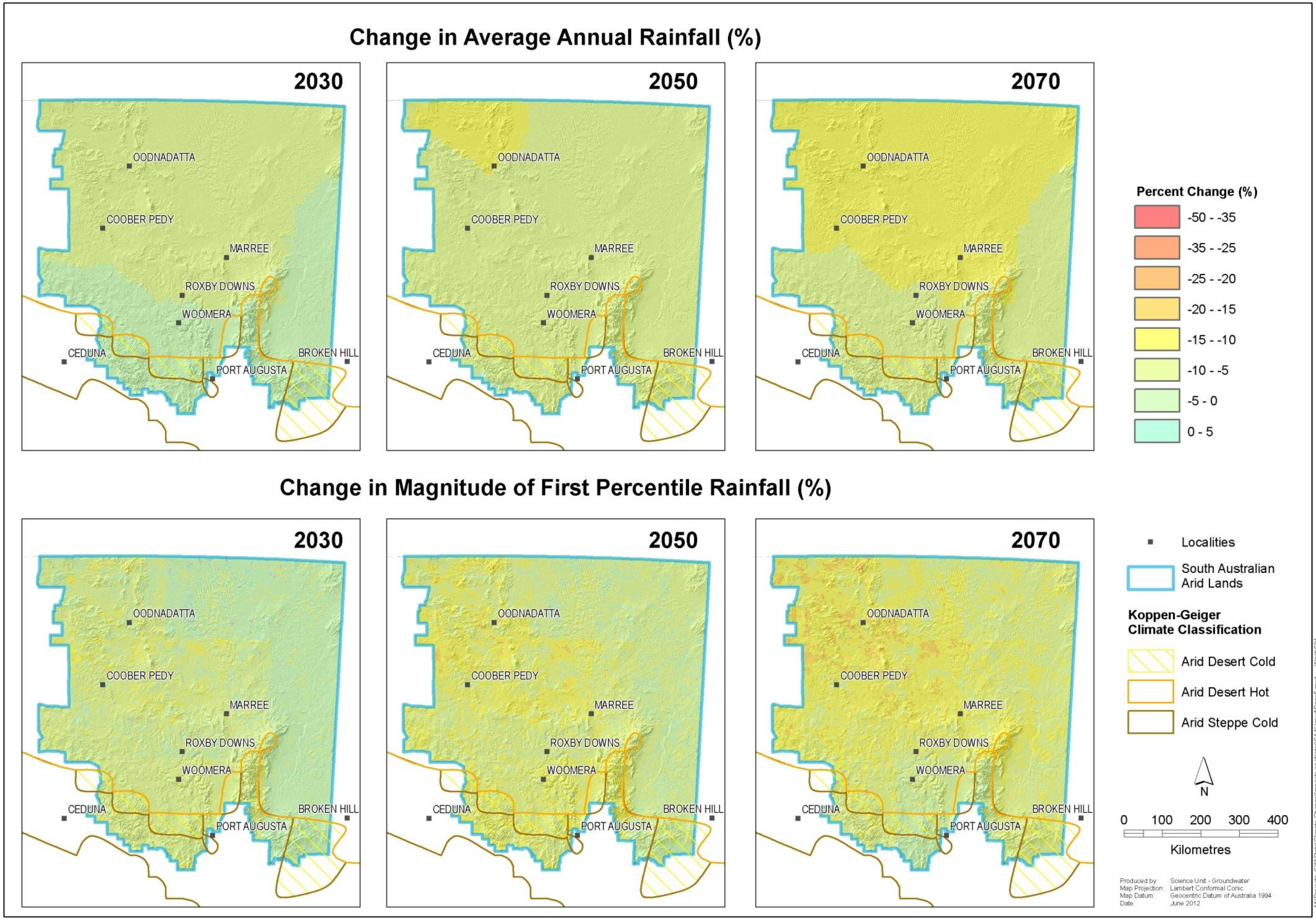


Figure 11. Change in average annual and first percentile rainfall for the 'most likely' case projections (LASG-IAP GCM) and low emissions

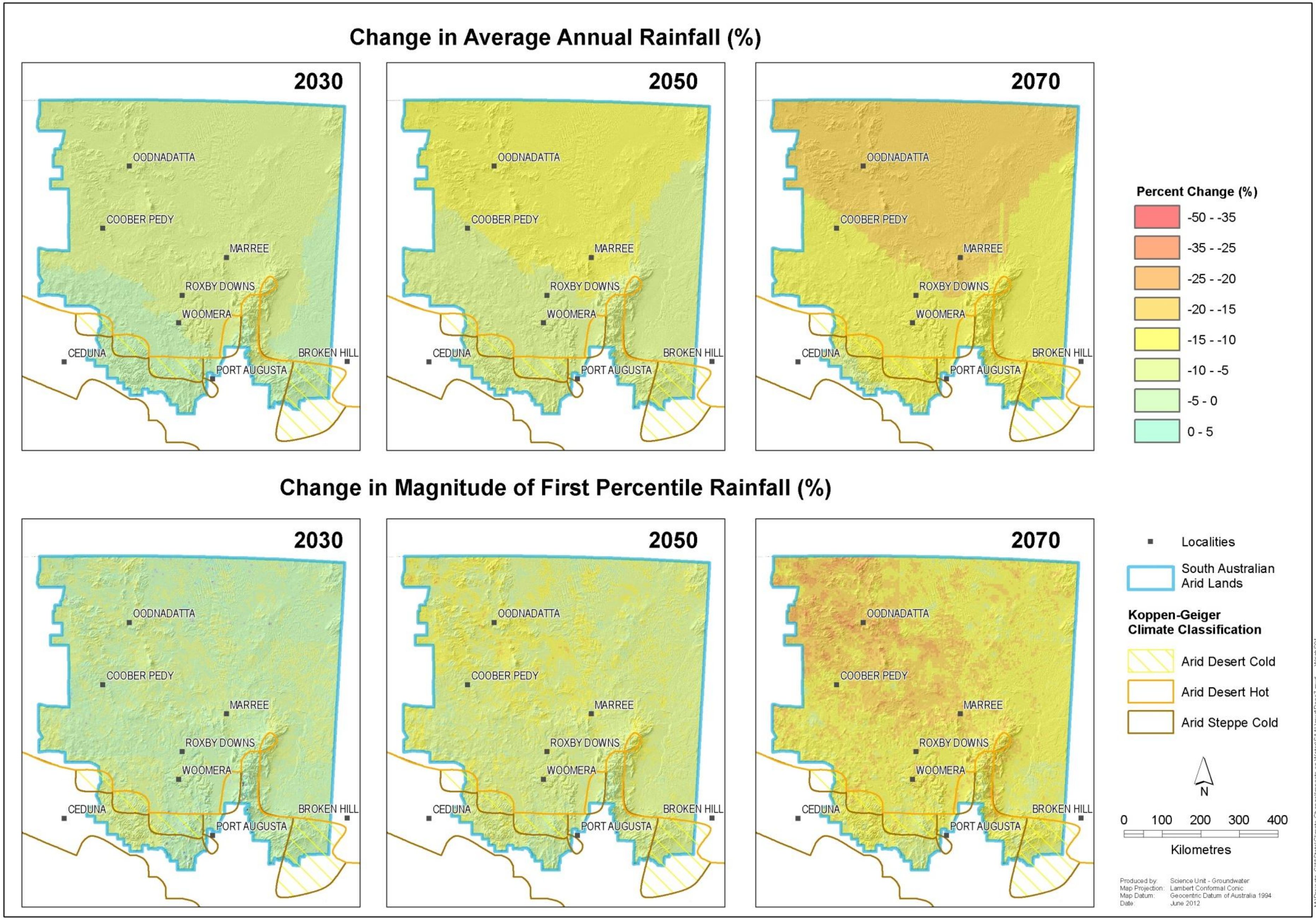


Figure 12. Change in average annual and first percentile rainfall for the 'most likely' case projections (LASG-IAP GCM) and high emissions

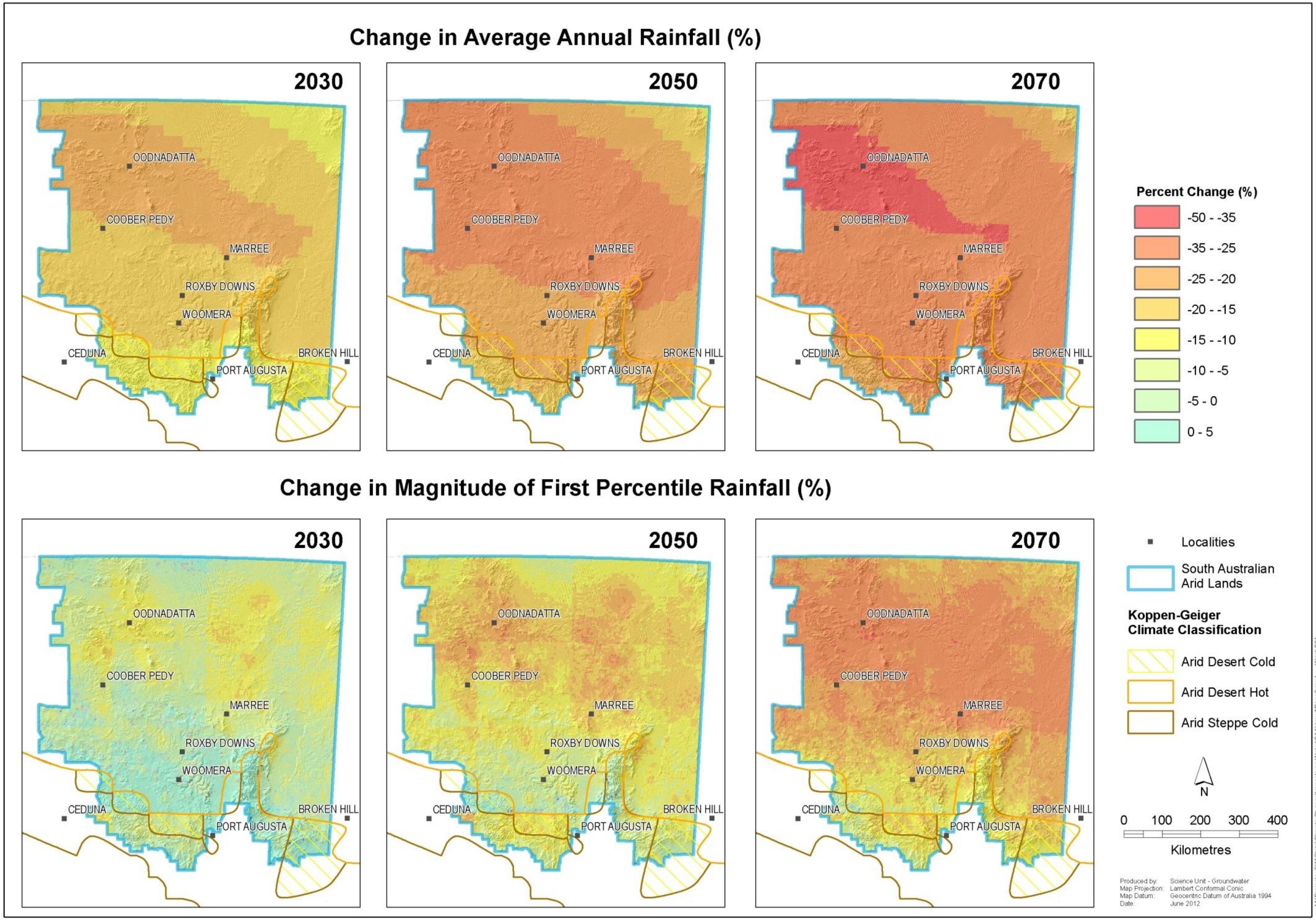


Figure 13. Change in average annual and first percentile rainfall for the 'worst' case projections (GFDL 2.0 GCM) and low emissions

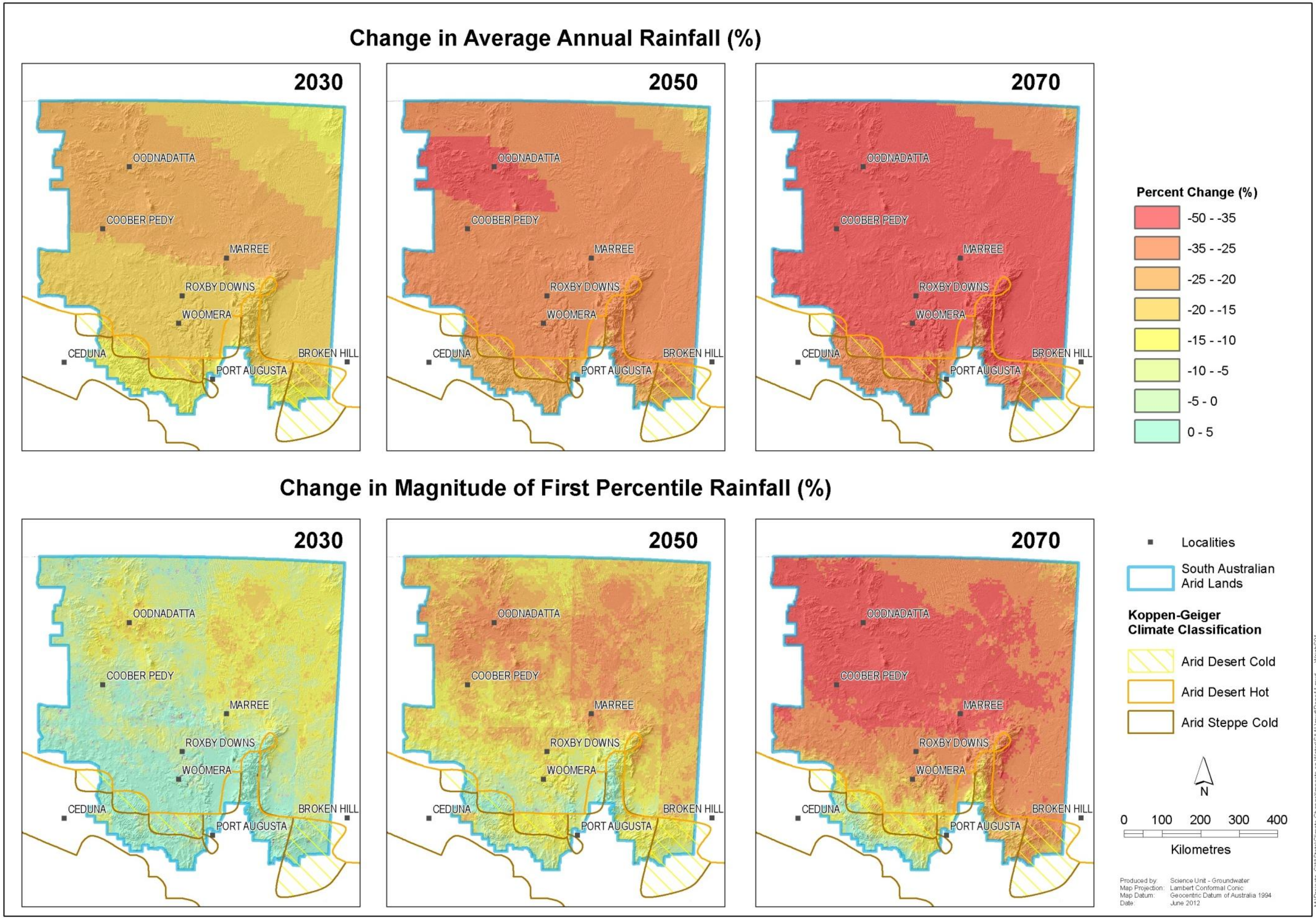


Figure 14. Change in average annual and first percentile rainfall for the ‘worst’ case projections (GFDL 2.0 GCM) and high emissions

3.2.3.3. Number of Months with Rainfall Greater Than 100 mm

Groundwater recharge in the 'hot desert' climate sub-zone is likely to be governed by localised and indirect recharge resulting from extreme rainfall events rather than diffuse recharge (de Vries & Simmers, 2002). Figures 15–20 show the historic and projected frequency of high rainfall periods (greater than 100 mm/month) and the percentage changes in this frequency under a range of future climate scenarios compared to the 1990 historic baseline period. Historically, the occurrences of summer-dominant recharge events in the 'hot desert' climate sub-zone are most frequent in the north, while the southern-half of the climate sub-zone experiences not more than one recharge event every 10 years, on average. The number of months that had a total rainfall greater than 100 mm over the 1990 baseline period (i.e. 1970–99) has been calculated and presented as the average number of years between recharge events (where recharge events are defined as any month with rainfall greater than 100 mm) in the top left map of each of the one-page arrays of maps in Figures 15 through 20. Most of the southern half of the Arid Desert Hot climate zone recorded less than one event every 9 or more years (Fig. 15) and as such, the projected changes in the frequency of extreme rainfall events are expected to have a minor impact on the sustainability of local groundwater resources for this area. The exception is the northern Flinders Ranges where, for the 1990 baseline case, recharge events occur around every 2–5 years.

For most of the region, it is difficult to present the change in number of months with rainfall greater than 100 mm/month in percentage terms, as the change in a small number of events can lead to a misleadingly high percentage change. For example, a reduction in the number of events from two in the 1990 historic baseline period to one event for a future projection scenario represents a 50% reduction. However, the representation of this frequency of occurrence is highly uncertain in locations where only one or two events occurred over a 30-year period. A different 30-year period (or a longer period) may have produced a different result. In order to provide a better representation of the percentage changes to the frequency of recharge events, adjacent cells have been aggregated from 0.05° grid cells to 0.25° grid cells in order to 'smooth' the changes across the landscape. Also, the maximum percentage change (Figs 15–20) has been limited to ±50%. Whilst it is acknowledged that there are cells with projected changes greater than ±50% , these cells represent a small proportion of the region and generally occur for cases where the number of recharge events is very low. Hence, the scale in the maps in Figures 15–20 has been limited to ±50% to allow clearer detail in the smaller percentage changes that occur in the north of the region.

The frequency of recharge event analysis broadly indicates that under the 'best' Climate Future case, there will likely be an increase in the frequency of recharge-generating rainfall events but, under 'most-likely' and 'worst' Climate Futures cases there will likely be a decrease. More specifically, the data for the frequency of extreme recharge-generating rainfall events (compared to the 1990 baseline case)show that:

- For the 'best' Climate Futures case, for both low and high-emissions scenarios (Figs 15 and 16), an increase in the frequency of recharge events is projected for areas (1) east of Oodnadatta; (2) northeast of Marree; and (3) the northern Flinders Ranges and the plains to the east of the ranges. There is a general trend in projections of small percentage increases in the number of recharge events to the east, grading to increases of up to 50% toward the west; relative to the 2030 time horizon, the areal extent of the projected increases is greater at the 2050 time horizon and greatest at 2070.
- For the 'most-likely' climate futures case, for both the low and high-emissions cases (Figs 17 and 18), reductions in the frequency of recharge events in the north of the region are widespread. The percentage reduction in the number of recharge events shows no spatial trends at the 2030 time horizon, but is greatest in the west of the region at the 2050 and 2070 time horizons. Around the

northern Flinders Ranges, under the low-emissions scenario, there is little change in the frequency of recharge events across the three time horizons. However, under the high-emissions scenario at the 2030 and 2050 time horizons the frequency of recharge events is around 4–5 years between events, but by the 2070 time horizon a reduction in frequency is projected to greater than 9 years between events for most of this area.

- For the 'worst' Climate Futures case, for both the low and high-emissions cases (Figs 19 and 20), the reduction in the frequency of recharge events to greater than nine years between events is projected for almost the entire SAALNRM Region. For the northern Flinders Ranges, at the 2030 time horizon, a frequency of around 4-5 years between recharge events is projected. By 2070, a reduction in frequency to greater than 9 years between events is projected for most of this area. Spatial trends in the percentage change in the number of recharge events are not apparent.

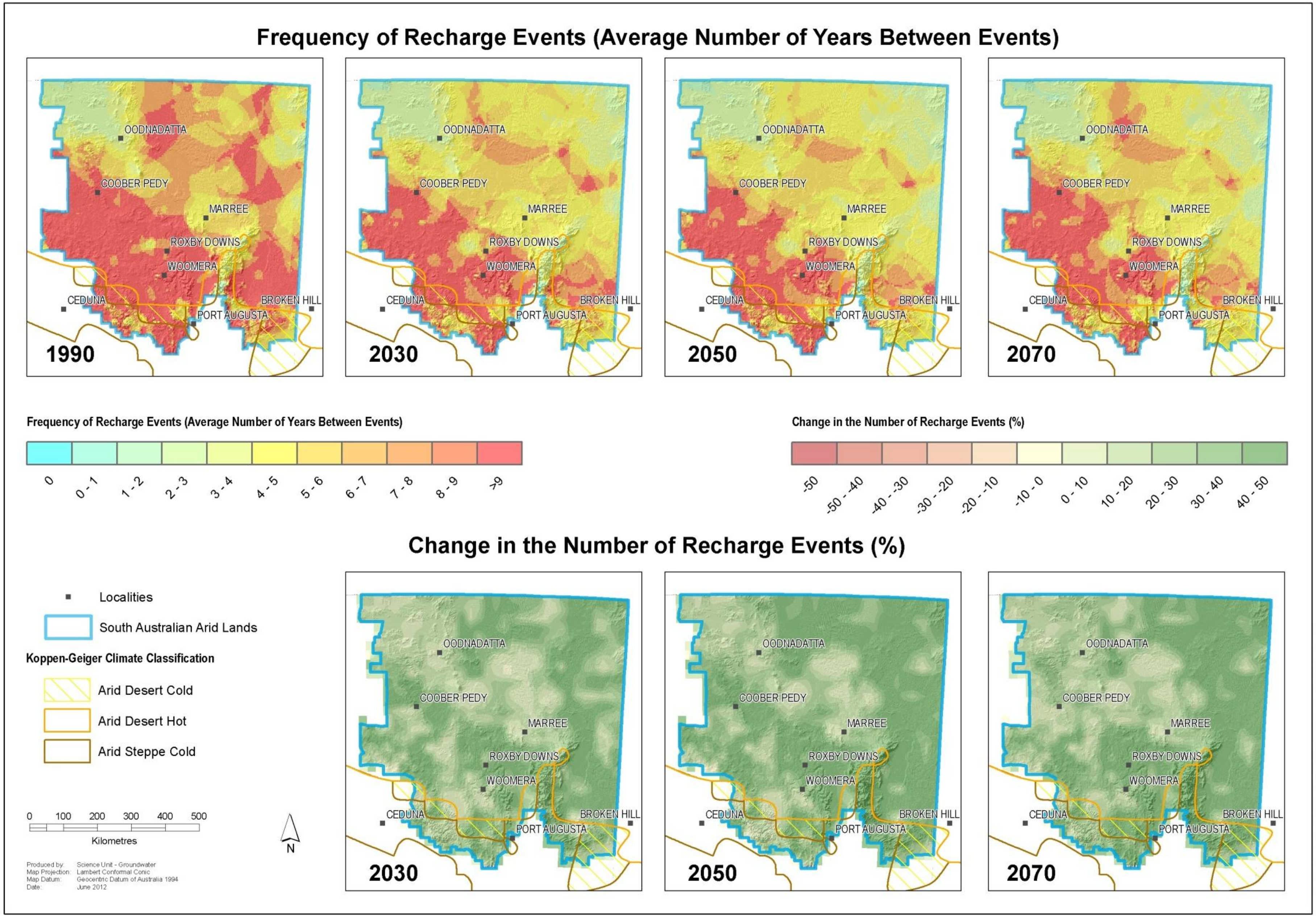


Figure 15. Change in the frequency of recharge-generating rainfall events (i.e. rainfall greater than 100 mm/month), and the number of events as a percentage, for the 'best' case projections (ECHO-G GCM) and low emissions

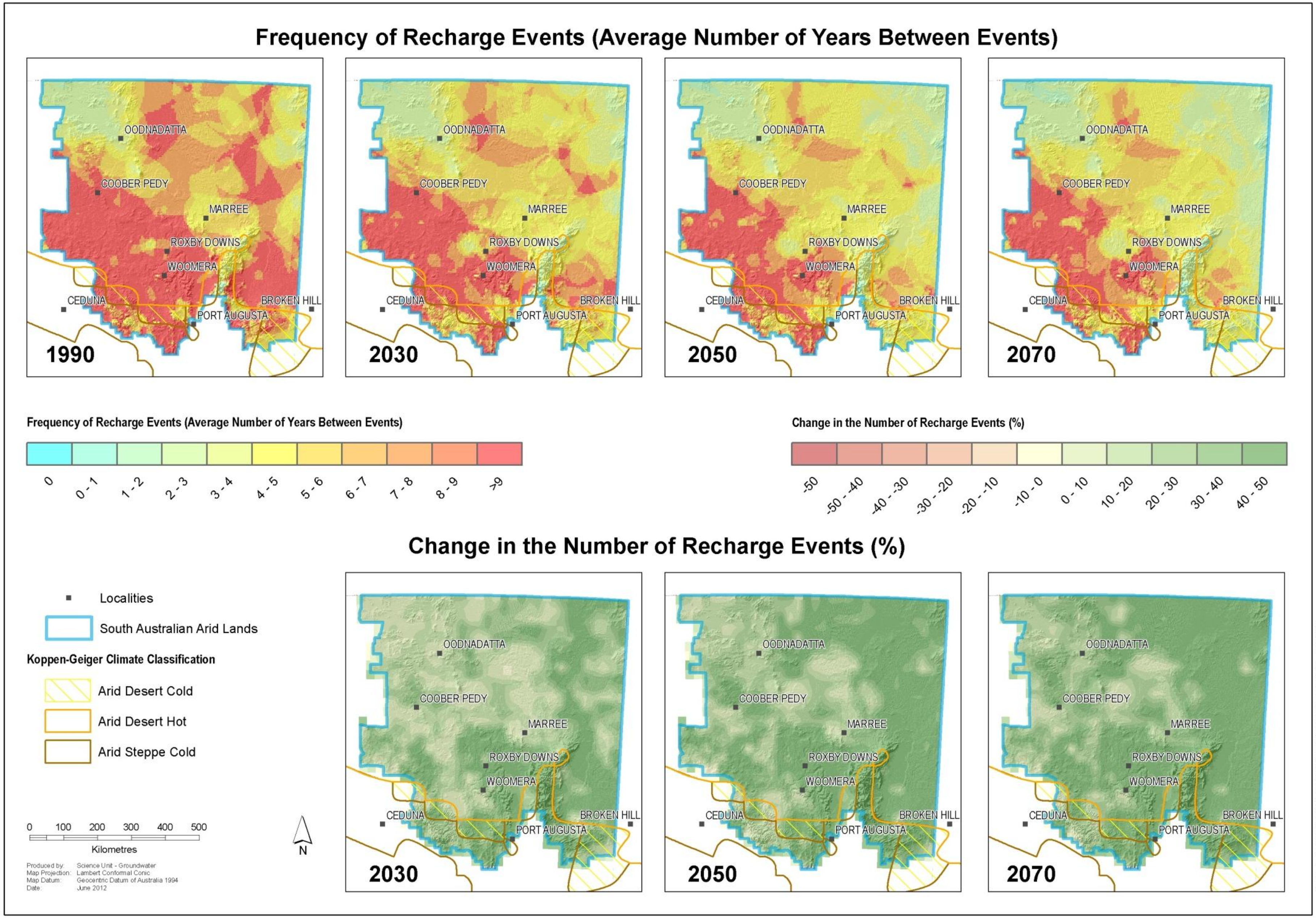


Figure 16. Change in the frequency of recharge-generating rainfall events (i.e. rainfall greater than 100 mm/month), and the number of events as a percentage, for the 'best' case projections (ECHO-G GCM) and high emissions

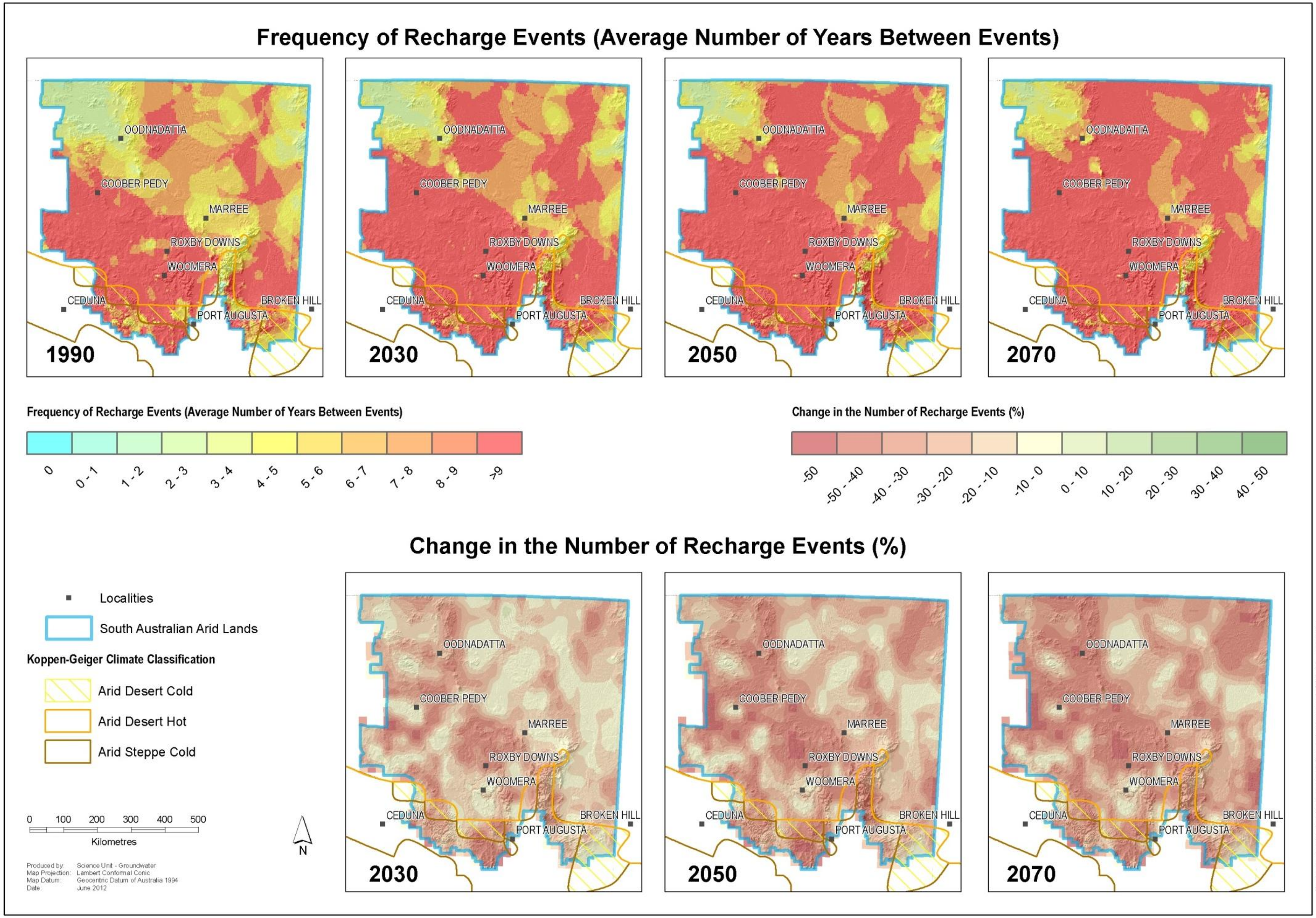


Figure 17. Change in the frequency of recharge-generating rainfall events (i.e. rainfall greater than 100 mm/month), and the number of events as a percentage, for the 'most likely' case projections (LASG-IAP GCM) and low emissions

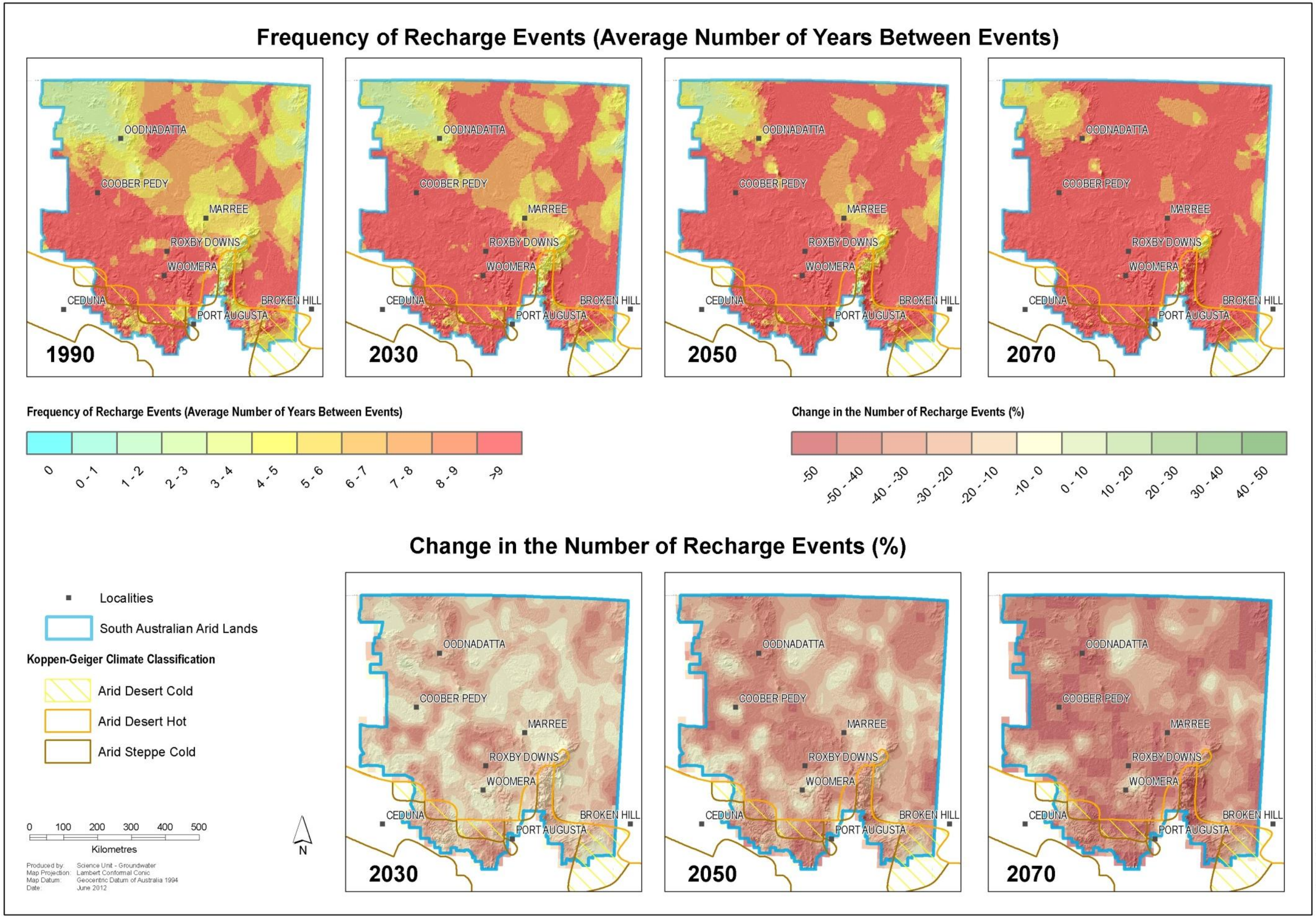


Figure 18. Change in the frequency of recharge-generating rainfall events (i.e. rainfall greater than 100 mm/month), and the number of events as a percentage, for the 'most likely' case projections (LASG-IAP GCM) and high emissions

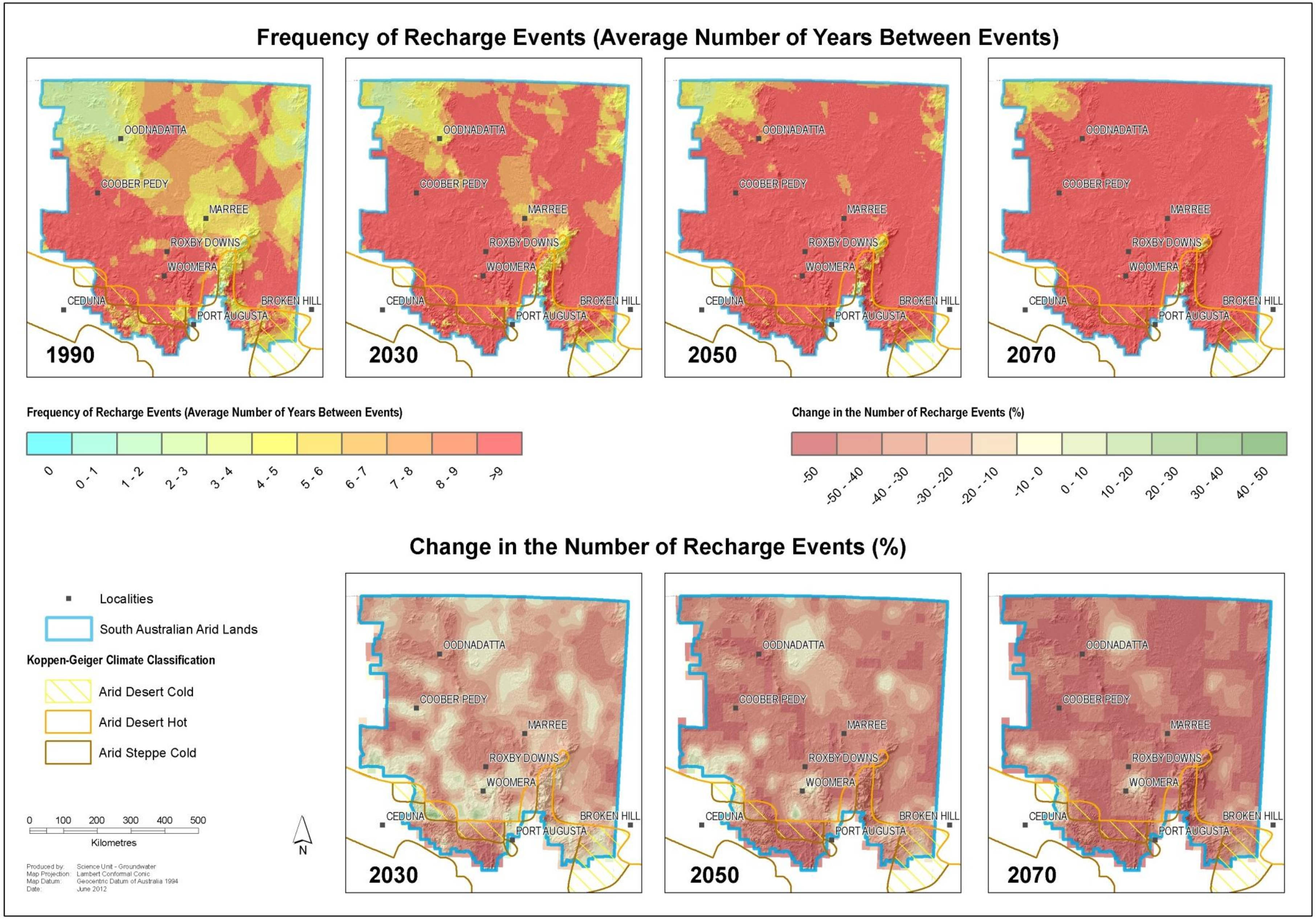


Figure 19. Change in the frequency of recharge-generating rainfall events (i.e. rainfall greater than 100 mm/month), and the number of events as a percentage, for the 'worst' case projections (GFDL 2.0 GCM) and low emissions

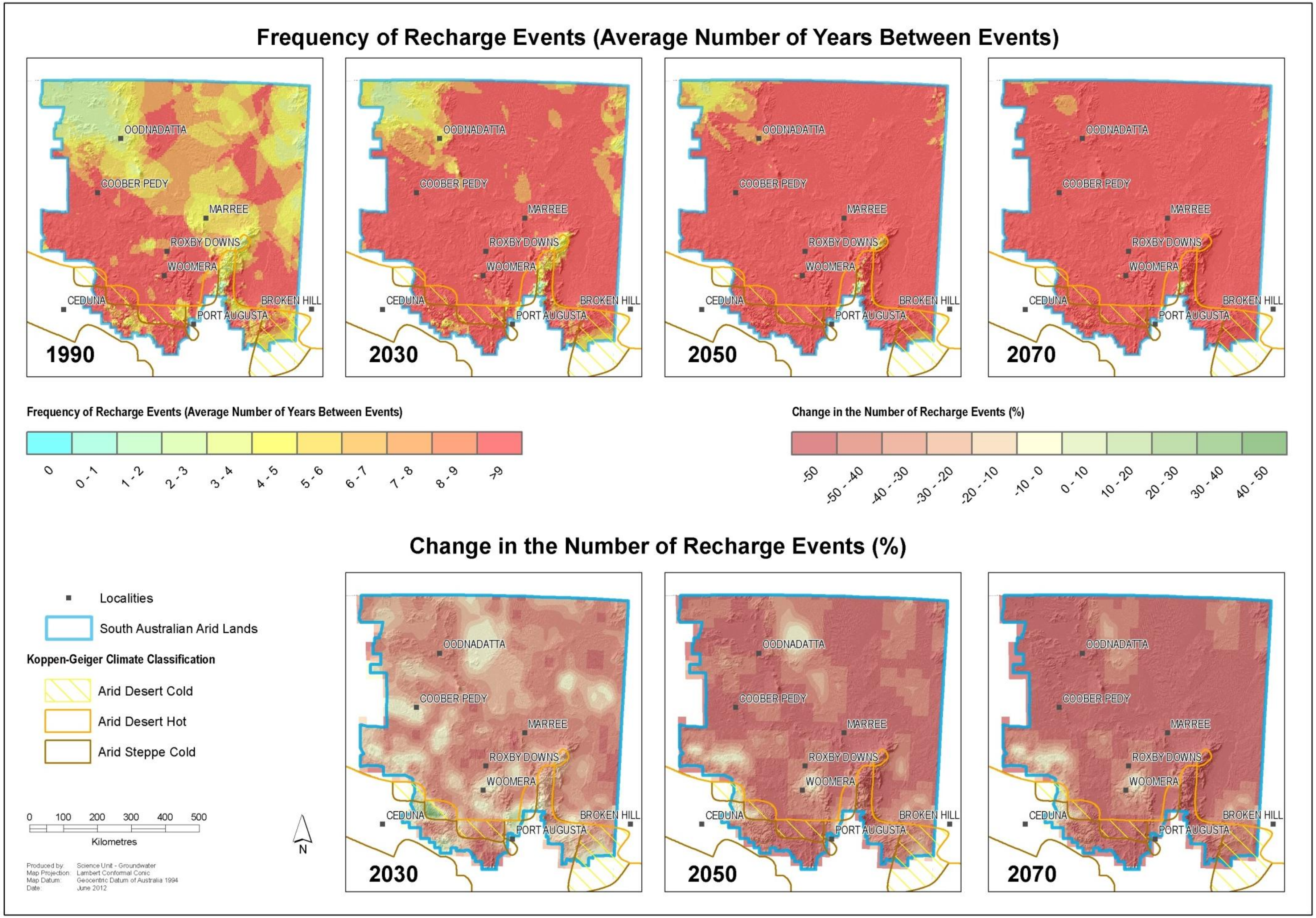


Figure 20. Change in the frequency of recharge-generating rainfall events (i.e. rainfall greater than 100 mm/month), and the number of events as a percentage, for the 'worst' case projections (GFDL 2.0 GCM) and high emissions

3.3. *CLIMATE CHANGE IMPACTS ON RUNOFF*

A surface water runoff model developed as part of the ARIDFLO project has been used to investigate the potential impacts of climate change on the surface water resources of the region. The ARIDFLO project, as part of the Lake Eyre Basin Agreement (Costelloe *et al*., 2004), aimed to improve the understanding of the ecological functioning of river systems in remote outback Australia. The project provided some of the best understanding of surface water hydrology in the SAALNRM Region, namely the Cooper, Diamantina and Neales-Peake river systems. The main aim of ARIDFLO was to investigate and describe connections between patterns of river flow and responses by animal and plant communities in the Lake Eyre Basin Rivers. The methodology included surveying fish, waterbirds, macroinvertebrates and vegetation and modelling stream flow, water quality and ecological responses. The model selected was for the Neales-Peake catchment, selected due to constrained hydrological nature of this system, in which flood extents and flood paths are not as variable as in the complex channel-country reaches of the lower Cooper and Diamantina Rivers, which were also investigated as part of the ARIDFLO project.

3.3.1. THE NEALES-PEAKE CATCHMENT

The Neales-Peake catchment (Fig. 21) is located on the western side of the Lake Eyre Basin and drains into Lake Eyre North. The Neales-Peake River—an unregulated, ephemeral river system—rises on the stony tablelands that form the western rim of the Lake Eyre Basin. The headwaters form at an altitude of 300–370 m and run a course of 430 km before reaching their terminus in Lake Eyre North at approximately sea level. The catchment area is around 34 000 km^2 with a median annual rainfall of 140 mm. Rainfall is summer dominant (December–March) but large rainfall events can occur during the winter months (Costelloe *et al*., 2004).

The in-channel waterholes located within the Neales-Peake catchment vary from shallow (up to 2.5 m deep), ephemeral waterholes to deeper waterholes (2.5–4.5 m deep) that are semi-permanent. Whilst deeper, permanent waterholes are not common, the Algebuckina Waterhole—the largest and deepest water body within the catchment—acts as an important refuge for the aquatic biota during periods of prolonged drought (Costelloe *et al*., 2004).

Figure 21. The Neales-Peake catchment (Photo: Roger Young) (NHT & DWLBC, 2002)

3.3.2. NEALES-PEAKE CATCHMENT RUNOFF MODEL

The Neales-Peake catchment rainfall-runoff model (Fig. 22) is a distributed runoff model constructed over a 5 km x 5 km grid. Rainfall and evaporation inputs are applied at a daily time step to simulate runoff across the catchment, based on the storage in each cell. The model was originally used to simulate the expected frequency of flooding for a number of wetlands in the catchment. The flow at the downstream end of the model has been chosen as an indicator of the possible impacts to runoff and streamflow as a result of climate change. This location corresponds to the Tardetakarinna Waterhole, at which Costelloe *et al.*(2004) reported a frequency of flooding of 16 in 24 years for the period 1974–2002, based on simulated flows.

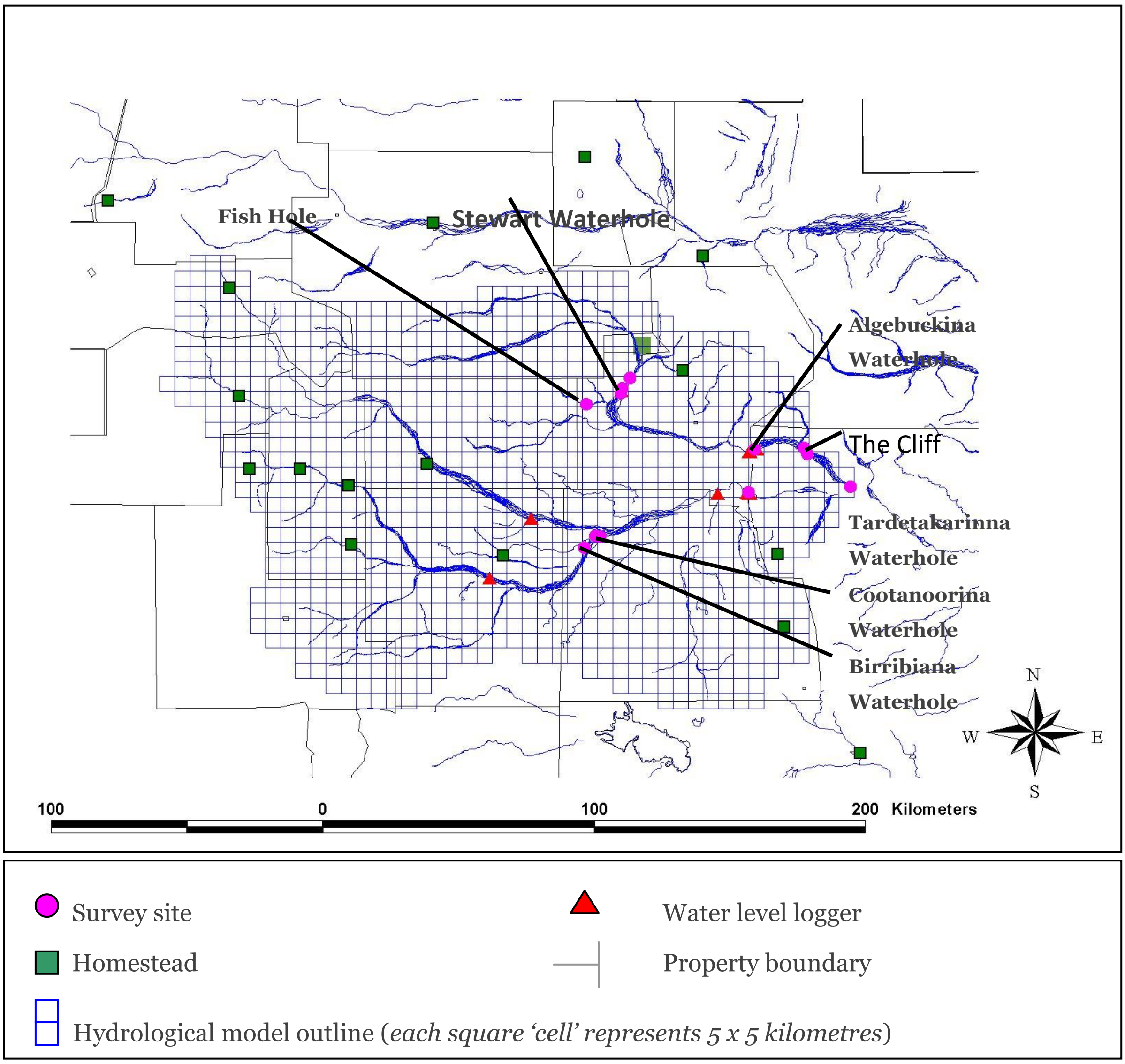


Figure 22. Neales-Peake reach survey sites, water level logger installations and the coverage of the hydrological model. (NHT & DWLBC, 2002).

3.3.3. MODEL INPUTS AND CALIBRATION

The Neales-Peake system is ungauged and, prior to the ARIDFLO project, stream flow data were not collected. Anecdotal reports of local pastoralists report that in-channel flow events occur once or twice per year. Larger flooding events with significant floodplain inundation appear to occur less frequently (Costelloe *et al.,* 2004). The ARIDFLO project was conducted during a particularly wet period for the

Neales-Peake catchment (2000–02) and consequently, data from a number of high-flow events were recorded. A number of smaller floods and flows also occurred during the study period. These events occurred only in parts of the river system, the lower Neales (downstream of Oodnadatta) experiencing the highest flows during this period (Costelloe *et al.,* 2004).

The model was calibrated at the Algebuckina Waterhole node using water-level logger data that recorded flow volumes following a number of rainfall events. The model showed variable performance, the best-performing model run unable to accurately simulate all flow events. Low flows in particular were often underestimated (Fig. 23). The model performed well for the February–March 2002 event, but appears to overestimate the June 2001 flood and underestimate the other flows (Costelloe *et al.,* 2004).

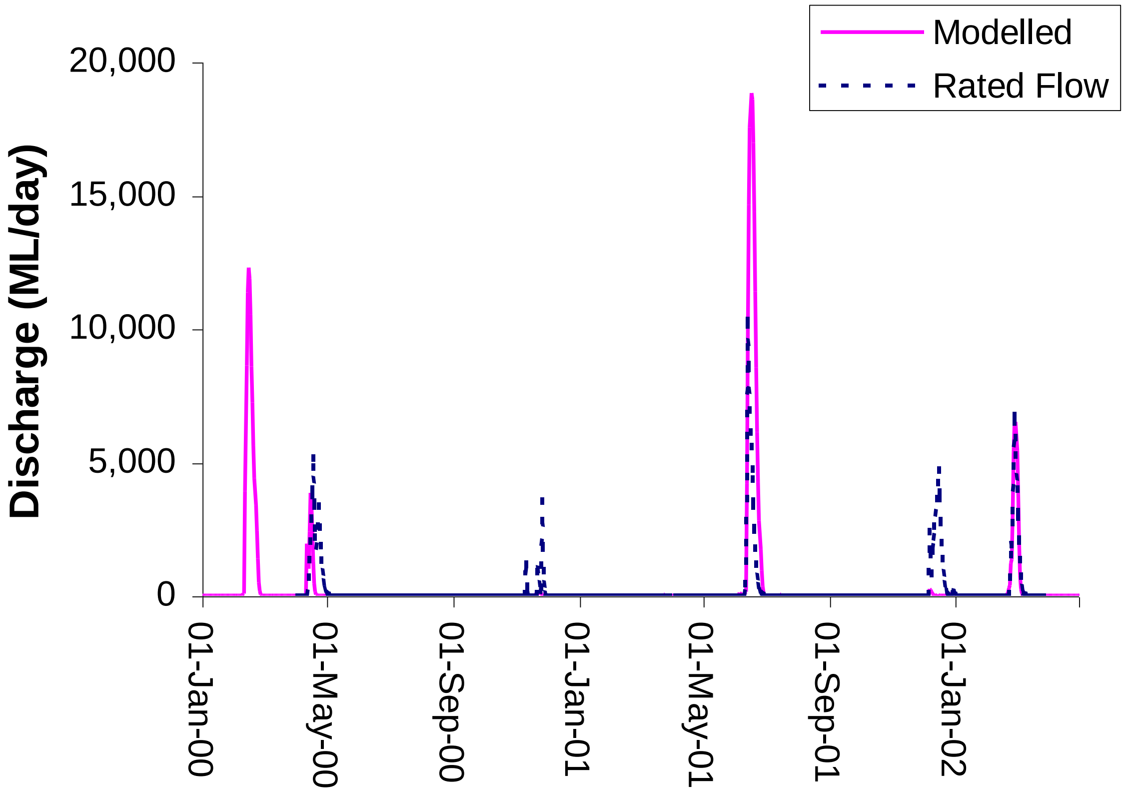


Figure 23. Modelled and observed flow at Algebuckina Waterhole, Neales River for period January 2000 to March 2002 (Costelloe *et al.,* 2004)

3.3.4. HISTORICAL CLIMATE FOR THE NEALES-PEAKE MODEL

In arid areas, rain may not fall for several consecutive years. Conversely, intense rainfall can deliver total annual rainfall in a single event. The runoff events in the Neales-Peake catchment are highly episodic and, while the monthly averages presented here provide some indication of the seasonality in the catchment, mean rainfall statistics in arid environments are often misleading and care should be taken in their interpretation.

Rainfall data for the period 1959–2003 was used in the Neales-Peake model to assess the potential impact in water resources from climate change. It has been assumed that OzClim projections, which are relative to the period 1975–2004, are also suitable to compare with this longer historical period. Across the Neales-Peake catchment, monthly average potential evapotranspiration (PET) is greater than monthly average rainfall for all months of the year (Fig. 24). The median monthly rainfall (represented by the horizontal black line within each blue box) is low—generally less than 10 mm/month—and the 25th–75th percentile monthly rainfall (denoted by the extent of each blue box) shows large variability around the median.

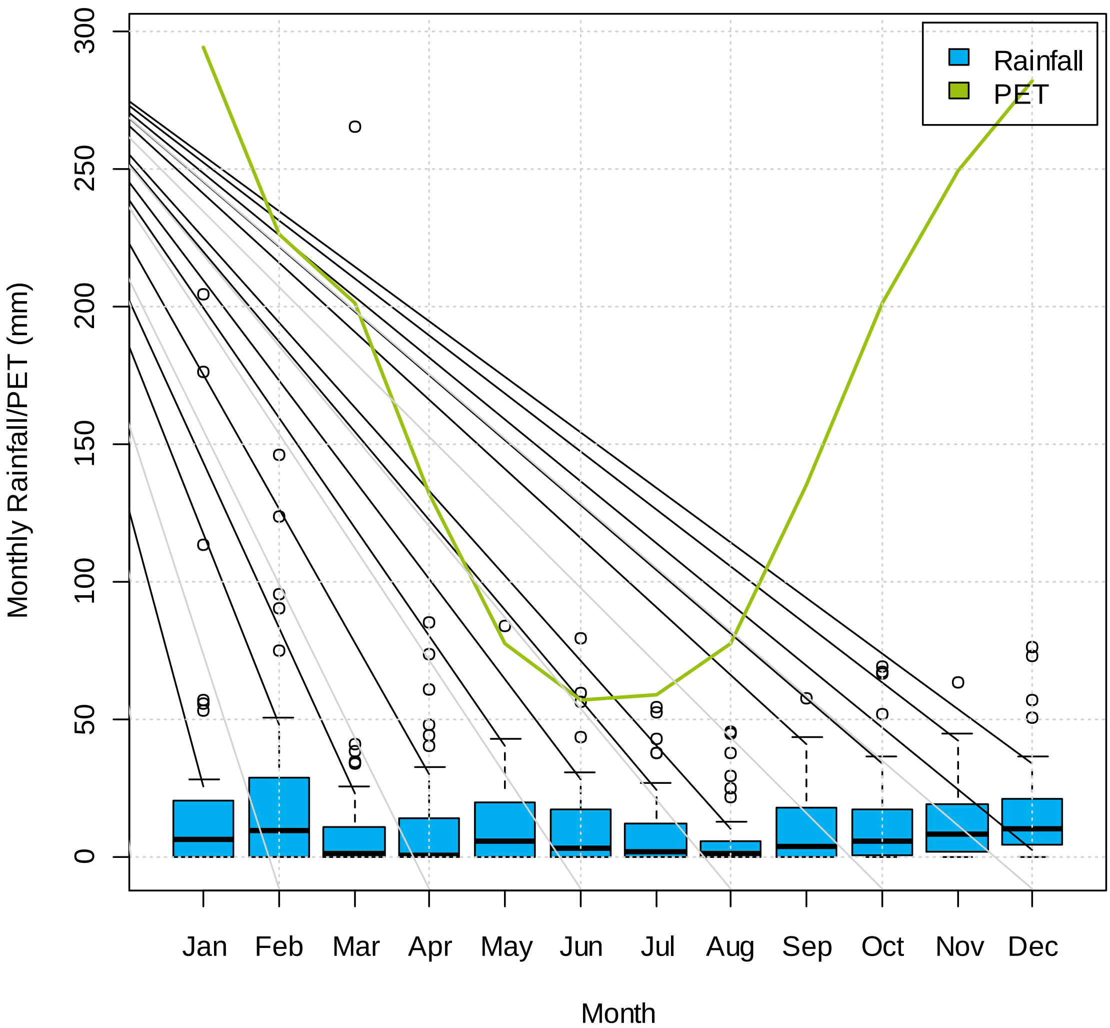


Figure 24. Monthly average rainfall and PET for the area represented by the Neales-Peake catchment rainfall-runoff model. The edges of the blue boxes represent the 25th and 75th percentile monthly rainfall. The whiskers extending beyond each box represent 1.5 times the range of rainfall shown within that box and circles represent monthly rainfall totals that fall outside this range, which can be considered extreme events.

The largest monthly rainfall over the 1959–2003 period typically occurs in the months of January and February and there was only four months in this 44-year period in which the monthly rainfall exceeded the potential evapotranspiration.

The simulated monthly average runoff resulting from these climate inputs is shown in Figure 25. The largest runoff events generally occur in January and February in response to the high rainfall, with runoff persisting into March and April. However, runoff events in this catchment are highly episodic and while the monthly averages presented here provide some indication of the seasonality in the catchment, average runoff conditions are not typical of actual conditions from year to year.

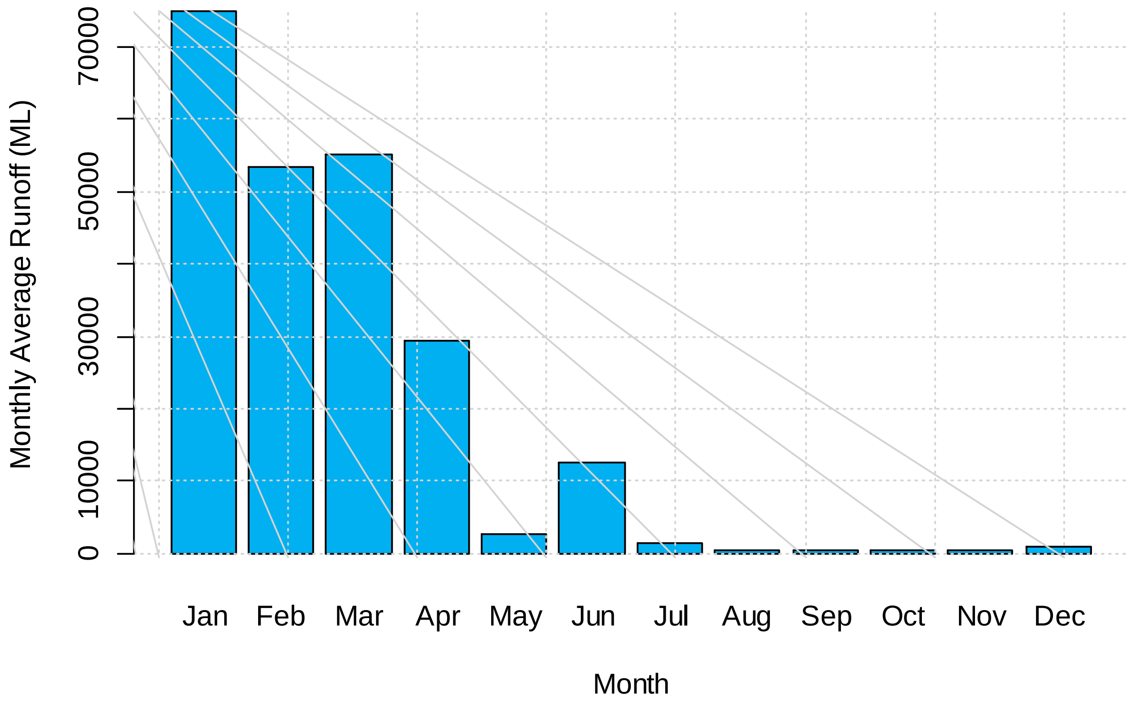


Figure 25. Simulated Monthly Average runoff from the Neales Model

3.3.5. CLIMATE CHANGE RESULTS

The climate projections of four GCMs that Gibbs *et al*. (2011) selected as being suitable for South Australia, and which have PET projections available, have been downscaled to provide input suitable for the Neales-Peake runoff model. These four GCMs are the LASG-IAP, MRI, NCAR-CCSM3 and CSIRO Mark 3.5 models. An indication of where these four GCMs fall within the Climate Futures analysis (Sect. 3.1) is shown in Figure 26. The four GCMs selected for this study produced a wide range of daily rainfall and PET data. The downscaling adjustments were calculated based on the average catchment rainfall presented in the previous section, and then applied to each cell in the model individually for each day. A constant percentage change was applied to the PET data, depending only on the season.

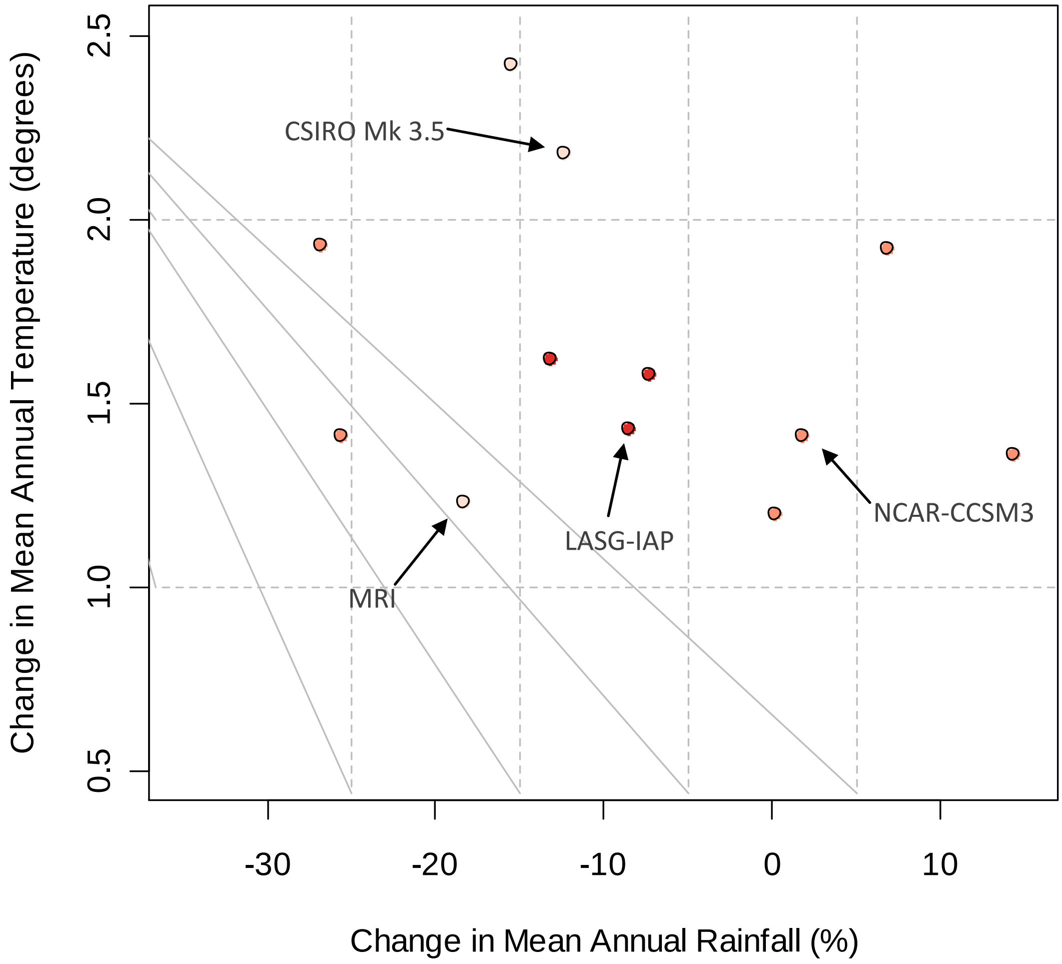


Figure 26. GCM Projections for Moomba for 2050 with high emissions, showing the results of the Climate Futures analysis and the four GCMs used in the Neales-Peake catchment rainfall-runoff model.

3.3.5.1. Climate

The projected changes in average annual rainfall, which have been calculated after applying the seasonal rainfall changes through the daily downscaling procedure, are shown in Figure 27. The CSIRO Mk 3.5 GCM projects the greatest reduction in average annual rainfall. The remaining GCMs are relatively consistent in their projections of change in rainfall across all time horizons and emission scenarios. The choice of emission scenario appears to have little impact on the projected changes in rainfall for 2030. By 2050, the high-emission scenario projections are very similar to the low emission scenario projections at the 2070 time horizon.

For each of the GCMs and for the different time horizons and emissions scenarios considered, the projected change in summer rainfall (Fig. 28) is very different to the projected change in annual rainfall (Fig. 27). For example, the LASG-IAP GCM projects a large reduction in summer rainfall events, whilst the MRI GCM projects an increase. This range in climate projections from a small sample of GCMs highlights the high level of uncertainty in projecting future climate patterns in arid regions of South Australia.

Notably, the GCM-derived projections of changes in mean annual rainfall in the 2050 high emissions scenario (Fig. 26) do not correspond well with the percentage changes shown in Figure 27. This is partly due to the slightly different locations considered, Moomba in Figure 26 and the average of the extent of the Neales-Peake model in Figure 27. However, most of the disparity is due to the annual changes in Figure 27 being based on mean annual rainfall after applying the GCM-projected adjustments for each season, whereas the projections illustrated in Figure 26 reflect the mean annual rainfall change values provided by OzClim (CSIRO, 2012). Investigations undertaken as part of this study have identified that the combined seasonal rainfall projections provided on OzClim are not always consistent with the annual projections for the same scenario and GCM. This is likely due to the regression algorithms that are applied by OzClim (CSIRO, 2012) in deriving percentage changes in rainfall.

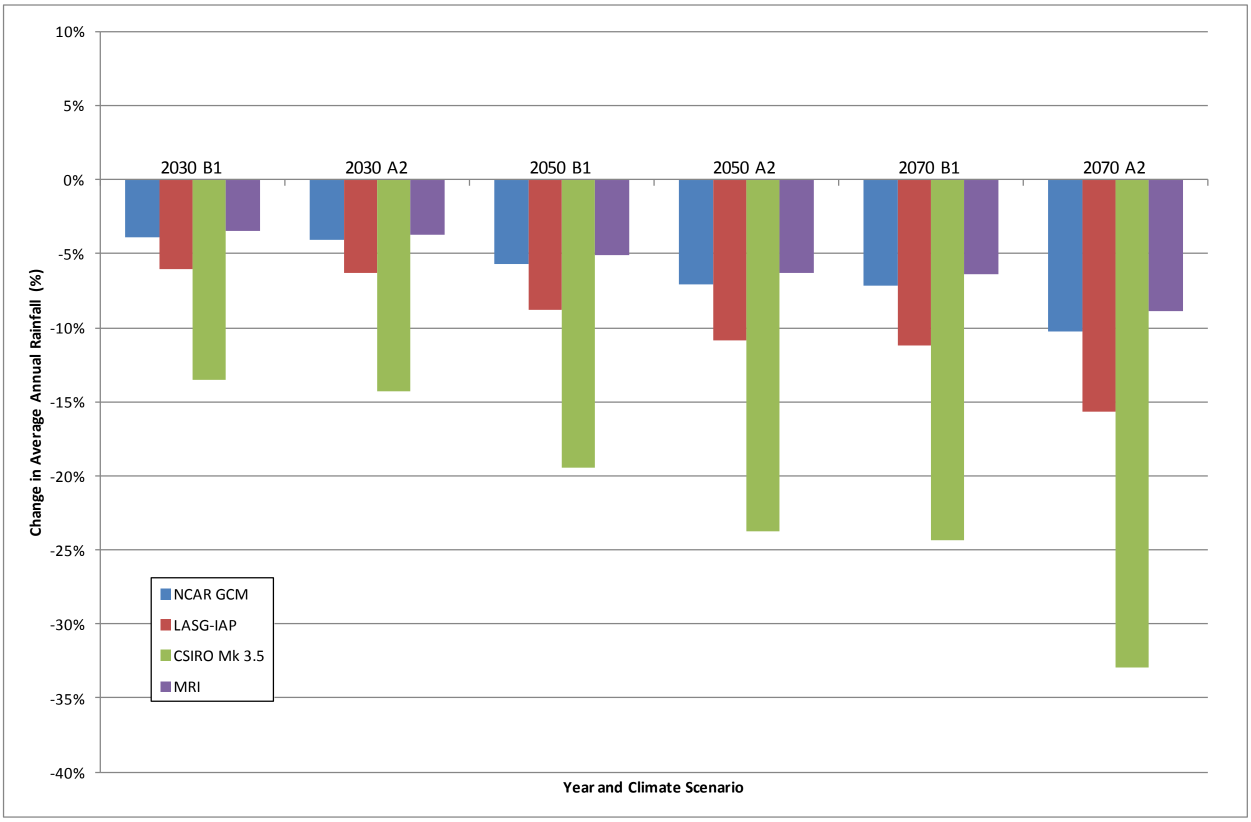


Figure 27. Reduction in average annual rainfall produced by the four different GCMs under the B1 and A2 emissions scenarios based on OzClim data at the centre of the Neales model domain

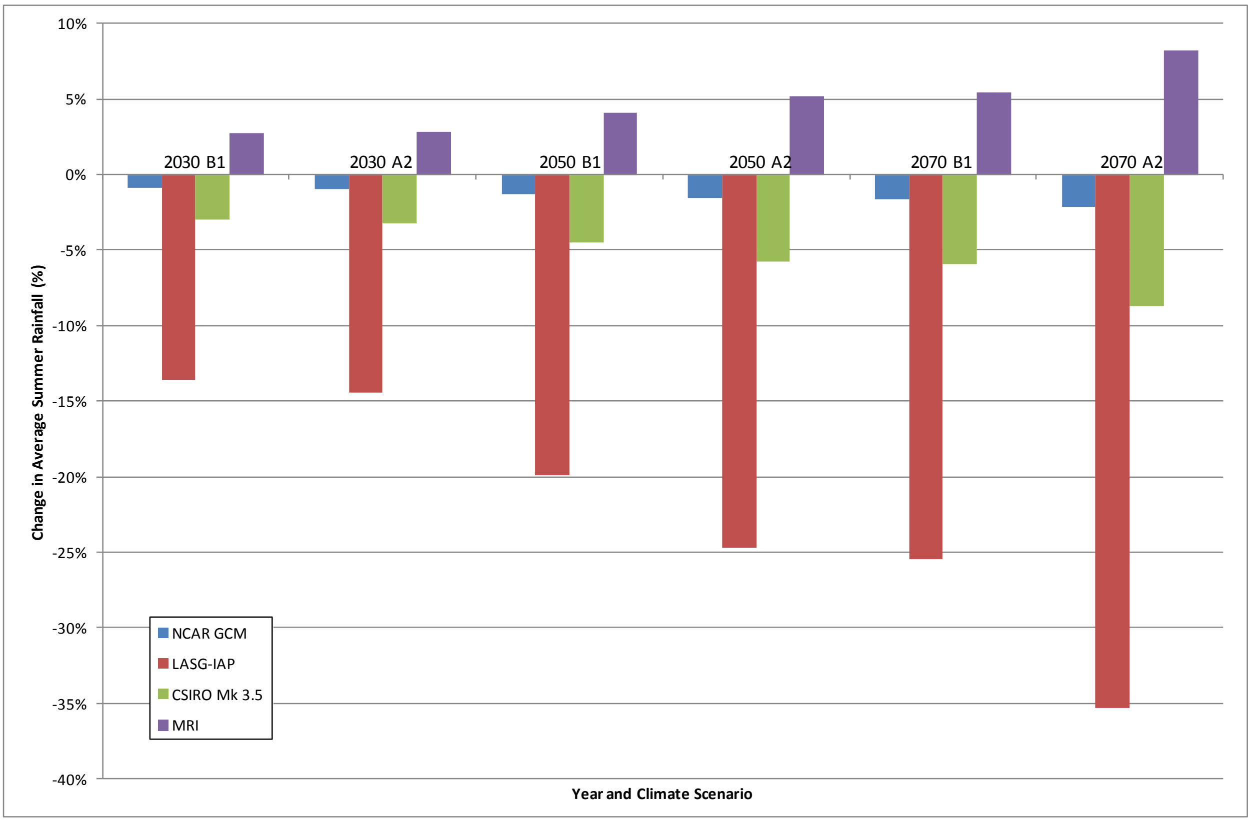


Figure 28. Change in average summer rainfall produced by the four different GCMs under the B1 and A2 emissions scenarios based on OzClim data at the centre of the Neales model domain

The projected increases in PET (Fig. 29) are relatively small. The greatest change in annual average PET is projected by the NCAR GCM, which projects increases in annual PET of less than 4%, even for the 2070 high emissions case. For summer PET, up to a 5% increase is projected by the CSIRO Mk 3.5 GCM for 2070 with high emissions (Fig. 30), however the LASG-IAP GCM projects very little change. The provision of projections of PET change was identified as an important GCM selection criteria to produce consistent input datasets for impact assessments of for the DFW Impacts of Climate Change on Water Resources project, however it is unlikely to be a determining factor in the context of the SAAL NRM Region. This is firstly because the projections only suggest very small increases in the PET, and secondly, because the average annual PET is already over 10 times greater than average annual rainfall, such that small increases in potential evapotranspiration are likely to have a limited effect on the actual evapotranspiration that is likely to occur.

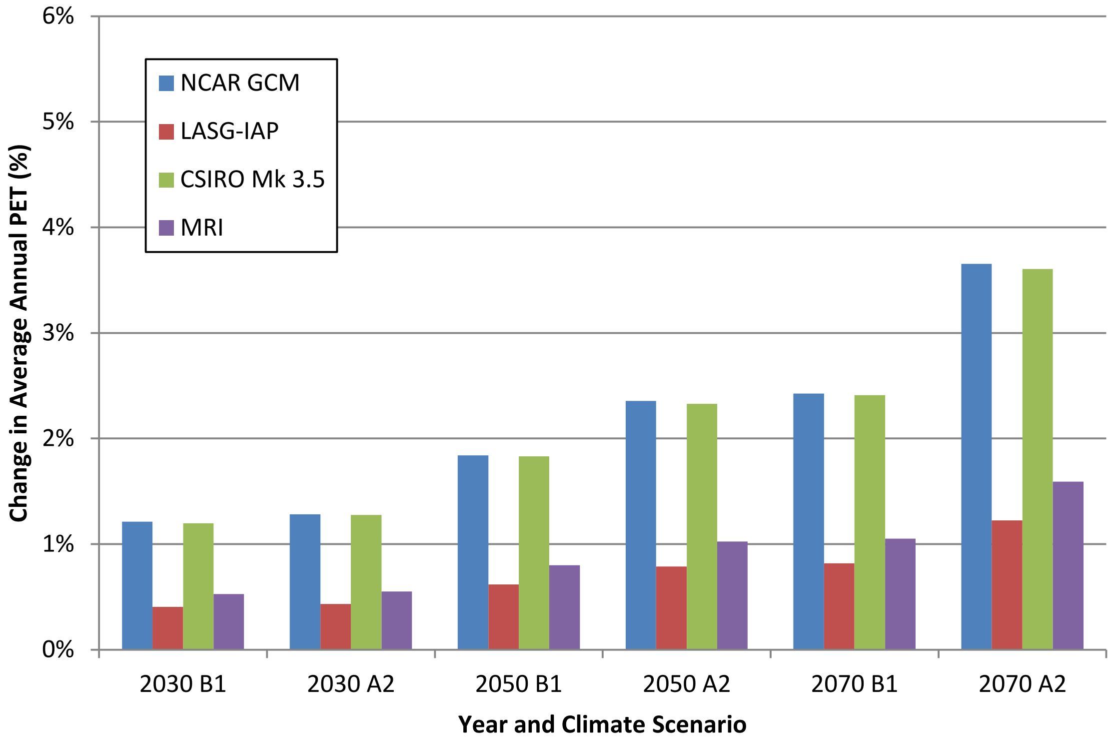


Figure 29. Increase in average annual PET produced by the four different GCMs under the B1 and A2 emissions scenarios based on OzClim data at the centre of the Neales model domain

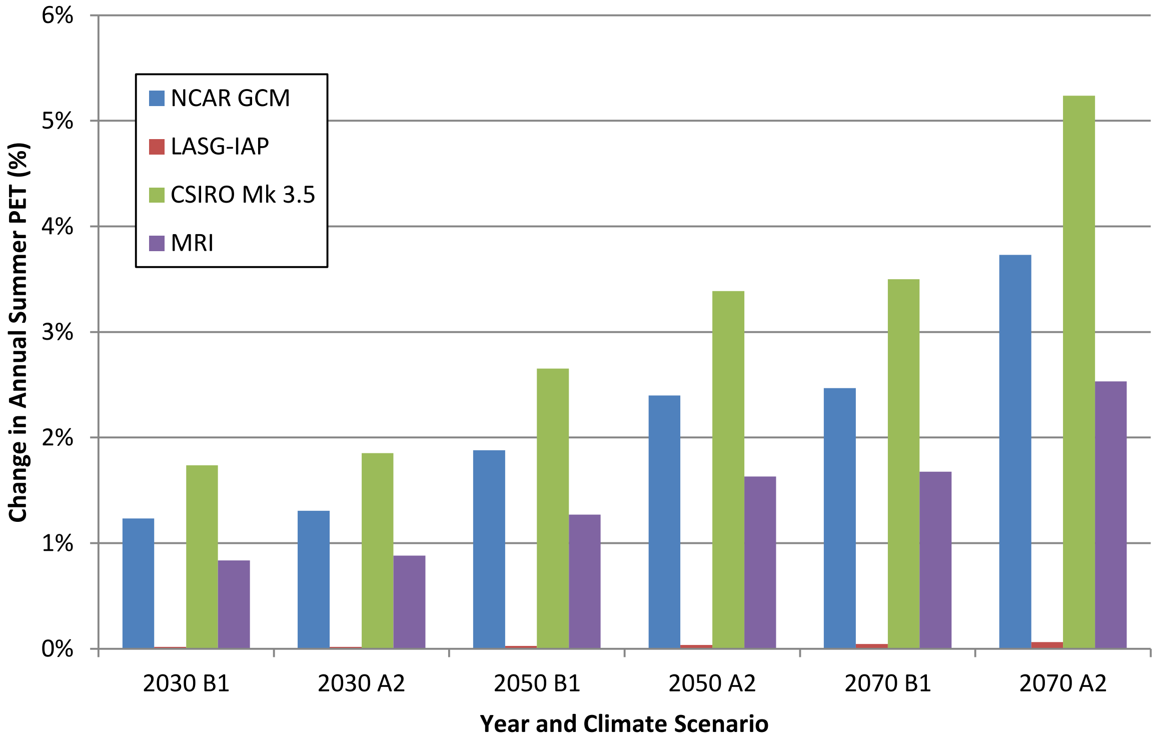


Figure 30. Increase in summer annual PET produced by the four different GCMs under the B1 and A2 emissions scenarios based on OzClim data at the centre of the Neales model domain

3.3.5.2. Runoff

The changes in average annual runoff had a much stronger correlation with summer rainfall (R^2=0.56) compared to annual average rainfall (R^2=0.01). Consequently, the percentage change in summer rainfall has been selected as the independent variable against which to consider the sensitivity of runoff (Fig. 31). However, the modelled runoff resulting from the climate projections of the NCAR-CCSM3 GCM do not show a relationship with summer rainfall. In Figure 31 it can be seen that the changes in summer rainfall projected by the NCAR-CCSM3 GCM are negligible, but large changes in the average annual runoff are projected. This is due to the large changes in rainfall projected by that GCM for the other seasons, particularly winter. For the three other GCMs, a strong relationship between winter rainfall and annual runoff can be seen, with a slope of a 2.1% change in annual runoff for a 1% change in summer rainfall, if the results from the NCAR-CCSM3 GCM are removed.

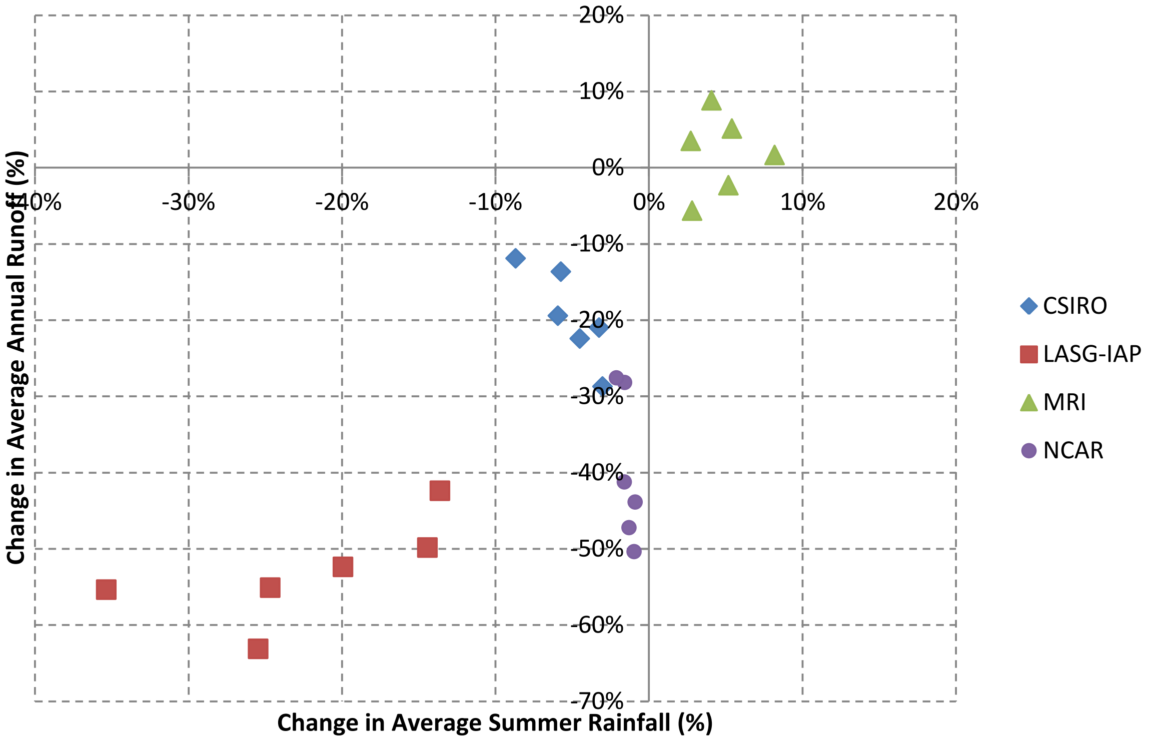


Figure 31. Changes in average annual runoff from the Neales River model for the corresponding projected change in summer rainfall.

For the episodic rainfall events that typically occur in the Neales-Peake catchment, average annual runoff is not a good predictor of the potential impacts to the region's water resources—rather, it is the elapsed time between episodic events that is likely to be important. The Tardetakarinna Waterhole, which is located at the final node of the model, has a cease-to-flow depth of 2.2 m (Costelloe *et al.,* 2004). This is approximately equal to the annual average evapotranspiration, so the waterhole is likely be dry after around one year without inflows. An increase in the length of dry periods beyond one year is likely to adversely affect the biota that depend on more frequent refilling events.

The mean duration of the dry periods was compared for the each of the climate scenarios considered, as an indicator of the level of risk to the region's waterhole-dependent biota. As a baseline for comparison, a simulation based on historic rainfall resulted in a mean dry period length of 53 days. For the purposes of this analysis, a dry period was defined as seven or more consecutive days with flow less than 1 ML/d.

Model results indicate that the correlation between the change in the length of dry periods and average annual rainfall (R^2=0.44) was greater than with the change in average summer rainfall (R^2=0.25).

Consequently, the impact of percentage changes in annual average rainfall on the duration of dry periods is considered in this analysis and presented in Figure 32.

Model results indicate that a reduction in the average annual rainfall will result in an increase in the mean length of the dry period. The slope of the relationship is close to one-to-one (i.e. a 1% reduction in rainfall leads to an increase in the average length of dry periods by approximately 1%). However, there is large variance in the model results, indicated by a large degree of scatter in the data (R^2=0.44). This is likely to be attributable to the wide range of changes in seasonal rainfall amounts projected by the four GCMs.

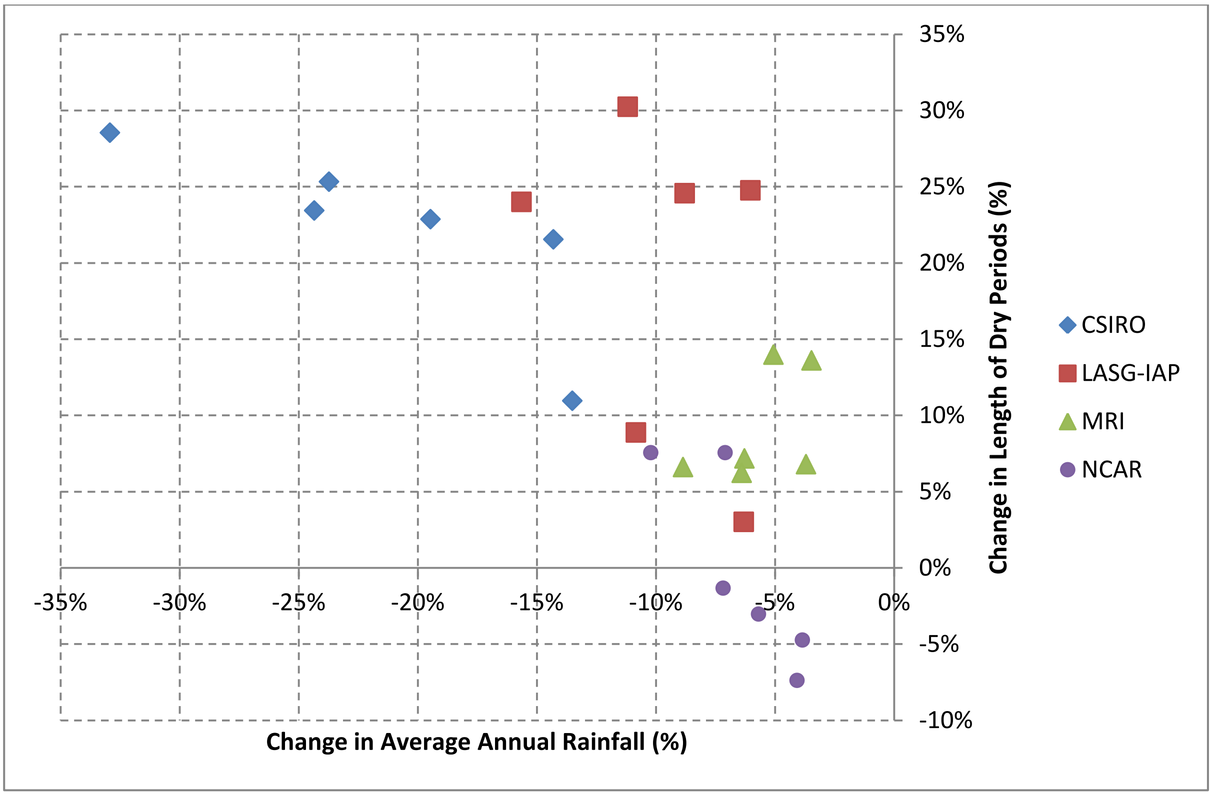


Figure 32. Change in the length of dry periods between runoff events for the projected change in average annual rainfall

3.4. CLIMATE CHANGE IMPACTS ON THE GREAT ARTESIAN BASIN

The Far North Prescribed Wells Area (FNPWA) is largely aligned with the margins of the part of the GAB that lies within South Australia. Underground water from the primary aquifers of the GAB is critical to the health of ecological communities and the viability of the pastoral, mining and energy resource industries in the FNPWA (SAAL NRMB, 2009). Due to its extremely large scale, the vulnerability to climate change of the groundwater resource of GAB within South Australia is markedly different to the more localised aquifer systems of the SAAL NRM Region. The capacity of the GAB as a water resource is largely dependent on the amount of groundwater in storage in the system and flowing across the state border from the north and east, rather than on recharge occurring in South Australia.

The Far North Prescribed Wells Area Water Allocation Plan (FNPWA WAP) (SAAL NRMB, 2009) provides the current management framework for the groundwater resources of the GAB. The FNPWA WAP adopts a resource management approach based on an acceptable fall in aquifer pressure levels and provides indicative consumptive pool volumes for each of four management zones. The impacts of future climate change on the use of groundwater from the GAB aquifers will be dependent on the effects that future changes in recharge occurring within the recharge areas of the basin in Queensland and New South Wales may have on changes in aquifer pressures in areas where groundwater is extracted.

Two recent natural resource research projects have provided new understanding of the recharge processes of the GAB in South Australia and the effects of contemporary and longer-term recharge changes on aquifer pressures.

The National Water Initiative project 'Allocating Water and Maintaining Springs in the Great Artesian Basin' (AWMSGAB project) has provided a new understanding of the relative quantities of the main water balance components of recharge, discharge and aquifer flow and of the status of the water balance within the South Australian section of the GAB. The findings of the groundwater recharge and hydrodynamics study of the AWMSGAB project (Love *et al*., 2013) indicate that overall recharge and inflow to the basin in South Australia is less than was assumed or estimated by previous studies because 1) the impact of groundwater flowing from Queensland to SA is probably less significant than previously estimated, and 2) the recharge occurring in the western margin of the basin is very small. These findings are reinforced by a further key finding of the AWMSGAB project's hydrodynamic modelling study, that aquifer pressures in the GAB are in a state of slow, long-term decline.

The findings of Love *et al.* (2013) indicate that present day recharge at the western margin of the GAB in SA is very low and that it may be that only episodic flood recharge in the northern ephemeral rivers (Finke, Plenty and Hale rivers) of the Western Eromanga region is significant. This recharge is significant locally, and is an important source of recharge to the parts of GAB aquifer that give rise to the Dalhousie Springs group. If climate change during the 21st century has an impact on the frequency of large episodic flooding events, then episodic flood recharge in these northern rivers is likely to be affected by this change. However, the AWMSGAB project findings indicate that an upper limit for this recharge source under the current and recent historic climate is an annual average of less than 13 GL/y, which is very small compared to the overall scale and groundwater capacity of the western region of the GAB in South Australia. Furthermore, the annual average diffuse recharge occurring extensively across the western margin of the GAB is estimated to be less than 0.2 mm/y. Much greater rates than this occur in areas of higher relief rock outcrop and as flood recharge in some of the rivers to the north, however these occur in only a very small fraction of the area of the western margin and therefore generate only small volumes of recharge compared to the size of the GAB groundwater resource (Love *et al*., 2013).

The implication of these findings is that the amount of groundwater available for extraction from the GAB in South Australia is not likely to be significantly impacted by any future reductions to the amount of contemporary recharge occurring within the recharge areas at the western margin of the basin, simply because the current rates of recharge are so low compared to the scale of the GAB aquifers.

Another recent research study into the GAB groundwater resource is the CSIRO's 'Great Artesian Basin Water Resource Assessment' (GABWRA project) (Smerdon *et al*., 2012a).

The GABWRA project conducted a numerical modelling study of aquifer pressures in Central and Western Eromanga regions of the GAB using the GABtran single-layer groundwater model (Welsh, 2006) for a range of future climate and groundwater development scenarios. These included 'wet', 'mid' and 'dry' future scenarios, according to the projections of a number of climate models. The possible changes in aquifer pressures in the Central Eromanga regions of the GAB were projected under scenarios in which recharge in the high recharge areas in the northeast of the GAB was scaled up (by up to 56%) or down (by up to 27 %) depending on a range of possible future climate scenarios. The results predicted that the change in aquifer pressure within the South Australian part of the Central Eromanga region due to the climate-driven recharge changes alone was less than one metre (Smerdon and Ransley, 2012). Similar scenario modelling was conducted for the Western Eromanga region, which includes much of the South Australian section of the GAB, and contains the majority of pastoral industry groundwater users of the GAB in South Australia. For this region the recharge scaling (to represent future climate scenarios) was applied only to the recharge areas of the western margins of the GAB within SA and the Northern Territory. The model outcomes predicted aquifer pressure reductions between 2010 and 2070 throughout the western Eromanga region in response to the 'mid' and 'dry' scenarios, with declines of 5 to 10 m or more in the most westerly parts of the region under the 'dry' scenario. Under the 'wet' scenario the model outcomes predicted aquifer pressure increases for the whole region in 2070, with rises of more than 5 m in some of the most westerly and northerly parts of the region (Smerdon *et al*., 2012b).

These model outcomes are highly dependent on the amount of recharge that actually occurs in the western margin recharge zones. The occurrence of such significant recharge is somewhat contradicted by the findings of AWMSGAB project, which indicate that the amount of recharge occurring in the western margin of the GAB is very low.

If the contemporary rate and volume of recharge occurring at the western margin are as small compared to the size of the GAB resource as indicated by the findings of the AWMSGAB project, it is unlikely that a reduction in recharge at the western margin due to future climate change will have a significant impact on water levels. Even the large percentage reductions in frequency of recharge events projected by the 'worst-case' GCM projections (as indicated by Figures 19 and 20) are unlikely to have a significant effect on aquifer pressure levels in the South Australian part of the GAB.

However, the model results of the GABWRA project indicate that aquifer levels within the western GAB are very sensitive to changes in recharge rates in the western margin recharge areas. If an increase in recharge were to occur in response to an increase in frequency of large rainfall events if the 'best-case' future climate were to eventuate, then an increase in aquifer levels could be expected to occur. The outcomes of the modelling of the 'wet' future climate scenario by the GABWRA project indicate that the timescale of such an increase could be in the order of a few decades and that the extent of the increased water levels due to increased recharge could affect much of the most westerly half of the SA section of the GAB.

The impacts of climate change in the 21st century on GAB aquifer pressures should not be considered in isolation from other factors affecting aquifer pressures in the GAB groundwater system. The groundwater hydrodynamics study conducted by the AWMSGAB project concluded that the GAB aquifer system is probably not in steady state, but is undergoing a change in state in response to long-term climate variation. Groundwater pressure levels across the GAB are undergoing re-equilibration to a reduction in recharge at the margins of the basin over a multi-millennia time scale. Natural groundwater discharge processes, such as via springs and diffuse discharge through overlying aquitards, are driven by present-day aquifer potential levels, which are not in equilibrium with the contemporary recharge rate. Hence, current discharges from the basin are likely to be greater than recharge and the system is in a state of ongoing pressure decline. Modelling undertaken by the GABWRA project considered the effects on aquifer pressures of a continuation of the rehabilitation of uncontrolled flowing bores throughout the GAB. The results of this suggested a rise in pressures in the Western Eromanga region over the period 2010 – 2070. When the effects of bore rehabilitation were examined in isolation from the modelled climate change impacts, the projected aquifer pressure levels were found to rise by up to 5 m throughout much of the Western Eromanga region in South Australia (Smerdon *et al*., 2012b).

The FNPWA WAP mandates limitations on the allowable groundwater pressure change that may occur due to groundwater extractions. The volume of groundwater available for extraction from the GAB in SA is currently controlled by these pressure change limits. In the longer term future, the amount of water available for extraction from the GAB aquifers within the FNWPWA will be dependent on:

1. recovery in aquifer pressures that may result from ongoing rehabilitation of uncontrolled flowing bores,
2. the amount of groundwater pressure change that may be considered acceptable under future regulatory frameworks, and
3. decline in aquifer pressures that may result from:
   i. natural rises and falls in water levels that occur over very long periods of time in very large scale aquifer systems such as the GAB, and
   ii. impacts of 21st century climate change on contemporary recharge.

It is unlikely that climate change impacts on GAB recharge occurring in South Australia will cause a reduction in water availability, however an increase in water availability is possible if the wetter or ‘best’ future climate case scenarios eventuate. The impacts of climate change on recharge that occurs at the eastern side of the GAB, primarily in Queensland, may result in significant positive or negative impacts on aquifer pressures in the South Australia part of the GAB, however the outcomes of modelling of these impacts are inconclusive.

Assessments of future water availability in the western GAB should also take account of the other drivers of groundwater level change discussed here, as well as future changes in regulatory frameworks. These may have at least as much influence as climate change on the future availability of groundwater from the GAB in South Australia.

4. CONCLUSIONS

Understanding the potential impacts of climate change on the capacity of water resources in the SAALNRM Region is an important step towards the planning of the region's water resources for the medium- to long-term future.

The region can be broadly described as having two distinct climate zones: (1) along the southern-SAALNRM Region boundary, where rainfall is winter dominant and the climate is typically semi-arid; and (2) north of the semi-arid climate zone, where rainfall is summer dominant and the climate is more arid. Rainfall generally becomes increasingly episodic and unpredictable toward the north of the region. Due to the low rainfall and high potential evapotranspiration in the arid zone, groundwater recharge is likely to occur only following extreme rainfall events. Previous studies have shown that in arid environments similar to the northern SAALNRM Region, recharge occurs episodically, typically resulting from rainfall events greater than around 100 mm/month (Harrington, Cook & Herczeg, 2002; Tweed *et al.,* 2011).

There are only limited data available with which the capacity of the groundwater resources in the SAALNRM Region might be estimated. Groundwater and rainfall data are sparse at both the regional and local scale, making it difficult to determine any relationship that might exist between contemporary rainfall and groundwater level response. Consequently, it is difficult to develop and calibrate numerical models of recharge and runoff to quantify the likely risks, which has been the approach taken in projecting impacts to water resources as a result of climate change in previous ICCWR studies.

Sufficient data were available to investigate the impacts of climate change projections on the surface water availability for the SAALNRM Region using a rainfall-runoff model for the Neales River. Modelling results indicate that the largest rainfall events, generally occurring in the months of January and February, lead to the highest stream flows occurring in summer and into autumn. The LASG-IAP GCM projects a large reduction in summer rainfall events, while the MRI GCM projects an increase. This range of variability between only a limited selection of GCMs indicates how difficult it is to identify consistent or likely projections for the arid regions of the state. The projected increases in potential evapotranspiration are small, at less than 4% for even the worst case projections of the annual average PET, and up to a 5% change in Summer PET projected for the worst case (CSIRO Mk 3.5 GCM for 2070 with high emissions). The most likely case (LASG-IAP GCM) projects very little change at all for the summer PET. However, the average annual PET is over 10 times greater than average annual rainfall in this region. Consequently, this small increase in potential evapotranspiration is likely to have a limited effect on the actual evapotranspiration and therefore on the flow in the region's surface water systems.

For the episodic events typical of the Neales catchment, the average annual runoff is not a particularly informative measure of changes in the catchments. For the ecological health of waterholes, it is the time between these episodic events that is important. To consider these changes, the mean length of the dry periods between flow events was compared for the each of the climate scenarios considered. While there is large scatter in the results when compared to the change in rainfall (R^2=0.44), caused by the different changes in the rainfall amounts for the different season for each GCM, the slope of the relationship is close to one-to-one, where a 1% reduction in rainfall leads to an increase in the average length of dry periods by approximately 1%.

For the remainder of the SAALNRM Region, rainfall metrics have been used to provide projections of the impact of climate change on the water resources. The metrics selected are the changes, compared to the 1990 baseline climate, in:

- annual average rainfall, as an indicator of the overall projected change

- the first percentile daily rainfall amount, as an indicator of the change in the magnitude of the largest rainfall events
- the frequency of rainfall events of greater than 100 mm/month, as an indicator of episodic large rainfall events that generate groundwater recharge in the arid north of the region.

Projected changes in the magnitude and frequency of the largest rainfall events, compared to the 1990 historic baseline period, are considered to be indicative of the resulting changes in frequency of groundwater recharge events in the arid part of the region with summer-dominant rainfall.

The Climate Futures approach of Clarke *et al.* (2011) was used to select a suitable subset of GCMs that are representative of the full range of projected future climates for the region. Three GCMs were selected that represent, the 'best', 'most-likely' and 'worst' future climate case projections for the SAALNRM Region. High and low greenhouse gas emissions scenarios were considered for time horizons of 2030, 2050 and 2070.

The GCM selected to represent the 'best' future climate case projects increases in average annual rainfall of 0–5% (compared to the 1990 baseline case) across most of the region in both the low or high-emissions scenarios, except close to the south-western boundary of the region where reductions in average annual rainfall of up to around -5% are projected. In the projections of the GCM selected for the 'most-likely' future climate case, changes in average annual rainfall show a general trend of small reductions toward the southeast and southwest, but large reductions of up to 19% are projected in the arid north under a high-emissions scenario at the 2070 time horizon. Reductions in average annual rainfall are most pronounced under the 'worst' Climate Future – projected to decrease by 35–50% across most of the SAALNRM Region by 2070 under a high-emissions scenario.

Results for the extreme rainfall events (the first percentile daily rainfall) compared to the 1990 historic baseline period, show that the direction of change varies between the climate models considered. With the 'best' future climate case model, under both low and high-emissions scenarios, increases of up to approximately 5% in extreme rainfall events are projected across the entire SAAL region. With the 'most-likely' and 'worst' future climate case GCMs, reductions of up to 26.6% and 50% respectively are projected for the 2070 time horizon under the high-emissions scenario.

A reduction in the frequency of the large episodic rainfall events expected to lead to groundwater recharge (months of rainfall greater than 100 mm) is projected when results are averaged across the whole SAALNRM Region. However, these reductions are highly variable due to the very low frequency of months with rainfall greater than 100 mm for most of the region; in some cases an average of less than once every 10 years. Averaged across the whole region, the projected changes to the frequency of these large rainfall events, according to the 'most-likely' future climate case GCM, suggest average decreases in the frequency of these events to be 18–21% in 2030, 30–33% in 2050 and 35–47% in 2070, under low and high-emissions scenarios respectively. There is no clear spatial bias or trend in these changes, but the percentage reductions are generally greatest in the west of the region at the 2030, 2050 and 2070 time horizons.

The potential for climate change to affect the future availability of groundwater for extraction from the Great Artesian Basin was also investigated. Due to its extremely large scale, the vulnerability to climate change of the groundwater resource of GAB within South Australia is markedly different to the more localised aquifer systems of the region. The capacity of the GAB as a water resource is largely dependent on the amount of groundwater in storage in the system and flowing across the state border from the east, rather than on recharge occurring in South Australia.

It is unlikely that climate change impacts on GAB recharge occurring in South Australia will cause a reduction in water availability, however an increase is possible if the wetter or 'best' future climate case scenarios eventuate. The impacts of climate change on recharge that occurs at the eastern side of the

GAB, primarily in Queensland, may result in significant positive or negative impacts on aquifer pressures in the western GAB, however the outcomes of modelling of these impacts is inconclusive.

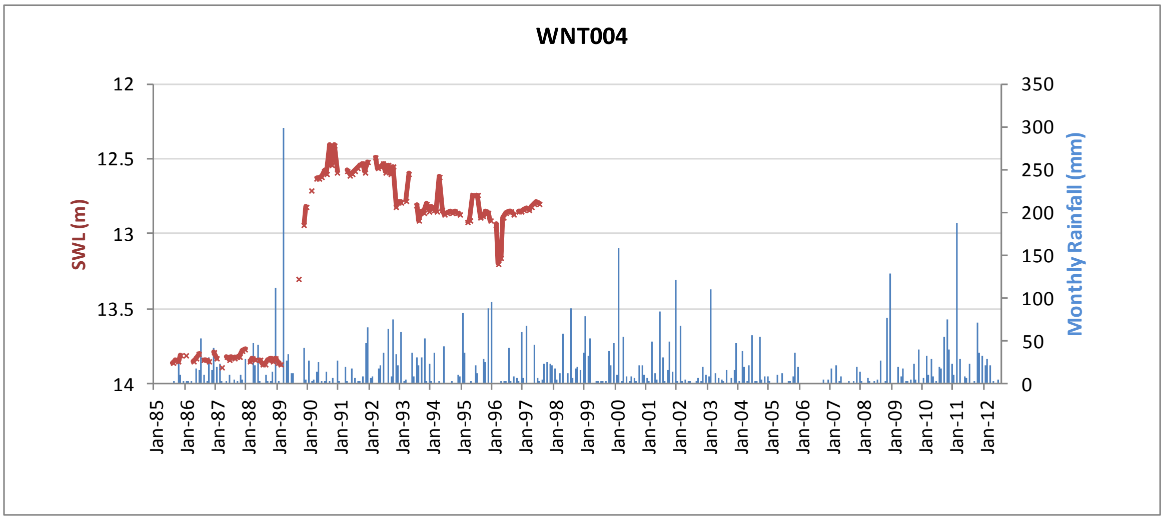
Groundwater extraction from the GAB in South Australia is currently controlled by aquifer drawdown limits imposed by the FNPWA Water Allocation Plan. In the longer term future (2050-2070) it is likely that the amount of water available for extraction from the GAB aquifers within the FNPWA will be dependent on:

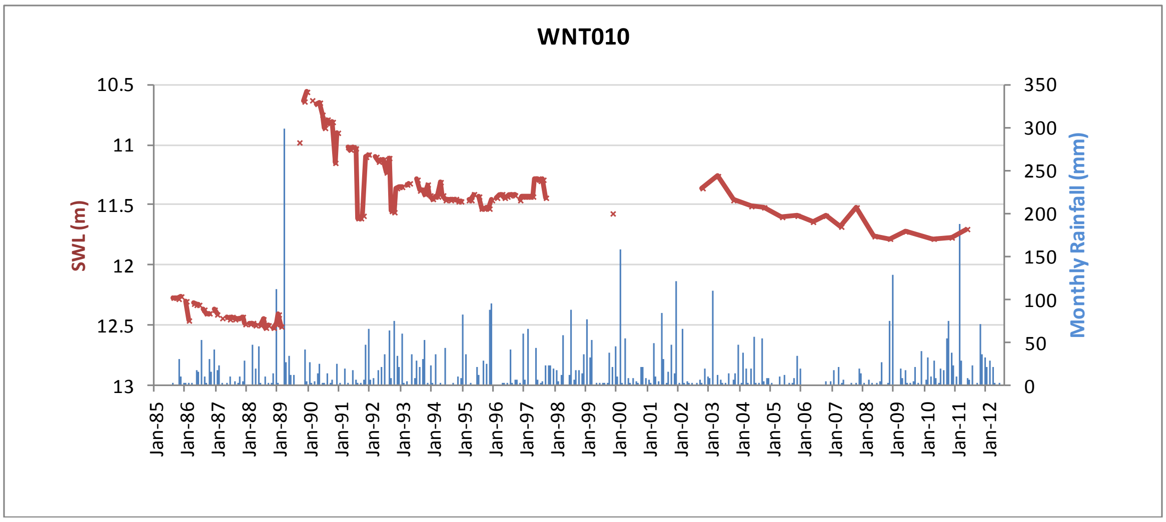
- the changes in aquifer pressures that may result from ongoing rehabilitation of uncontrolled flowing bores;
- the decline in aquifer pressures that may result from 1) natural rises and falls in water levels that occur over long periods in very large scale aquifer systems such as the GAB, and 2)the impacts of 21st century climate change on contemporary recharge of the aquifers;
- the amount of groundwater pressure change that may be considered acceptable under future regulatory frameworks.

Assessments of future water availability in the western GAB should take account of the drivers of groundwater level change discussed here as well as future changes in regulatory frameworks, which may have at least as much influence as climate change on the future availability of groundwater from the GAB in South Australia.

APPENDICES

A. MARLA RAINFALL AND GROUNDWATER LEVELS





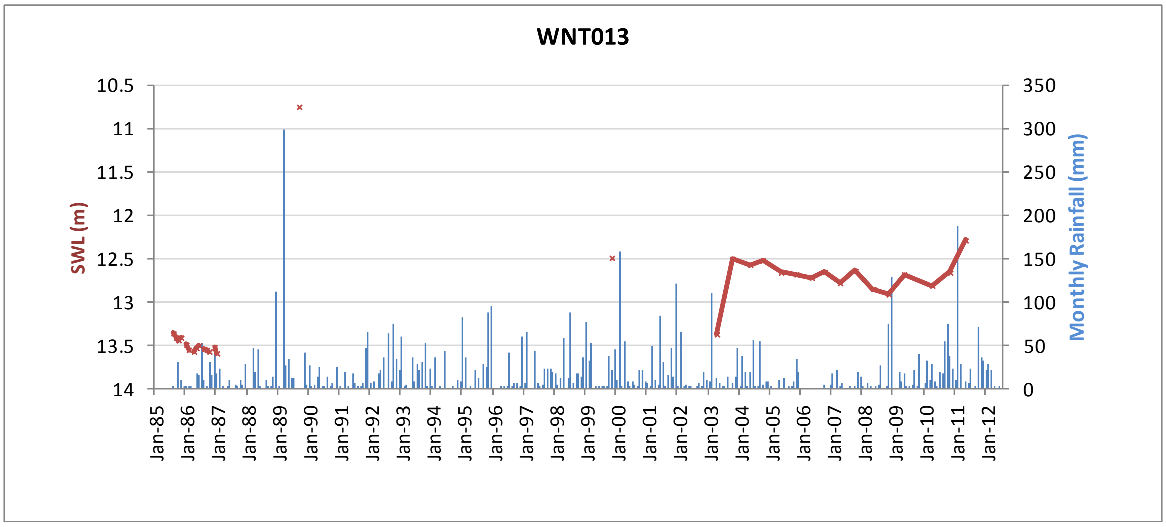
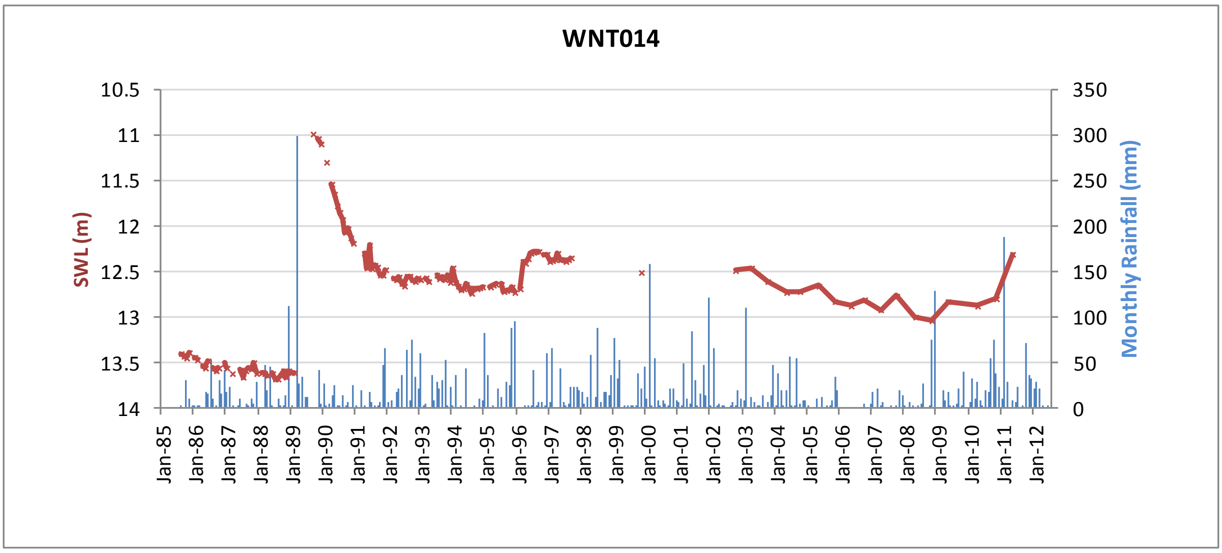
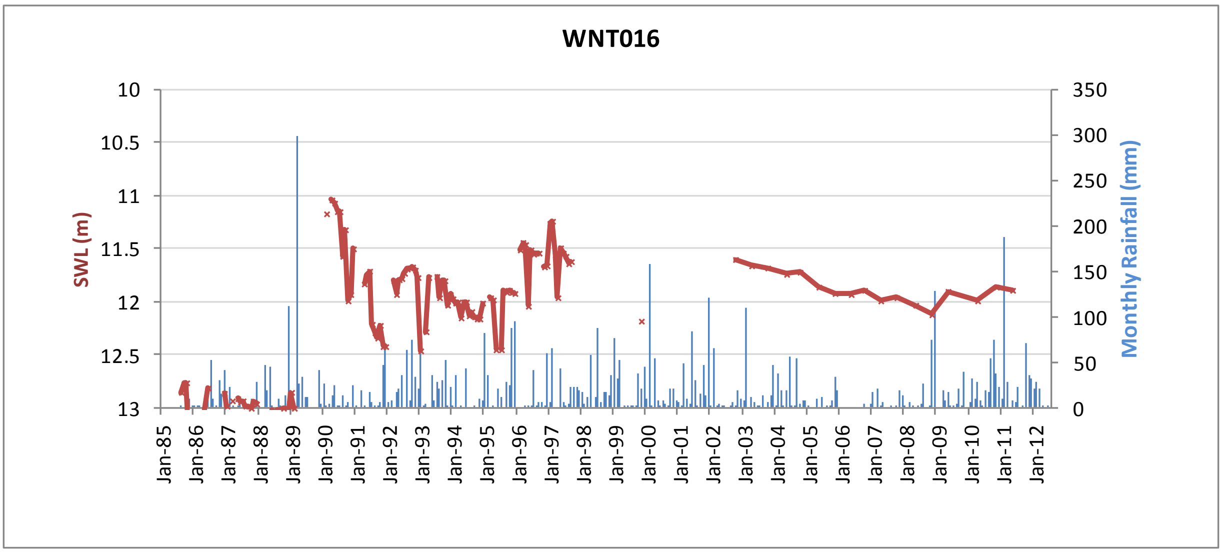


Figure A1. Monthly rainfall and groundwater levels and for town water supply wells located around Marla





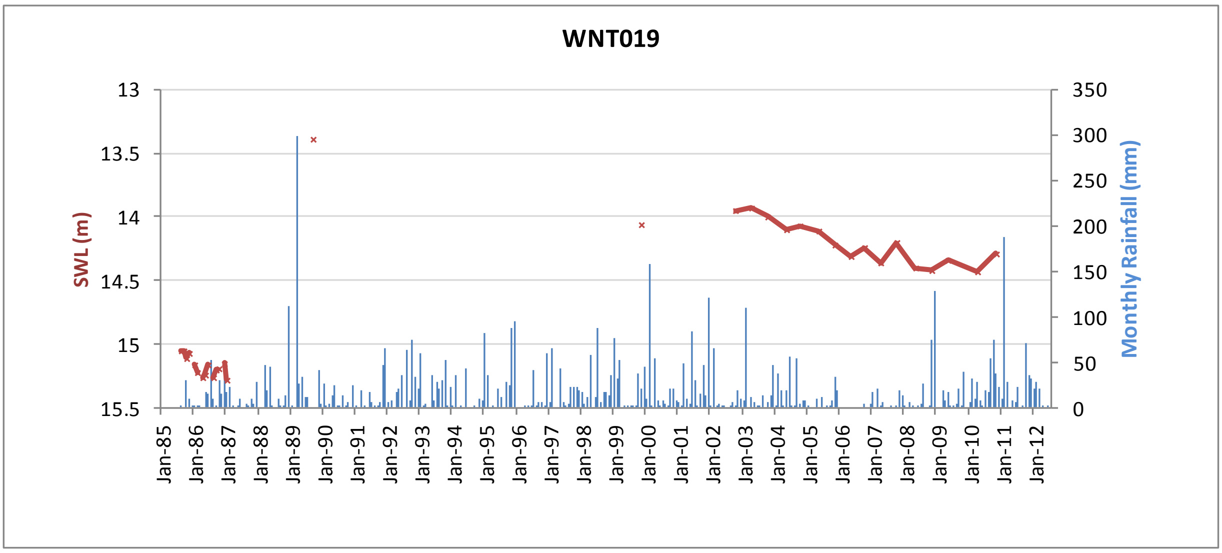
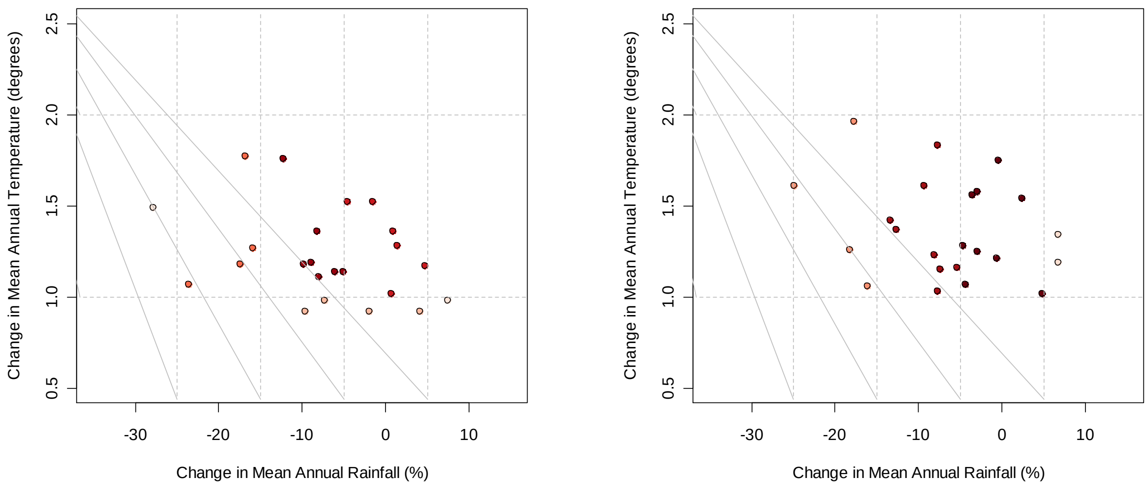


Figure A2. Monthly rainfall and groundwater levels and for town water supply wells located around Marla

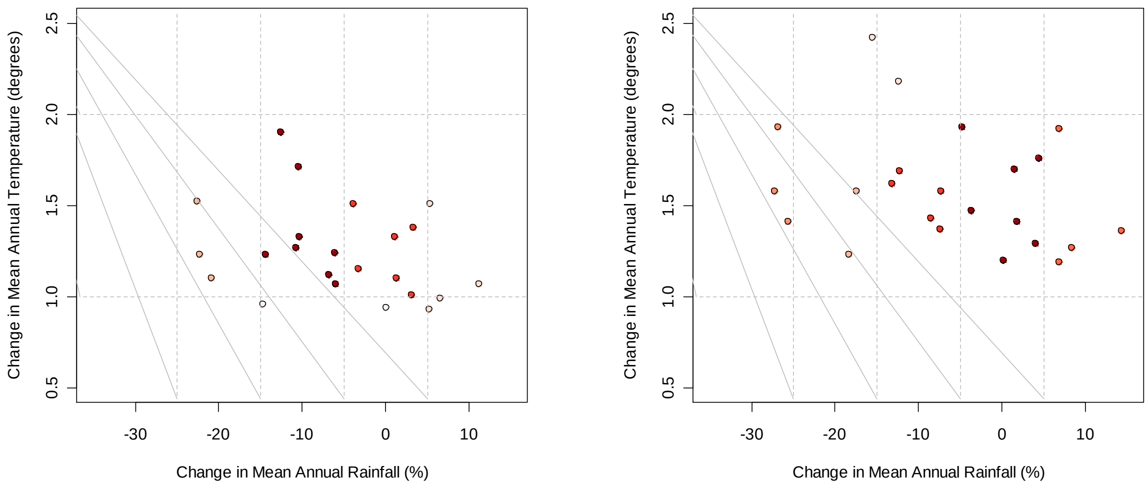
B. CLIMATE FUTURES USING ALL AVAILABLE GCMS

All GCMs is defined as the 23 IPCC Fourth Assessment Report GCMs (IPCC, 2007) and the CSIRO Mark 3.5 GCM.



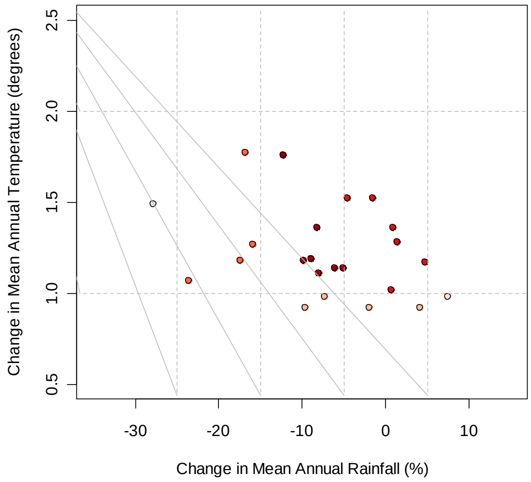
B1 Emissions A2 Emissions

Figure A3. GCM Projections for Woomera for 2050 using all available GCMs

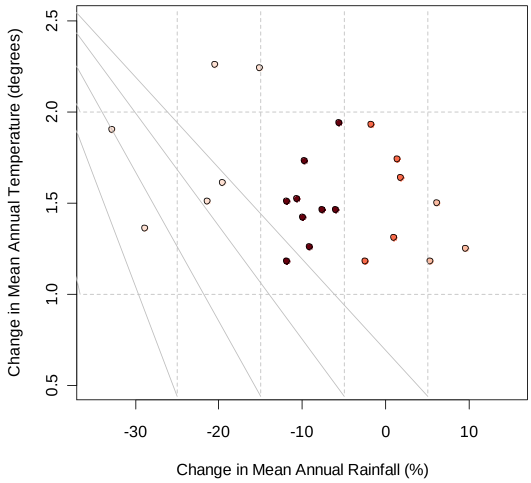


B1 Emissions A2 Emissions

Figure A4. GCM Projections for Moomba for 2050 using all available GCMs



B1 Emissions



A2 Emissions

Figure A5. GCM Projections for Oodnadatta for 2050 using all available GCMs

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

Shortened forms

~	approximately equal to
bgs	below ground surface
EC	electrical conductivity (µS/cm)
K	hydraulic conductivity (m/d)
ma	million years
pH	acidity
pMC	percent of modern carbon
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
w/v	weight in volume
w/w	weight in weight

GLOSSARY

ABS — Australian Bureau of Statistics

APY — Anangu Pitjantjatjara Yankunytjatjara

Aquatic ecosystem — The stream channel, lake or estuary bed, water, and/or biotic communities, and the habitat features that occur therein

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through

Aquifer, confined — Aquifer in which the upper surface is impervious (see 'confining layer') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them

AWBM — Australian Water Balance Model

AWNRM(B) — see Alinytjara Wilurara Natural Resources Management (Board**)**

BCCR — Bjerknes Centre for Climate Research

Baseflow — The water in a stream that results from groundwater discharge to the stream; often maintains flows during seasonal dry periods and has important ecological functions

Biodiversity — (1) The number and variety of organisms found within a specified geographic region. (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems

BoM — Bureau of Meteorology, Australia

Bore — See 'well'

Catchment — That area of land determined by topographic features within which rainfall will contribute to run-off at a particular point

Confining layer — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

CSIRO – Commonwealth Scientific and Industrial Research Organisation

DENR – Department of Environment and Natural Resources

DFW — Department for Water (Government of South Australia)

DTEI — Department for Transport, Energy and Infrastructure

DWLBC — Department of Water, Land and Biodiversity Conservation (Government of South Australia)

DWR – Department for Water Resources

Environmental water requirements — The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk

Evapotranspiration — The total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies

GCM — Global Climate Model

GFDL — Geophysical Fluid Dynamics Laboratory

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

GLOSSARY

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or high flow conditions; measured in metres per day

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers; see also 'hydrology'

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere; see also 'hydrogeology'

IAP —- Institute of Atmospheric Physics

ICCWR — Impacts of Climate Change on Water Resources

IPCC — International Panel on Climate Change

Irrigation season — The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May

Leaching — Removal of material in solution such as minerals, nutrients and salts through soil

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams or predicting ecological response to environmental change

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things.

MT — Maralinga Tjaṟutja

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc). See also recharge area, artificial recharge

Natural resources — Soil, water resources, geological features and landscapes, native vegetation, native animals and other native organisms, ecosystems

NCAR — National Center for Atmospheric research

NHMM — Non-homogenous Hidden Markov Model

NRM — Natural Resources Management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

EPNRM — Eyre Peninsula Natural Resources Management (region)

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

Obswell — Observation Well Network

PET — Potential evapotranspiration

Prescribed area, surface water — Part of the state declared to be a surface water prescribed area under the Act

Prescribed watercourse — A watercourse declared to be a prescribed watercourse under the Act

Prescribed water resource — A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed well — A well declared to be a prescribed well under the Act

PWA — Prescribed Wells Area

PWRA — Prescribed Water Resources Area

Raster – a data structure representing a grid of pixels, or points of color, in which each pixel holds a single value representative of a spatial variable depicted by the raster

Recharge area — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. See also artificial recharge, natural recharge

SA Water — South Australian Water Corporation (Government of South Australia)

Specific yield (S_y) — The volume ratio of water that drains by gravity, to that of total volume of the porous medium. It is dimensionless

SRES — Special Report on Emissions Scenarios

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

Surface Water Archive — An internet-based database linked to Hydstra and operated by DWLBC. It contains rainfall, water level, streamflow and salinity data collected from a network of surface water monitoring sites located throughout South Australia

Tertiary aquifer — A term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago)

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground

Vadose zone — The zone between the land surface and the water table. This includes the zone of soil water and the capillary fringe. Also called the unsaturated zone.

Water allocation — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) In respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation

Water allocation, area based — An allocation of water that entitles the licensee to irrigate a specified area of land for a specified period of time usually per water–use year

WAP — Water Allocation Plan; a plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with the Act

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse

Well — (1) An opening in the ground excavated for the purpose of obtaining access to underground water. (2) An opening in the ground excavated for some other purpose but that gives access to underground water. (3) A natural opening in the ground that gives access to underground water

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.

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