TECHNICAL REPORT

IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES IN SOUTH AUSTRALIA

PHASE 4 VOLUME 1: FIRST ORDER ASSESSMENT AND PRIORITISATION OF WATER-DEPENDENT ECOSYSTEMS

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Government of South Australia
Department for Water

IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES IN SOUTH AUSTRALIA

PHASE 4 VOLUME 1:

FIRST ORDER RISK ASSESSMENT AND PRIORITISATION OF WATER-DEPENDENT ECOSYSTEMS

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FOREWORD

South Australia's Department for Water leads the management of our most valuable resource—water.

Water is fundamental to our health, our way of life and our environment. It underpins growth in population and our economy—and these are critical to South Australia's future prosperity.

High quality science and monitoring of our State's natural water resources is central to the work that we do. This will ensure we have a better understanding of our surface and groundwater resources so that there is sustainable allocation of water between communities, industry and the environment.

Department for Water scientific and technical staff continue to expand their knowledge of our water resources through undertaking investigations, technical reviews and resource modelling.

Allan Holmes
CHIEF EXECUTIVE
DEPARTMENT FOR WATER

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SUMMARY

Aquatic ecosystems in South Australian are identified as being at risk of degradation from water resource usage (both groundwater and surface water) (Harding 2009; Harding & O'Connor 2012), land use change, drainage and salinisation (Kingsford *et al.* 2011). The superimposed impacts of climate change are an additional source of risk, likely to exacerbate already existing threats to water-dependent ecosystems (WDEs).

The Department for Water (DFW) project *Impacts of Climate Change on Water Resources (ICCWR)* was established in 2010 under the *New Knowledge for the Future component* of the Department's *Groundwater Program*. The project aims to provide an improved understanding of the risk to water resources and water-dependent ecosystems in South Australia arising from changes in water availability due to climate change and climate variability.

This report is presented as *Volume 1 of Phase 4 of the ICCWR project: To assess the risks of significant impacts of climate change on water-dependent ecosystems*. This report is preceded by related reports completed by the ICCWR project (Wood & Green 2011; Gibbs *et al*. 2011; Green *et al*. 2011) and a preliminary risk assessment of Groundwater Dependent Ecosystems (GDEs) to water resource usage (Harding & O'Connor 2012).

In the southern agricultural area of South Australia, annual rainfall is projected to decrease by up to 10–15 per cent by 2030 and up to 25–30 per cent by 2070 (CSIRO 2007). Along with increased evaporation, these climatic variables may have significant impacts on the State's water resources and associated aquatic ecosystems, with subsequent consequences for sustainable water allocations. With climate change projections indicating a generally drier outlook for South Australia, the State is facing a risk of reduced availability of high quality water resources (Wood & Green 2011).

In general, the projected changes in climate indicate that temperature increases are likely to be greatest in spring and autumn and the greatest decreases in rainfall are likely to occur in winter and spring. Some regions are likely to have slightly increased summer rainfall. Significantly, many seasonal wetlands in temperate regions of the State rely on winter and spring rainfall to fulfil environmental water requirements to support aquatic ecosystems that are adapted to seasonal inundation regimes. These projected reductions are likely to result in increased drying of aquatic ecosystems, including potential loss of seasonally inundated shallow ecosystems, significant changes in water regime (i.e. from permanent to ephemeral) and loss of low flows in watercourses.

The effects of climate change on the ecology of Water-Dependent Ecosystems (WDEs) is complex and difficult to predict, as aquatic ecosystems may experience non-linear or threshold responses to disturbance. Due to sparse ecological data for WDEs in South Australia and the lack of consistent aquatic ecosystem monitoring, the use of climate change hydrological modelling outputs to extrapolate or model impacts on WDEs may be limited to sites where ecological and hydrological data already exists, or rely on conceptual understanding of ecosystems and species threshold responses.

For these reasons, an initial prioritisation method using available Statewide spatial datasets in a geographical information system (GIS) was adopted. A relative risk rating was determined from a combination of factors that were identified as having the potential to influence the risk from climate change for WDEs. The result is an initial 'first order' Statewide scale assessment of climate change risk associated with water-resources use for all of South Australia's mapped wetlands and watercourses. This is intended to guide the selection of priority regions for more detailed assessment of the potential impacts of climate change on water-dependent ecosystems.

SUMMARY

The assessment methodology draws upon the results of an analysis of the impacts of climate change on water resources (Wood & Green 2011) and examined factors such as: the sensitivity of a defined water resource (either groundwater or surface water resource) to yearly rainfall variations; the importance of water resources for consumptive use; and specific climate change projections (produced by CSIRO (2007)). Based on these criteria, a risk priority score was calculated for each mapped wetland polygon in South Australia. A ranking of risk from climate change and a subsequent evaluation method was developed to identify priority regions according to these scores. It must be emphasised that this initial risk assessment examines the likelihood of impact from climate change on water dependent ecosystems and does not reflect the future sustainability or condition of ecosystems.

The outcomes of the initial prioritisation show that the risk ranking of priority WDE regions generally agrees with climate change risk rankings of major water resources (e.g. prescribed wells areas) in South Australia (Wood & Green 2011). The higher ranking WDEs identified were predominantly those that received high scores for the importance of resource usage, particularly where both surface and groundwater usage were assessed as high and where climate change impacts on winter rainfall declines were greatest. The analysis therefore generally identifies ecosystems in the southern agricultural areas, Flinders Ranges and along the coast as having the highest risk rankings, owing to their vulnerability to changes in seasonal rainfall and recharge.

High priority regions identified for further investigation into the impacts of climate change on WDEs included the Lower Limestone Coast PWA; Southern Basins PWA, Eastern Mount Lofty Ranges PWRA, Unprescribed South East NRM region, Western Mount Lofty Ranges PWRA and Musgrave PWA. Also of significance were the Far North PWA and the Unprescribed SA Murray-Darling Basin NRM Region which includes the River Murray and Coorong and Lower Lakes.

The assessment of climate change impacts was limited to analysis within South Australia and does not take into consideration potential climate change projections for contributing cross-border surface and groundwater catchments, which may have an effect on water availability to WDEs. In addition, the assessment was also confined to mapped wetlands and watercourses and hence it does not assess potential impacts to other WDE types such as rockholes, soaks, stygofaunal habitats and phreatophytic vegetation. The impact of sea level rise and potential for salt water intrusion on WDEs was not assessed.

Further work within Phase 4 of the ICCWR project aims to include more detailed analysis of WDE impacts based on the application of the modelled hydrological outputs to the priority regions identified in this report and Wood & Green (2011).

Recommendations for progressing the assessment of impacts of climate change on WDEs, include:

- investigate the potential use of probabilistic statistical modelling (such as Bayesian Belief Networks) to assist in making more detailed predictions of risk to specific WDE features in high priority regions identified in this report
- use of expert workshops to review and validate the outputs of the initial risk assessment and identify any inconsistencies with field based knowledge
- assessing potential impacts of climate change on other WDE features such as springs and rockholes
- assessing ecosystem vulnerability (contributing to the likelihood of risk) and ecological value for high priority regions
- assessing ecological, physico-chemical and hydrological data availability in priority regions that could be utilised and developed into coupled hydrological - hydraulic - ecological-response models for determining climate change scenario impacts on WDEs and to consider the development of WDE conceptual models to assist where insufficient data are available

SUMMARY

The outcomes of the ICCWR project will facilitate a more predictive and proactive priority driven adaptive management approach for South Australia's water resources.

1. INTRODUCTION

1.1. PROJECT BACKGROUND

The Department for Water (DFW) is the lead agency for managing South Australia's water resources and has the responsibility for ensuring that water is managed sustainably in South Australia to support our economy and health, as well as the environment. DFW advises on the quantity, quality, use and availability of water resources and in doing so, it is critical to identify current and potential risks to environmental water requirements. Specifically, strategic priorities for DFW are to ensure Water-Dependent Ecosystems (WDEs) are protected and can adapt to climate change and that environmental water is transparently accounted for and evaluated. However in order to effectively develop these strategies, water managers need to understand potential climate change impacts on streamflows, groundwater levels and aquatic ecosystems.

The DFW project *Impacts of Climate Change on Water Resources* (ICCWR) was established in 2010 under the *New Knowledge for the Future* component of the department's *Groundwater Program*. The Groundwater Program addresses Target 3.9 of South Australia's Strategic Plan 2007 which requires that 'South Australia's water resources are managed within sustainable limits by 2018'. The Project also addresses Action 43 of the **Water for Good** water security plan for South Australia: *Commission, where required, regional scale studies on the Impacts of Climate Change on Water Resources.*

The ICCWR project contributes towards the fulfilment of Object 3(a) of the *Natural Resources Management Act 2004* which states '*decision-making processes should effectively integrate both long term and short term economic, environmental, social and equity consideration*'. Climate change forecasting is also identified as a research priority under Goal One of the State NRM Plan (2006).

1.1.1. PREVIOUS WORK

This report is preceded by related reports completed by the ICCWR project (Wood & Green 2011; Gibbs *et al*. 2011; Green *et al*. 2011)) and a preliminary risk assessment of WDEs in South Australia (Harding & O'Connor 2012).

A prioritisation report (Wood & Green 2011) provided a preliminary guide to the relative risk posed by climate change for all of South Australia's water resources, identifying those water resources for which the impacts of climate change present the greatest risks to water supply for use. In the context of this report, a separate identifiable water resource was determined by the dependence on the resource by a community (Wood & Green 2011) and included specific unconfined and confined groundwater resources and surface water resources of importance, often spatially defined by water management area boundaries (eg. Natural Resource Management (NRM) region or Prescribed Wells Areas (PWA)).

A preliminary risk assessment of WDEs (Harding & O'Connor 2012) provided an assessment of the spatial distribution of mapped wetlands and watercourses, likelihood of groundwater dependency and potential risk posed by groundwater extraction to wetlands. These two reports provided the key datasets utilised for a first order assessment of the relative risk of climate change to WDEs.

A more detailed assessment of the applicability of climate change projections to South Australian conditions and a method to downscale these projections to create 'future climate' datasets was completed in the ICCWR report 'ICCWR – Phase 2: Selection of Future Climate Change Projections and Downscaling Methodology' (Gibbs *et al*. 2011).

Priority water resource areas identified by Wood & Green (2011) were selected for more detailed modelling studies of surface water runoff and groundwater recharge rates under a selection of relevant climate change scenarios as Phase 3 of the ICCWR project (Green *et al*. 2011).

1.1.2. AIMS

The aim of Phase 4 of the ICCWR project was to prioritise South Australia's WDEs according to the potential risks posed by climate change. A risk assessment approach following methods developed by Wood & Green (2011) in Phase 1 of the ICCWR project was adopted, in which a relative risk rating has been determined from a combination of the likelihood and potential impact of climate change on wetlands and watercourses. The result is an initial 'first order' risk assessment for all of South Australia's mapped wetlands and watercourses, aimed at guiding the selection of priority regions for more detailed assessment.

This report describes the initial risk assessment method and presents the results of a Statewide scale prioritisation of mapped WDEs in South Australia. It is recommended that key regions, where high risks to wetlands and watercourses from climate change have been identified, be considered for a more detailed assessment of risk in the third phase of the ICCWR project.

1.1.3. EXCLUSIONS AND LIMITATIONS

The assessment of climate change impacts was limited to analysis of existing datasets for South Australia and does not take into consideration potential climate change projections for contributing cross-border surface and groundwater catchments, which may have an effect on water availability to WDEs. In addition, the assessment was also confined to mapped wetland polygons and does not assess potential impacts to other WDE types such as rockholes, soaks, phreatophytic vegetation and stygofaunal habitats. The impacts of sea level rise and potential for salt water intrusion on WDEs were not assessed.

Due to the lack of ecological data for WDEs on a Statewide basis, the overall assessment method closely reflected and relied upon the climate change risk to broad scale water resources (such as regional unconfined aquifers, catchments and water management areas) as determined by Wood & Green (2011). Wood & Green (2011) primarily identifies climate change risks to water resources from a consumptive perspective. It was considered that risk to an entire water resource was an acceptable surrogate measure for risk to individual WDEs at a coarse scale. This was based on the assumption that change in hydrology in a WDE caused by a decline in regional water resource availability (either groundwater or surface water) would have a detrimental effect on the ecological values of an individual WDE.

This assessment does not take into consideration the vulnerability of ecosystems or the ecological or social consequences of damage to ecosystems due to a lack of data necessary to undertake an assessment of these components at a Statewide scale. The assessment relied on derived Statewide datasets and is subject to the inherent limitations of the input data. Climate change predictions are also subject to considerable uncertainty. The results of this report should therefore be viewed in consideration of the limitations of the input data and in the context of an initial risk rating process aimed at broadly identifying priorities and recommendations for further analysis.

1.2. CLIMATE CHANGE IN SOUTH AUSTRALIA

Many areas of South Australia have experienced a decline in surface water flows and groundwater levels over the past decade compared to long term averages. This has resulted in an increased risk to the security of water supplies for regional communities, industry and the environment. Scientific evidence strongly indicates that climate change is occurring in Australia and CSIRO projections (CSIRO 2007) predict that an ongoing change in climate in South Australia can be expected. Specifically, a change is predicted in rainfall and evaporation patterns compared with long term recorded averages, including:

- 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.

In the southern agricultural areas of South Australia, annual rainfall is projected to decrease by up to 10–15 per cent by 2030 and up to 25–30 per cent by 2070 (CSIRO, 2007). Agriculture, natural ecosystems and water resources are likely to be significantly affected if rainfall declines and temperature increases are sustained under future climate conditions. Of immediate concern to South Australia will be the impacts of decreased rainfall and its increased variability. Along with increased evaporation, the combined impacts may have significant consequences for the State's natural water resources, impacting on sustainable water allocations. With climate change projections indicating a generally drier outlook for South Australia, the State is facing a risk of reduced availability of high quality water resources (Wood & Green 2011).

1.2.1. CLIMATE PROJECTIONS

Climate models are the best tools available for projecting future climate. A number of potential future greenhouse-gas emission rates were examined as part of the IPCC Special Report on Emission Scenarios. The scenarios ranged from storylines which describe a future world of very rapid economic growth and a global population that peaks mid-century (A1 and A2), to the B1 and B2 story-line, which describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability (Gibbs *et al.* 2011). Whilst no predictions are given on which storyline is the most likely to occur, results of recent emissions inventories show that anthropogenic greenhouse gas emissions are currently tracking near the IPCC high emissions scenarios (Global Carbon Project 2009), indicating that climate change in the upper ranges is more likely to occur.

Gibbs *et al.* (2011) identified four General Circulation Models (GCMs) that were applicable to South Australian conditions, based on the representation of historic temperature, rainfall and atmospheric pressure (Suppiah *et al.* 2006). The NCAR A2 CCSM3 GCM accessed through the CSIRO OzClim website (http://www.csiro.au/ozclim/, accessed 20/03/2011) provides projections that are close to the middle of the range of all suitable projections for both rainfall and Potential Evapotranspiration (PET) and was used in the first order assessment of risks to WDEs. Table 1 presents average climate change projections, compared to the 1990 base climate (IPCC baseline for projections), for Natural Resources Management (NRM) Regions in South Australia using the NCAR CCSM3 GCM. The 1990 baseline data is calculated using data from the time period 1975-2004. In general, temperature increases are likely to be greatest in spring and autumn and the greatest decreases in rainfall are likely to occur in winter and spring. Some regions are likely to have slightly increased summer rainfall. Significantly, many seasonal wetlands in temperate regions of the state rely on winter and spring rainfall to fulfil environmental water requirements to support aquatic ecology that have adapted to seasonal inundation regimes.

Climate projections are subject to uncertainties at each level of analysis: greenhouse gas emissions scenarios, the relationship between these emissions scenarios and the concentration of greenhouse gases in the atmosphere, the response of the climate to that concentration and the linkage between global circulation and regional models (Jin *et al.* 2009). The cumulative nature of these uncertainties means that the range of climate change projections can be considerable. However, it is well established that precipitation variability will increase because of climate change and projections of future temperatures are more consistent (Kundzewicz *et al.* 2007).

Table 1. Median Climate Change Projections for NRM Regions of mean temperature and rainfall for 2070 compared to 1990 baseline.

NRM Region	Low emission scenario (B2)		High emission scenario (A2)	
South East				
Spring	**Temp** + 1.3 °C	**Rain** - 7.2%	**Temp** + 1.6 °C	**Rain** - 9%
Summer	**Temp** + 1.0 °C	**Rain** + 1.1%	**Temp** + 1.2 °C	**Rain** + 1.4%
Autumn	**Temp** + 1.3 °C	**Rain** -10.3%	**Temp** + 1.7 °C	**Rain** - 13.0%
Winter	**Temp** + 1.0 °C	**Rain** - 6.8%	**Temp** + 1.3 °C	**Rain** - 8.6%
South Australian Murray Darling Basin				
Spring	**Temp** + 1.6 °C	**Rain** - 2.7%	**Temp** + 2.0 °C	**Rain** - 3.4%
Summer	**Temp** + 1.1 °C	**Rain** + 8.0%	**Temp** + 1.3 °C	**Rain** + 10.0%
Autumn	**Temp** + 1.5 °C	**Rain** - 4.5%	**Temp** + 1.9 °C	**Rain** - 5.7%
Winter	**Temp** + 1.2 °C	**Rain** - 8.1%	**Temp** + 1.5 °C	**Rain** - 10.2%
Adelaide & Mt Lofty Ranges				
Spring	**Temp** + 1.4 °C	**Rain** - 7.6%	**Temp** + 1.8 °C	**Rain** - 9.6%
Summer	**Temp** + 1.0 °C	**Rain** + 1.2%	**Temp** + 1.3 °C	**Rain** + 1.5%
Autumn	**Temp** + 1.4 °C	**Rain** - 6.5%	**Temp** + 1.8 °C	**Rain** - 8.1%
Winter	**Temp** + 1.1 °C	**Rain** - 8.2%	**Temp** + 1.4 °C	**Rain** - 10.3%
Kangaroo Island				
Spring	**Temp** + 1.2 °C	**Rain** - 12.2%	**Temp** + 1.5 °C	**Rain** - 15.3%
Summer	**Temp** + 0.9 °C	**Rain** - 0.7%	**Temp** + 1.2 °C	**Rain** - 0.9%
Autumn	**Temp** + 1.2 °C	**Rain** - 11.5%	**Temp** + 1.5 °C	**Rain** - 14.5%
Winter	**Temp** + 1.0 °C	**Rain** - 8.4%	**Temp** + 1.3 °C	**Rain** - 10.6%
Northern & Yorke				
Spring	**Temp** + 1.6 °C	**Rain** - 4.1%	**Temp** + 2.1 °C	**Rain** - 5.1%
Summer	**Temp** + 1.1 °C	**Rain** + 5.9%	**Temp** + 1.4 °C	**Rain** + 7.3%
Autumn	**Temp** + 1.5 °C	**Rain** - 3.1%	**Temp** + 1.9 °C	**Rain** - 3.9%
Winter	**Temp** + 1.3 °C	**Rain** - 10.4%	**Temp** + 1.6 °C	**Rain** - 13.1%
Eyre Peninsula				
Spring	**Temp** + 1.5 °C	**Rain** - 12.1%	**Temp** + 1.9 °C	**Rain** - 15.2%
Summer	**Temp** + 1.1 °C	**Rain** + 1.7%	**Temp** + 1.3 °C	**Rain** + 2.2%
Autumn	**Temp** + 1.4 °C	**Rain** - 6.6%	**Temp** + 1.7 °C	**Rain** - 8.2%
Winter	**Temp** + 1.3 °C	**Rain** - 12.7%	**Temp** + 1.6 °C	**Rain** - 15.9%
South Australian Arid Lands				

Spring	**Temp** + 1.9 ˚C	**Rain** + 1.6%	**Temp** + 2.4 ˚C	**Rain** + 2.0%
Summer	**Temp** + 1.4 ˚C	**Rain** + 5.1%	**Temp** + 1.8 ˚C	**Rain** + 6.3%
Autumn	**Temp** + 1.7 ˚C	**Rain** - 0.9%	**Temp** + 2.2 ˚C	**Rain** - 1.1%
Winter	**Temp** + 1.7 ˚C	**Rain** - 14.6%	**Temp** + 2.1 ˚C	**Rain** - 18.3%
Alinytjara Wilurara				
Spring	**Temp** + 1.9 ˚C	**Rain** - 8.9%	**Temp** + 2.3 ˚C	**Rain** - 11.2%
Summer	**Temp** + 1.4 ˚C	**Rain** - 6.3%	**Temp** + 1.8 ˚C	**Rain** - 7.9%
Autumn	**Temp** + 1.7 ˚C	**Rain** - 9.3%	**Temp** + 2.1 ˚C	**Rain** - 11.7%
Winter	**Temp** + 1.6 ˚C	**Rain** - 12.7%	**Temp** + 2.0 ˚C	**Rain** - 16.0%

Model: NCAR CCSM3 Global Warming Rate: Low Source: www.csiro.au/ozclim Accessed: April 2011

1.3. WATER-DEPENDENT ECOSYSTEMS AND CLIMATE CHANGE

Climate has a major role in controlling the physical, chemical and hydrological processes that affect species composition, biodiversity and persistence of water dependent ecosystems. Changes in climate, particularly changes in the mean temperature, rainfall and evaporation, as well as the variability of extreme climate events, such as drought, will determine the impacts to WDEs. In addition to the direct effects of climate change, indirect impacts such as increasing pressures on water resource usage, the spread of invasive and exotic species, salinisation, eutrophication and acidification are all likely to increase. Whilst there are numerous papers describing and summarising likely changes to WDEs as a result of climate change, there are very few sources of information with quantitative relationships that can be used to make predictions.

South Australian wetlands have already been identified as being at risk due to existing pressures such as water resource usage (both groundwater and surface water) (Harding 2009; Harding & O'Connor 2012), land use change, drainage and salinisation (Kingsford *et al.* 2011). The superimposed risk of climate change is therefore likely to exacerbate already existing non-climatic pressures on WDEs.

Globally, of all ecosystems, aquatic ecosystems appear to have the highest proportion of species at risk of extinction due to climate change (Millennium Ecosystem Assessment 2005) and coastal and inland wetlands have been identified as among the ecosystems most vulnerable to climate change worldwide (Millennium Ecosystem Assessment 2005) and in Australia (Hennessy *et al.* 2007).

1.3.1. HYDROLOGY

Climate change impacts, including changes in the timing and amount of precipitation and increases in the rates of evapotranspiration and air temperature, will have a direct effect on the hydrological regimes of WDEs in South Australia. These factors will affect the relationship between precipitation and runoff, as well as groundwater recharge, which determine the hydrology of WDEs.

Relationships between temperature, rainfall and runoff in response to climate change projections vary considerably. In the Murray-Darling Basin, a 15% reduction in inflows has been observed for a 1˚C rise in average temperature; a 2˚C rise could result in a 55% reduction in inflows from reduced precipitation and increased evapotranspiration (Pittock & Finlayson 2011). Green *et al.* (2011) found that a reduction of surface water runoff in the Clare Valley (South Australia) of up to 57% to 73% may result from a 2070 median climate projection. Similarly, potential reductions of up to 58% in groundwater recharge resulting from median climate change scenarios for a 2070 climate from a 15% reduction in winter rainfall were also shown (Green *et al.* 2011). These reductions will result in increased drying of aquatic ecosystems, including potential loss of seasonally inundated shallow ecosystems, significant changes in water regime (i.e. from permanent to ephemeral) and loss of low flows in watercourses.

Climate change impacts to ecosystems with significant groundwater dependence are vulnerable to changes in recharge. Global groundwater modelling shows a decline in groundwater recharge of greater than 10% for more than 20% of the global land area by 2050 (Aldous *et al.* 2011). It is expected that less rainfall and higher PET predicted for South Australia will result in reduced groundwater recharge, particularly in shallow unconfined aquifers and lower groundwater levels.

1.3.2. WATER QUALITY

Higher air temperatures and variations in runoff are likely to produce adverse changes in water quality within WDEs. Higher air temperatures have been associated with increased surface water temperatures (Jin *et al.* 2009). More intense and extreme rainfall events are likely to lead to an increase in turbidity and introduction of pollutants and nutrients from adjacent agricultural areas. Increased nutrient load and higher surface water temperatures promote algal blooms and increase the bacteria and fungi content (NCCARF 2010; Pittock & Finlayson 2011) of surface waters. Lowering of water levels in rivers and lakes may lead to the re-suspension of bottom sediments, liberating toxic compounds and contributing to acidification. Reduced stream flow and groundwater through-flow has the potential to cause increases in salinity in some stream and wetland ecosystems. Additionally, direct impacts of changes in salinity and water chemistry may be expected from rising sea levels and saltwater intrusion of neighbouring saline aquifers. Increased evapo-transpiration in semi-arid and arid regions may lead to the salinisation of shallow aquifers causing increases in salinity on dependent aquatic ecosystems (NCCARF 2010).

In South Australia, reduced surface inflows have resulted in increased salinity in the lower River Murray and declining condition of the Coorong and Lakes Alexandrina and Albert from low water levels, acidification, increasing salinity and changes in ecological character (Kingsford *et al.* 2011).

1.3.3. AQUATIC BIOTA

Individual aquatic organisms and ecosystems survive within specific ranges of temperature, water regime and chemical conditions. If they are exposed to conditions outside their normal environmental range, they must adapt or migrate, or they will be lost (Jin *et al.* 2009). The sensitivity of a particular species is determined by physiology (e.g. metabolic requirements and tolerances to climatic conditions), ecology (e.g. life history, habitat use, behaviour, dispersal and biotic and abiotic interactions) and genetic diversity (McCarty 2001; Jin *et al.* 2009).

For example, breeding populations of colonial nesting waterbird species require inundation of certain depths and duration and timing. Climate change is expected to decrease flood frequency to major colonial waterbird nesting wetlands in Australia, potentially threatening the survival of populations that were formerly prevalent (Kingsford *et al.* 2004). Native fish populations have declined dramatically as a result of changes in flow in the River Murray, disrupting the natural water-regime triggers for fish spawning, persistence and thermal pollution (Pittock & Finlayson 2011).

For biota dependent on aquatic ecosystems, the degree of adaptation to climate change will be related to the degree to which certain aquatic habitats are diminished, the abilities of species to disperse and the ability to overcome the effects of increased isolation and fragmentation of aquatic habitats. The effects of climate change on the overall biodiversity of WDEs is complex and has the potential to disrupt symbiotic or facilitative relationships between species (e.g. interrupting access to food sources) and changes in competition between species (Jin *et al.* 2009) that is difficult to predict. Disruption to the hydrology of aquatic ecosystems is also likely to benefit invasive exotic species and expansion of terrestrial ecosystems with a drying climate.

2. WATER-DEPENDENT ECOSYSTEMS TO CONSIDER

2.1. *WATER-DEPENDENT ECOSYSTEMS IN SOUTH AUSTRALIA*

Harding & O'Connor (2011) compiled and described spatial data identifying WDEs in South Australia, including springs, waterholes, permanent pools, karst features, wetlands and watercourses (Figure 1). There are currently 60 712 wetlands (excluding farm dams), covering an area of approximately 66 661 square kilometres mapped in South Australia and approximately 970 kms of perennial and 250 000 km's of non-perennial watercourses.

A high degree of groundwater dependency of WDEs in South Australia has been reported, with 54% of all mapped wetlands regarded as having the potential for groundwater interaction (Harding & O'Connor 2012).

2.1.1. IDENTIFYING VULNERABLE WDE TYPES

The vulnerability of WDEs to a generally drying climate depends largely on the sources of their water supply. Wetlands and watercourses, which are sensitive and therefore likely to be at risk, are those which are largely dependent upon precipitation and are isolated from other water sources such as inundation from streams and rivers, local runoff from upland areas or groundwater discharge (Winter 2000; Thompson *et al.* 2009). However shallow, unconfined groundwater resources that demonstrate responsiveness to rainfall are also likely to be rapidly impacted by reduced recharge, resulting in reduction or loss of groundwater flow to dependent ecosystems. Additionally, groundwater resources may be under increased extractive pressure as a result of reduced rainfall.

In general, a hotter and drier future climate is likely to reduce many wetlands in size, convert some wetlands to dry land, or shift one wetland type to another (e.g. seasonal wetlands may become ephemeral; permanent wetlands may become seasonal). These changes in frequency and timing of inundation have significant implications for aquatic biota and such changes in water regime have already been observed throughout many regions in South Australia following recent prolonged dry periods.

Depressional wetlands with small catchments and those with shallow water depth, non-permanent (temporary or seasonal), dependent on direct precipitation or shallow unconfined or perched aquifers, are likely to be the most vulnerable to climate change impacts (Jin *et al.* 2009; Winter 2000; Kusler 2005). Freshwater ecosystems may be considered at greater risk due to increased pressures on freshwater resources for human consumption and agriculture and the vulnerability and adaptive capacity of freshwater species to changes in water regime and water quality (NCCARF 2010).

In Victoria, Jin *et al.* (2009) identified shallow freshwater meadows and marshes in the south-west of the state and on the floodplains of the Victorian Riverina bioregion to be among inland wetlands most likely to be affected by climate change. Coastal wetlands and estuaries have been identified as being vulnerable to sea level rise (Kusler 2005).

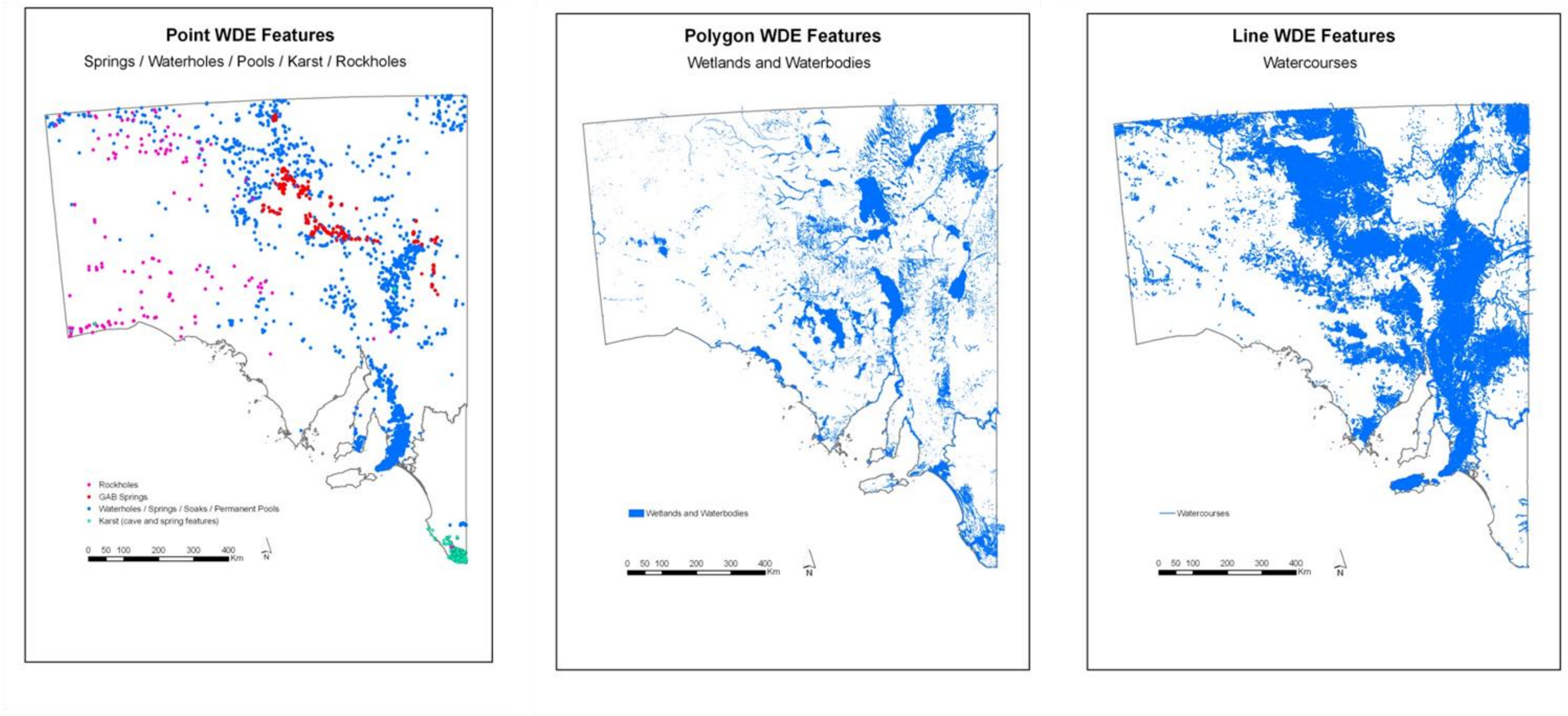


Figure 1. Water-dependent Ecosystems in South Australia

3. METHODOLOGY

3.1. *RISK ASSESSMENT METHOD*

An initial 'first order' risk assessment of the potential impact of climate change on the State's water-dependent ecosystems was conducted with the intention of identifying and prioritising regions with WDEs at potentially higher risk across the State.

The climate change risk assessment method largely follows and draws upon data gathered and analysed by Wood & Green (2011) who undertook a risk assessment of climate change impacts on the State's major water resources and Harding & O'Connor (2011) who provided a classification of groundwater-dependent ecosystems and preliminary risk assessment from groundwater extraction.

A Geographic Information System (GIS) was used to analyse existing and derived Statewide datasets. All spatial datasets utilised, including climate change projections, contain considerable limitations of scale and purpose and uncertainties in data accuracy. The scope of the risk assessment was limited to analysis of variables where data existed and that were applicable on a Statewide scale. The assessment therefore was able to analyse some components of threat and likelihood of impact. There was insufficient data available to analyse the consequences of impacts, or magnitude of potential loss and therefore, this risk assessment serves as an initial prioritisation. All mapped wetlands and watercourses within South Australia were assessed as WDEs.

Overall risk scores on a State scale were determined from rating values assigned to three components of risk, further described in the following sections:

- Level of potential threat from climate change (exposure) (Section 3.1.1)
- Likelihood of impact from climate change on water resources (sensitivity) (Section 3.1.2)
- Likelihood of increased water resource usage as a result of climate change (Section 3.1.3)

The components include direct sources of threat to WDEs from climate variables and an assessment of the likelihood of change from indirect non-climatic drivers already affecting WDE resources, which are likely to be exacerbated as a result of a changing climate, such as groundwater and surface water resource usage. Specific vulnerabilities of different WDE features were unable to be assessed at the Statewide level. The assessment was also limited to likelihood of impacts on hydrological processes, under the assumption that changes in hydrology are likely to cause detrimental impacts on the ecological values of WDEs. Climate change was thus considered an overarching source of risk that adds to and interacts with, a range of existing sources that have already significantly impacted WDEs in South Australia; resulting in loss, degradation and fragmentation of habitat, introduction and spread of invasive or exotic species and over usage of water resources.

A cumulative scoring method was used to determine the level of risk to WDEs as shown in Figure 2 and further described in the following sections. This included an assessment of the potential level of threat from climate change and the likelihood of potential impacts on the hydrology of WDEs (assessed as water resource sensitivity and potential for increased water usage). Climate change, water resource sensitivity and water resource usage components were summed to generate an overall cumulative risk rating score for each mapped WDE feature in South Australia, with a maximum score possible of 51, where high scores indicate the highest potential level of risk (refer Figure 2).

Due to the lack of ecological data for WDEs on a Statewide basis the overall assessment method was biased towards the climate change risk to water resources for human use. The ranking scores applied to the three assessment components do not reflect prior statistical assessment of values for each component or its underlying raw data. They are based on expert opinion (Wood & Green 2011) and were arbitrarily defined for this high level assessment only.

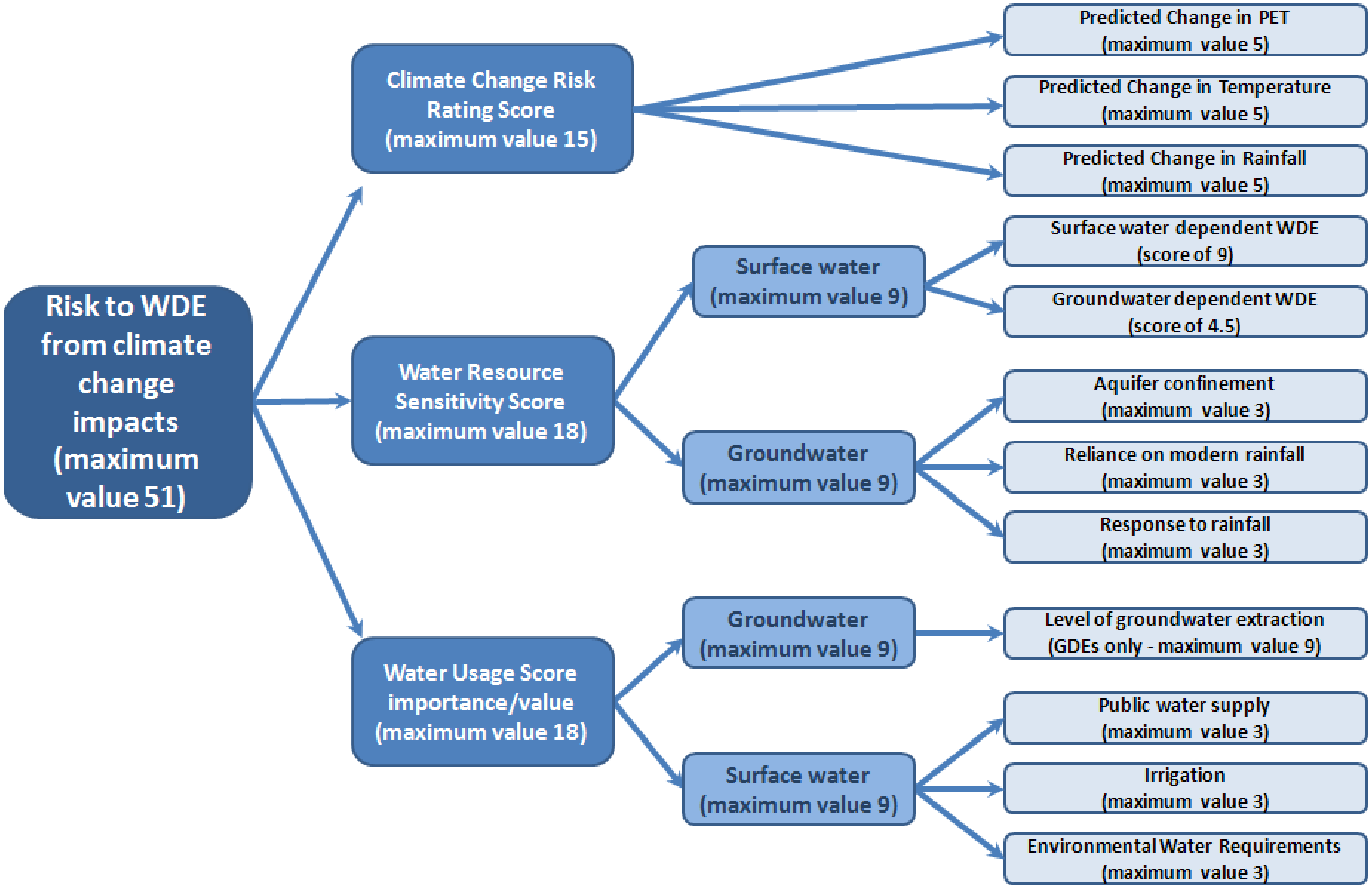
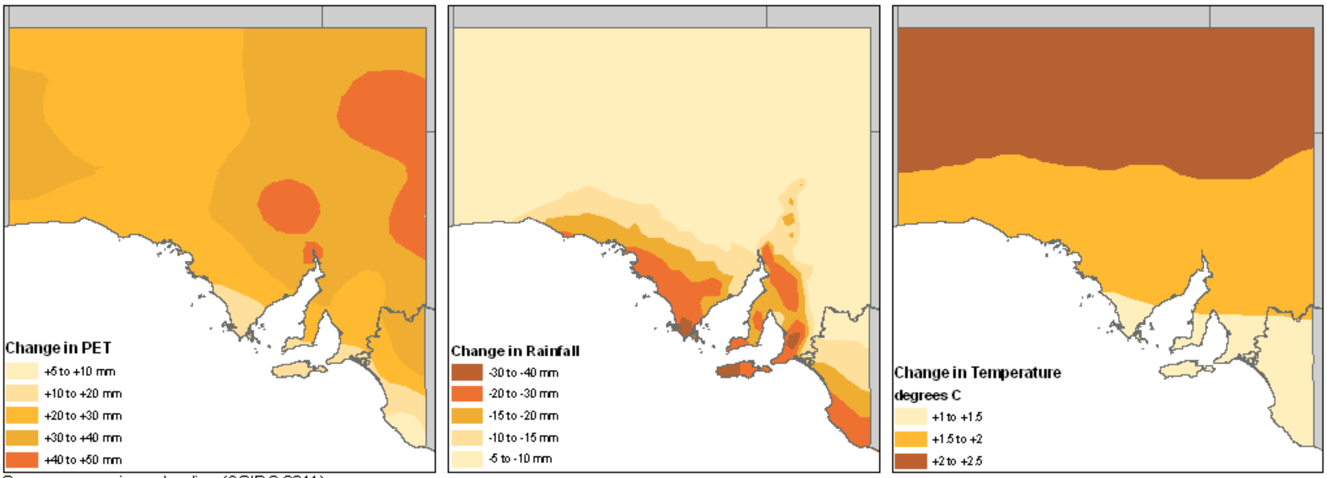


Figure 2. Flow chart showing how Statewide assessment of risk to WDE from climate change impacts have been calculated for wetland polygons

3.1.1. CLIMATE CHANGE RISK RATING SCHEME

The assessment of the level of threat contributed from climate change occurring within the locale of each WDE was based on the changes in average potential evapotranspiration (PET), temperature and average rainfall that are projected by General Circulation Models (GCMs). GCMs are the best tools available for simulating global and regional climate systems and generally provide reasonable representations of past trends of directly simulated climate variables. Gibbs *et al.* (2011) identified climate change projections that are the most appropriate to South Australia. The NCAR CCSM3 GCM was identified as providing a middle projection, between most extreme and least change cases. For the purposes of this risk assessment and prioritisation, a single climate change scenario was considered: the high (A2) emission scenario, winter-quarter, for a projected time horizon of 2070 (Figure 3).

The winter-quarter projections were selected for this assessment as this is the quarter in which rainfall and PET are most significant to runoff and recharge and is the period in which winter and spring rainfall is most significant in fulfilling environmental water requirements for seasonal wetlands in temperate regions of the State. The 2070 projection was selected as the change in climate is much greater than in the 2030 projection and gives a clearer indicator of the direction of change in rainfall and PET, which is the intention of the climate change risk rating. The high (A2) emission scenario was selected as recent emissions inventories that show anthropogenic greenhouse gas emissions are currently tracking near the IPCC high emissions scenarios (Global Carbon Project 2009).



Source: www.csiro.au/ozclim (CSIRO 2011)
Model: CCSM3. Emission Scenario: SRES marker scenario A2. Global Warming Rate: low

Figure 3. Climate change scenarios from base climate (1990) for the year 2070, winter – South Australia

Increases in temperatures and PET, combined with reductions in precipitation will likely reduce surface and groundwater levels, resulting in changes in persistence and extent of many WDEs in South Australia. Air temperature rises will increase surface water temperatures as a result of greater radiant heating (as a result of shallower water) and also decrease potential inputs of cooler groundwater. Increasing water temperature reduces the capacity of water bodies to store dissolved oxygen, increasing the likelihood of anoxia and potential for algal blooms (Jin *et al.* 2009).

Scores were assigned to each mapped WDE for the three climate change criteria; change in PET (Table 2), change in average rainfall (Table 3) and change in temperature (Table 4), based on the NCAR CCSM3 A2 GCM projection for winter 2070, relative to the base climate (1990) for the GCM grid square including the location of the WDE. The climate change risk was rated with a score from one to five for each criterion giving an overall climate change risk score out of 15 for each WDE feature, representing the potential exposure of each WDE feature to climate change scenario variables. Both the data ranges and scores were assigned arbitrarily and broadly matched methods used in Wood & Green (2011).

Table 2. Scoring system for change in PET criteria

Change in PET (mm)	Score
5 to 10	1
10 to 20	2
20 to 30	3
30 to 40	4
40 to 50	5

Table 3. Scoring system for change in rainfall criteria

Change in rainfall (mm)	Score
-5 to -10	1
-10 to -15	2
-15 to -20	3
-20 to -30	4
-30 to -40	5

Table 4. Scoring system for change in temperature criteria

Change in temperature (˚C)	Score
1 to 1.5	1
1.5 to 2	3
2 to 2.5	5

3.1.2. WATER RESOURCE AREA SENSITIVITY RATING SCHEME

The sensitivity of regional water resources to climate change were assessed as the first phase of the ICCWR project (Wood & Green 2011). The analysis by Wood & Green (2011) was aimed at identifying climate change risks to broad scale water resources (generally from a water supply for consumptive use perspective). In the absence of available data for individual WDEs, sensitivity to climate change of an entire water resource was used as a surrogate indication of sensitivity of individual WDEs and therefore, likelihood of impact. This was based on the assumption that the extent and persistence of WDEs were reliant on the availability of surface and groundwater resources. Limitations associated with the scale of assessment, use of arbitrary scoring systems and absence of data related to ecological sensitivities are therefore inherent. As a result analysis using this data was only applicable on a broad scale and was applied with low confidence.

Major water resources in South Australia were defined spatially using a combination of water management area boundaries (prescribed wells and prescribed surface water areas) and Natural Resources Management regions. The sensitivity of each of the identified major water resource areas to climate change was assessed by Wood and Green (2011) based on criteria including: aquifer confinement; reliance on modern rainfall recharge; and aquifer response. Scores were assigned separately for groundwater and surface water resources using the below rationale and scoring scheme for each criterion:

Resource Sensitivity Rating Scheme

Aquifer confinement: Refers to groundwater systems and is an assessment of whether the aquifer is unconfined (i.e. groundwater levels are at atmospheric pressure) and more likely to be linked to the current atmospheric climate and contemporary rainfall. The risk was based on a score out of three (three being unconfined, zero being confined). Scores between zero and three have been assigned for semi-confined aquifers.

Reliance on modern rainfall recharge: An assessment of whether the resource is reliant upon rainfall to maintain sustainable supplies. Unconfined groundwater resources were assessed on the seasonal response of the aquifer and the depth of the water table below ground level. Confined aquifers were generally assessed to have a relatively low reliance on contemporary rainfall and were given scores of 1 or 2 for this criterion.

Aquifer response buffering: An assessment of how responsive the resource is to variations in climate, based on data available from resource monitoring. For groundwater resources, this is an assessment of how they behave in wet and dry periods (i.e. do groundwater levels decline significantly in drought periods and do they recover rapidly in response to periods of rainfall?). This assessment was also largely influenced by the storage capacity of the resource. Larger groundwater resources have a lower ratio of recharge to storage, such that the capacity of the resource is less susceptible to inter-annual rainfall variations. The risk was assigned a score out of three. A score of three represents a strong relationship between rainfall and water levels, while a score of zero indicates no relationship.

Source: Wood & Green 2011

A summary of the scores assigned to the criteria above and the final resulting Resource Sensitivity Scores for each water resource assessment region are presented in Appendix A.

Groundwater Resource Sensitivity Score

Each of the above criteria were scored out of three based on the un-weighted assessment of attributes detailed in Wood & Green (2011) for unconfined groundwater resources (Appendix A) and spatially defined with use of prescribed water resource areas and NRM regions. The scores were added together for a maximum resource sensitivity score of 9 (Figure 4). Scores for groundwater resource sensitivity to climate change were applied only to WDEs identified as potentially groundwater dependent (Harding & O'Connor 2012) using a spatial coincidence with the water resource sensitivity data.

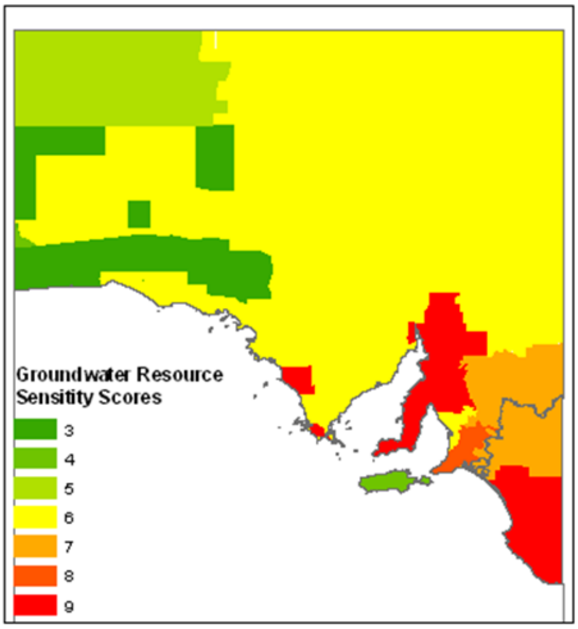


Figure 4. Sensitivity of major water resources to climate change impacts in South Australia

Surface Water Resource Sensitivity Score

As all surface waters were considered unconfined and particularly sensitive to rainfall and climate (Wood & Cameron 2011), a score of 9 was applied to all WDE features which were likely to be reliant solely on surface water (identified as having a low likelihood of groundwater dependence), including wetland and watercourse features. All other WDEs were assigned a score of 4.5 as there was insufficient data available to determine levels of groundwater and surface water inputs to potential GDEs and therefore, potential sensitivity to climate induced changes in surface water availability at a Statewide scale.

3.1.3. WATER RESOURCE USAGE RATING SCHEME

Resource usage was assessed in order to identify current demands of water users for both groundwater and surface water, which are likely to increase under decreased rainfall predicted under climate change scenarios. The demand for groundwater is likely to increase in the future, mainly due to increased water use, but also due to the need to offset declining surface water availability due to increasing precipitation variability in general and reduced low flows (Bates *et al.* 2008). These demands on water resources have the potential to further impact the hydrology of WDEs.

Groundwater usage and surface water usage were assessed separately, under the assumption that increased groundwater usage was likely to have the greatest impact on groundwater dependent ecosystems. Limitations associated with the identification of potential groundwater dependent ecosystems at the Statewide scale completed by Harding & O'Connor (2012), assessment of levels of groundwater usage (Harding & O'Connor 2012) and surface water usage (Wood & Green 2011), contribute to considerable uncertainties in this assessment. Harding & O'Connor (2012) provided a map of relative intensity of groundwater extraction, which included analysis of licensed and unlicensed extraction, plantation forestry and mining. Surface water resource usage was assessed more broadly, within prescribed watercourses in South Australia (Wood & Green 2011).

Groundwater Usage

The level of groundwater extraction was assessed by Harding & O'Connor (2012) including the use of water licensing data, intensity of wells, plantation forestry and mining and is shown in Figure 5. Scores for groundwater resource usage level were applied only to WDEs identified as potentially groundwater dependent (Harding & O'Connor 2012), using the spatial coincidence of WDE features that are likely to be groundwater dependent with intensity of groundwater extraction. A score was assigned to each mapped WDE for this criterion, based on the relative level of groundwater extraction provided by Harding & O'Connor (2012). The scores ranged from zero to nine and are summarised in Table 5.

Table 5. Scoring system for groundwater resource usage

Level of groundwater extraction	Score
Very High	9
High	6
Moderate	4
Low	0

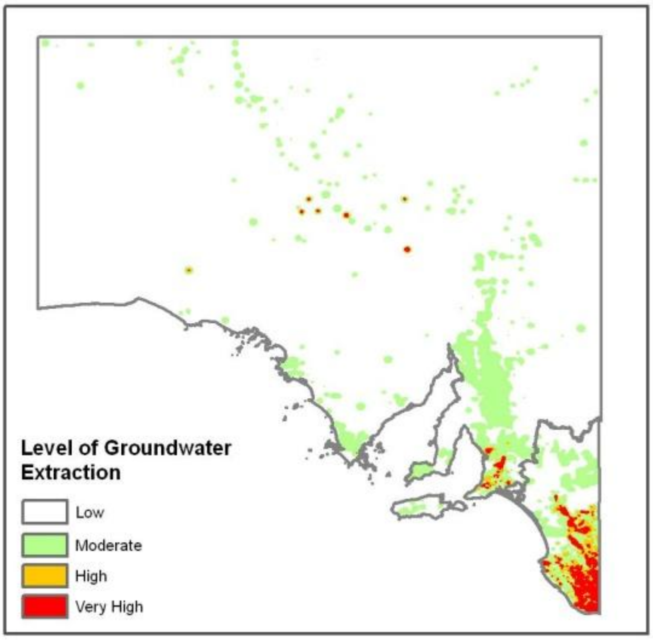


Figure 5. Level of groundwater extraction

Source: Harding & O'Connor 2012

Surface water Usage

The importance of surface waters for public water supply and irrigation, stock and industrial usage and environmental water requirements was assessed by Wood & Green (2011) using the following rationale:

Surface Water Resource Significance Rating Scheme

Public water supply: An assessment of how important the resource is for public water supply in towns or communities. The risk was assigned on a score from zero to three. Scores of 1, 2 and 3 represent low, medium and high reliance of public/community water supply of the resource, while a score of zero indicates no users of the resource in this category.

Irrigation, stock and industrial: An assessment of how important the resource is as source for licensed irrigation and industrial uses and for non-licensed stock water use. The risk was assigned a score out of three, representing low, medium and high reliance of irrigation, stock and industrial users on the resource. A score of zero indicates no identified users of the resource in this category.

Environmental water requirements: An assessment of how reliant water dependant ecosystems (WDEs) are on the resource. The risk was based on a score out of three. A score of three indicates high value ecosystems known to be dependent on the resource. A score of one indicates the presence of ecological assets, which may be at least partly dependent on the resource. A score of zero indicates no significant ecosystems are thought to be dependent on the resource.

Source: Wood & Green 2011

The three usage categories were assigned a score out of three, representing low (1), medium (2) and high (3) reliance by users of the resource. A score of zero indicates no identified users of the resource in this category and a score of 1.5 was assigned in cases where the level of use was unknown. Scores from this assessment for all identified surface water resource usage areas were summed as a total score out of 9 and are listed in Appendix B. Scores for surface water usage were applied to watercourses only, using the spatial coincidence of WDE features and surface water usage regions. The surface water resource of the River Murray received an automatic score of 9, recognising its known high usage as a surface water resource to South Australia, although was not included in the ICCWR Phase 1 assessment due to more detailed studies being available (Wood & Green 2011).

4. RESULTS AND DISCUSSION

4.1. PRIORITY WATER-DEPENDENT ECOSYSTEMS

The risk assessment was limited to South Australia and does not take into consideration climate change projections and water resource usage within large cross-border surface water and groundwater catchments that contribute to many WDEs in South Australia, including the Murray-Darling and Lake Eyre basins (Figure 6). Therefore, considerable uncertainty in the output can be assumed, particularly for the SA Murray-Darling Basin and also the Far North PWA. The certainty of the results was also subject to the limitations of the input data as discussed in previous sections and for this reason, should be considered relevant at a Statewide scale and as a preliminary assessment useful for identifying priority areas for further analysis.

Figure 4 shows the results of the risk ranking applied to all mapped wetlands and watercourses in South Australia, based on the assessment of climate change, water resource sensitivity and water resource usage. The higher ranking WDEs identified were predominantly those that received high scores for resource usage, particularly where both surface and groundwater usage were assessed as high and where predicted climate change impacts on winter rainfall declines were greatest. This reflects the assumption that water usage in already highly developed water resource areas is likely to increase under lower rainfall predictions (particularly the use of groundwater resources) and as a result, would further increase the susceptibility of WDEs to an altered hydrology. The analysis therefore generally identified ecosystems in the southern agricultural zone of the State, Flinders Ranges and along the coast as having the highest risk rankings.

There has been very few site-based or regional scale investigations in South Australia into the relationships between climate change and ecosystem response in order to compare or ground-truth the results of the initial Statewide risk ranking. However, some ecosystems documented as being at risk from the impacts of climate change, such as the River Murray, Coorong and Lower Lakes (Lester *et al.* 2011; Kingsford *et al.* 2011) were identified as high risk using the Statewide risk rating methodology. Whilst the use of an expert panel was out of the scope of the initial assessment, it was considered that this would be a useful step in validating the risk ranking outputs.

In order to prioritise regions for further investigation and in line with assessment methods used in Phase 1 of the ICCWR project (Wood & Green 2011), WDE risk ratings (for the combined scores for climate change risk, water resource sensitivity and resource usage) within prescribed and unprescribed water resource areas were analysed (Table 8). The highest average risk rating scores for WDEs were found to occur within the Barossa Valley PWRA, Southern Basins PWA, Eastern Mount Lofty Ranges PWRA, Tintinara-Coonalypn PWA and the Lower Limestone Coast PWA (Table 8). The regions identified reflect the likelihood of hydrologic impacts on WDEs from climate change located within these management areas; however this assessment does not take into consideration the vulnerability of ecosystems or the ecological or social consequences of damage to ecosystems in these regions due to a lack of data necessary to undertake an assessment of these components at a statewide scale.

The presence of wetlands of National (Directory of Important Wetlands in Australia (DIWA) ANCA 1996) or International (Ramsar Convention on Wetlands 1971) importance was used as an indication of the presence of significant WDEs within each water resource area (Table 8)and are shown in Appendix E. The list provided in Table 8 provides a general indication of the presence of ecologically important wetlands within water resource areas for the purpose of refining the selection of priority regions based on the consequence of potential degradation caused by climate change.

Table 6. WDE Climate Change Risk Ranking Score summary for water resource areas in South Australia

Prescribed / Unprescribed Water Resource Region	WDE Climate Change Risk Scores				Number of Wetlands Assessed	Number of Watercourse Line Features Assessed	DIWA listed wetlands present	Ramsar listed wetlands present
	Avg	Min.	Max.	SD				
Barossa Valley PWRA	**32.36**	16	42	6.62	9	156		
Southern Basins PWA	**29.82**	17	35	4.22	49	35	✓	
Eastern Mount Lofty Ranges PWRA	**29.76**	14	44	8.63	589	522	✓	
Tintinara-Coonalpyn PWA	**28.56**	15	34	4.45	358	2		
Lower Limestone Coast PWA	**28.12**	15	34	7.78	12970	90	✓	✓
Padthaway PWA	**28.02**	15	33	7.77	47	1		
Northern Adelaide Plains PWA	**27.75**	16	32	4.02	482	22		
Unprescribed South East NRM Region	**27.12**	15	34	3.48	2095	41	✓	✓
Baroota PWRA	**26.95**	19	35	6.72	6	34		
Western Mount Lofty Ranges PWRA	**25.62**	16	43	7.57	723	1226	✓	
Clare Valley PWRA	**25.48**	19	46	6.89	4	261		
Musgrave PWA	**24.83**	16	33	4.66	79	25	✓	
Marne & Saunders PWRA	**24.32**	14	42	7.95	19	143		
Unprescribed SA Murray Darling Basin NRM Region	**23.55**	14	35	4.04	4874	2116	✓	✓
Central Adelaide PWA	**23.39**	16	38	5.43	165	141	✓	
Noora PWA	**22.86**	15	33	4.52	428	117	✓	✓
Unprescribed Eyre Peninsula NRM Region	**22.79**	15	41	4.03	2608	2080	✓	
Far North PWA	**22.5**	17	35	5.03	16370	85641	✓	✓
Unprescribed Northern & Yorke NRM Region	**22.3**	15	38	4.63	2551	5700	✓	
Unprescribed Adelaide & Mount Lofty Ranges NRM Region	**22.28**	15	34	4.6	2095	189	✓	
Unprescribed Kangaroo Island NRM Region	**20.54**	16	29	3.14	556	1284	✓	
Unprescribed SA Arid Lands NRM Region	**20.12**	16	37	3.22	11562	30304	✓	
Morambro Creek PSWA	**21.0**	18	30	6.0	1	3		
Unprescribed Alinytjara Wilurara NRM Region	**19.19**	16	29	2.28	2793	10987		
Peake, Roby & Sherlock PWA	**17.25**	15	22	3.33	28	0		
Tatiara PWA	**15.98**	15	34	2.69	77	14	✓	
Mallee PWA	**15.89**	15	16	0.32	104	2		

When considering the presence of Nationally and Internationally recognised wetlands, the highest priority regions for further investigation into the impacts of climate change on WDEs include the Southern Basins PWA, Eastern Mount Lofty Ranges PWRA, Lower Limestone Coast PWA, Unprescribed South East NRM region, Western Mount Lofty Ranges PWRA and Musgrave PWA. Also of significance is the Unprescribed SA Murray-Darling Basin NRM Region, which includes the River Murray and Coorong and Lower Lakes and the Far North PWA (Table 6).

Not surprisingly, considering the use of similar datasets and methods, the risk ranking of priority WDE regions generally aligned with climate change risk rankings of major water resource management areas in South Australia (Wood & Green 2011). WDEs in the Barossa PWRA and Tintinara Coonalypn PWA received high average risk scores; however these regions have relatively few WDEs and none of known significance at the Statewide scale. Regions well known for the presence of highly significant WDEs including the Far North PWA, SA Murray-Darling Basin and Kangaroo Island had lower average scores than expected although individual WDEs were identified within these regions as being at high risk (Figure 4). This is reflective of the lack of Statewide data available for assessment of ecosystem vulnerability and value (Harding & O'Conner 2012). For these reasons, the result of this assessment may be used to support decision making and priority setting, but additional considerations (including expert opinion) should be used to help finalise the selection of priority regions and WDEs for further investigation. Overall the ranking of individual WDEs shown in Figure 6 provides an acceptable preliminary assessment of where WDEs are most likely to be at risk as a result of climate change. This provides a sound basis for assisting in the selection of priority regions and sites for more detailed assessments to understand the potential impacts of climate change on South Australia's WDEs.

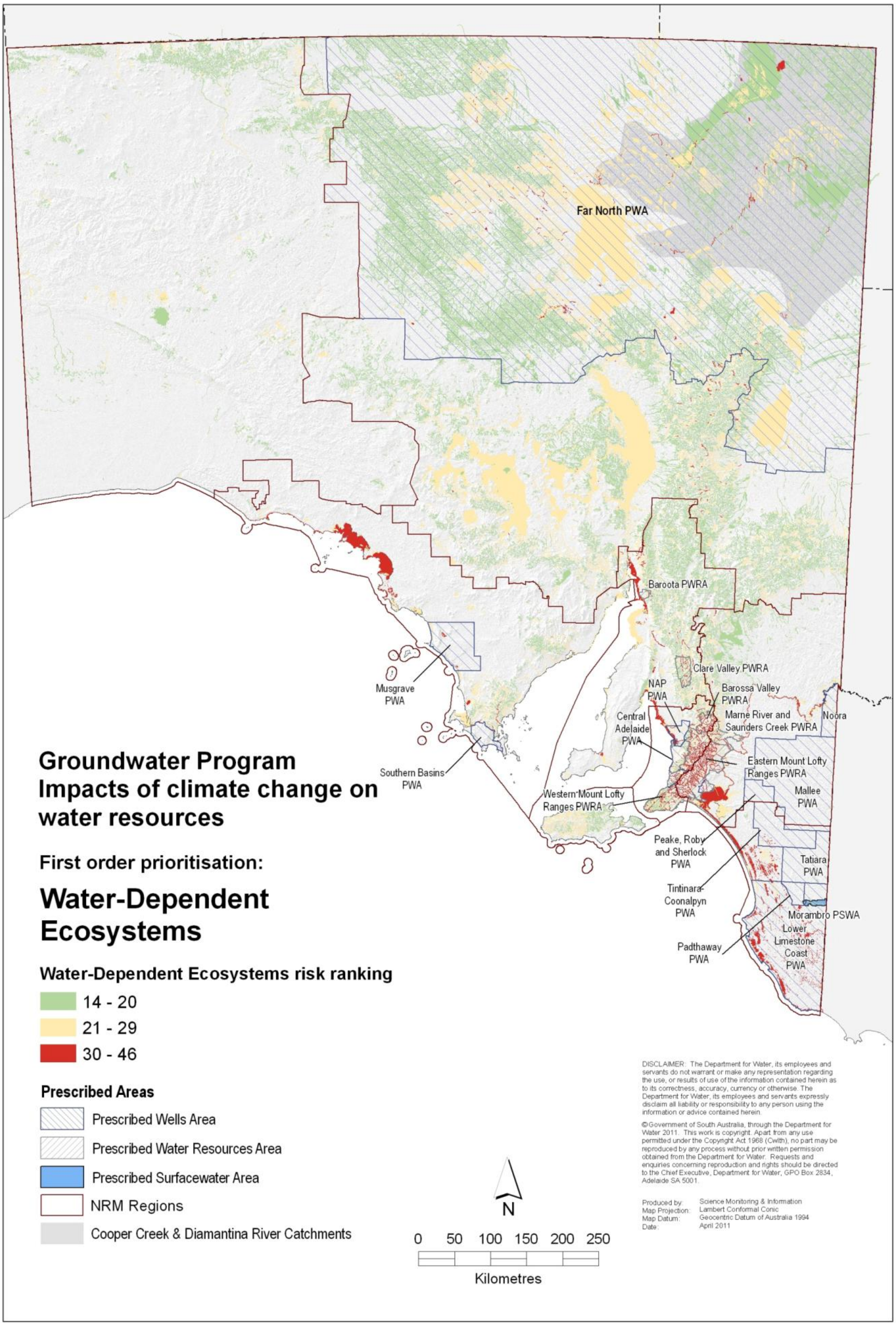


Figure 6. Preliminary assessment: Climate Change risk ranking for WDEs in South Australia

5. ADDITIONAL CONSIDERATIONS AND RECOMMENDATIONS

5.1. *HIGH ECOLOGICAL VALUE AQUATIC ECOSYSTEMS & ECOSYSTEM VULNERABILITY*

A risk assessment approach ideally requires the consideration of consequence, as well as likelihood. The consequences of detrimental impacts on WDEs can be shown to be influenced by the value (significance) of the asset. This information was not available at the Statewide scale, or in a consistent format for South Australia for inclusion in this initial risk assessment. Additionally, different WDE types are likely to have differing vulnerabilities to certain threatening processes or levels of threat. Krause *et al.* (2007) utilised wetland type classifications to determine the level of vulnerability to identified threats. A consistent approach to aquatic ecosystem classification across South Australia would be useful for assessing vulnerabilities to threatening processes within a risk assessment approach.

A National framework has been developed for identifying High Ecological Value Aquatic Ecosystems (HEVAE) through the Aquatic Ecosystems Task Group (AETG). The overall goal of a National HEVAE Framework is to provide a nationally consistent approach to the identification, classification and management of high conservation value aquatic ecosystems and to provide a vehicle to facilitate the management of HEVAE's for natural resource outcomes beyond water management obligations identified through the National Water Initiative (NWI). The National Framework has established a core set of ecological criteria for identifying aquatic ecosystems of high conservation value at both a National and regional scale. The application of the criteria has been trialled in the Lake Eyre Basin (Hale 2010) and the South East of South Australia (Butcher *et al.* 2011).Methods developed could be applied to other regions of South Australia as a consistent approach to identifying high value ecosystems. Having all mapped WDE features across the State classified under the HEVAE framework would assist in a more detailed assessment of ecological vulnerability and consequence of climate change on a Statewide basis.

5.2. *COUPLED HYDROLOGICAL AND ECOLOGICAL MODELS*

Groundwater recharge and surface water hydrological models which apply simulated future climate data sets derived from using downscaled General Circulation Models (GCMs) are being developed for priority regions in South Australia as Phase 3 of the ICCWR project (Green *et al*. 2011). The outputs of these models provide an opportunity to link hydrological modelling outputs to hydraulic and ecological-response models to assess the implications to important WDEs of future climate change scenarios. It is intended that further work within the ICCWR project will progress more detailed analysis based on the outputs of the downscaled models and the selection of priority sites as documented in this report.

In order to understand climate change effects on WDEs or components of ecosystems (e.g. species), the modelled hydrologic output can be paired with ecological data or models to determine ecological impacts of changes in hydrology (e.g. Thompson *et al*. 2009; Aldous *et al*. 2011; Lester *et al*. 2011). Modelling of ecological impact from climate change can however be problematic. Future hydrologic scenarios and their resulting ecological effects are highly uncertain because of compounded errors from the selection of GCMs and future climate scenarios, downscaling, hydrologic models and determination of ecological impacts from hydrologic changes (Aldous *et al*. 2011; Xu *et al*. 2005).

Many hydrologic models assume linear relationships between climatic changes and hydrologic responses, whereas aquatic ecosystems experience non-linear, often threshold responses to disturbance. Also, modelling impacts on ecology can be data intensive. For example, coupled hydrological, hydraulic and ecosystem-response models have been developed for the Coorong (Lester *et al*. 2011). These involve statistical analysis of observed biota, included bird abundance, commercial fish catch, macrophyte distribution, fish and benthic macroinvertebrate abundances related to physico-chemical datasets (water levels, depths, flow, salinity, meteorology and water quality). Therefore, modelling may be practical in regions/sites where extensive hydrologic, hydraulic and ecological data exists, but less so in regions where these are limited (Aldous *et al*. 2011).

Modelling based on conceptual understanding of ecosystem or species water regime and quality thresholds, either based on statistical analysis of monitoring datasets or expert opinion, can also be used to quantify the ecological consequences of different watering scenarios (e.g. Eco Modeller; eWater CRC 2011), however this approach is subject to limitations and errors associated with assumptions made when setting ecosystem threshold responses. Eco-Modeller has been used in Victoria (eWater CRC 2011) to construct models of species responses to habitat requirements (e.g. water depth and velocity) and then to test various watering scenarios to assess impacts on aquatic species in a wetland.

Due to sparse ecological data for WDEs in South Australia and a lack of consistent aquatic ecosystem monitoring, the use of climate change hydrological modelling outputs to extrapolate or model impacts on WDEs may be limited to sites where ecological and hydrological data already exists, or rely on conceptual understanding of ecosystems and species threshold responses.

5.3. EMERGING WATER-DEPENDENT ECOSYSTEM CONDITION ISSUES

Some water-dependent ecosystems in South Australia have shown marked declines in condition over the past decade. While in many cases these cannot yet be definitively attributed to successive years of below average rainfall or excessive consumptive water use, it is imperative to gain an understanding of the relationship between surface water and groundwater inputs, ecological response to changing hydrology and the effects of water resource extraction and climate change on the condition of WDEs.

Within the Department for Water, monitoring programs exist for quantifying groundwater and surface water resource condition and water usage (metering), which produce data used to determine the condition of water resources in the State and inform water resource allocation, policy and planning.

Currently, there is a lack of data and knowledge of environmental water requirements, aquatic ecosystem condition and ecologically acceptable limits of change in shallow groundwater levels for much of the State. The lack of such data for identified important ecosystems in South Australia will be a limitation in assessing the potential impacts of climate change on WDEs.

5.4. PROVIDING FOR ENVIRONMENTAL WATER REQUIRMENTS IN WATER ALLOCATION PLANS

Response to changes in climate (precipitation, PET or temperature) can be partly mitigated by management, such as land use and land cover, water storage and extraction. Hence opportunities for climate change adaptation exist and include conservation and mitigation strategies for maintaining water-dependent ecosystems. The development of water allocation plans have in the past adopted an adaptive management approach which responds to changes in the capacity of water resources to deliver environmental water requirements at regular WAP reviews. In selecting priority regions for first attention in the ICCWR project, the immediate needs of water allocation plans in development or review are taken into account.

5.5. BAYESIAN NETWORK MODELS

Many ecological processes impacted by changes in hydrology and climate are not well understood and are inherently subject to uncertainty and lack of data. Bayesian Belief Networks (BBNs) – probabilistic graphical models - potentially offer an effective way to deal with this lack of knowledge and more transparently communicate uncertainty when trying to ascertain the risks and consequences to ecosystems. Their application can add rigour and transparency to decision-making processes and have gained considerable interest from researchers, as well as government and other organisations involved in the management of natural resources (Merrit *et al.* 2010).

Bayesian Network Models have been used for determining environmental water provisions for WDEs in Queensland, New South Wales and Victoria and have the potential to accommodate the lack of data and uncertainty encountered in the initial risk assessment. BBN models are also designed to show areas where additional data parameters are required (Ghabayen *et al.* 2006) and as such, are potentially useful in guiding future monitoring and data collection activities.

5.6. RECOMMENDATIONS

The regions or sites selected for first attention in Phase 3 of the ICCWR project and in selection of sites for determining impacts of climate change on WDEs, should consider the priority rankings identified in this report, rankings of priority water resources (Wood & Green 2011) and the issues and limitations discussed in this technical report. These decisions will be made as part of a project scope review.

Recommendations for progressing the assessment of impacts of climate change on WDEs, include:

- investigate the potential use of probabilistic statistical modelling (such as Bayesian Belief Networks) to assist in making more detailed predictions of risk to specific WDE features in high priority regions identified in this report.
- use of expert workshops to review and validate the outputs of the initial risk assessment and identify any inconsistencies with field based knowledge
- assessing potential impacts of climate change on other WDE features such as springs and rockholes
- assessing ecosystem vulnerability (contributing to the likelihood of risk) and ecological value for high priority regions

  assessing ecological, physico-chemical and hydrological data availability in priority regions that could be utilised and developed into coupled hydrological - hydraulic - ecological-response models for determining climate change scenario impacts on WDEs and to consider the development of WDE conceptual models to assist where insufficient data is available.

The outcomes of the ICCWR project will facilitate a more predictive and proactive priority driven adaptive management approach for South Australia’s water resources.

APPENDICES

A. RESOURCE SENSITIVITY RANKING SCORES

NRM Region / Prescribed Water Resource	Resource Description	Water Resource Sensitivity Rating Scores				
		Aquifer confinement	Reliance on modern (rainfall) recharge	Aquifer Response buffering	Recharge catchment within area	**Resource Sensitivity Total Score**
GROUNDWATER RESOURCES						
Adelaide & Mt Lofty Ranges						
Barossa PWRA	Groundwater – upper aquifer	2	3	2	Yes	**7**
Central Adelaide PWA	Unconfined aquifer (Quaternary sands/gravels aquifer)	2.5	2	2	Yes	**6.5**
McLaren Vale PWA	Unconfined aquifer (Quaternary)	3	3	2	Yes	**8**
North Adelaide Plains PWA	Unconfined aquifer (Quaternary sediments)	3	2	1.5	Yes	**6.5**
Unprescribed AMLR	Groundwater (sedimentary aquifers)	3	1.5	1.5	Yes	**6**
Alinytjara Wilurara						
Unprescribed AW (Amata)	Unconfined aquifer	3	3	3	Yes	**9**
Unprescribed AW (Fregon)	Unconfined aquifer	3	1.5	1.5	Yes	**6**
Unprescribed AW (Indulkana)	Unconfined aquifer	3	3	3	Yes	**9**
Unprescribed AW (Kalka)	Unconfined aquifer	3	1.5	1.5	Yes	**6**
Unprescribed AW (Mimli)	Unconfined aquifer	3	1.5	1.5	Yes	**6**
Unprescribed AW (Pipalyatjara)	Pipalyatjara TWS (groundwater)	3	0	0	N/A	**3**
Unprescribed AW (Pukatja)	Unconfined aquifer	3	3	3	Yes	**9**
Unprescribed AW (Yalata)	Unconfined aquifer	3	1.5	1.5	Yes	**6**
Unprescribed AW (Yunyarinyi	Unconfined aquifer	3	1.5	1.5	Yes	**6**

(formerly Kenmore Park))						
Eyre Peninsula						
Musgrave PWA	Unconfined Quaternary sediments	3	3	3	Yes	**9**
Southern Basins PWA	Unconfined Quaternary Limestone	3	3	3	Yes	**9**
Unprescribed EP	Unprescribed groundwater: unconfined quaternary limestone and palaeochannel sand aquifers	3	1.5	1.5	Yes	**6**
Kangaroo Island						
Unprescribed Kangaroo Island	Unconfined + confined aquifers	1.5	1.5	1.5	Yes	**4.5**
Northern & Yorke						
Baroota PWRA	Unconfined aquifer (Quaternary)	3	3	3	Yes	**9**
Clare Valley PWRA	Unconfined aquifer (fractured rock aquifer)	3	3	3	Yes	**9**
Unprescribed NY (Balaklava)	Unconfined aquifer (TLA)	2	3	1.5	Yes	**6.5**
Unprescribed NY (Booborowie Valley)	Unconfined aquifer	3	3	3	Yes	**9**
Unprescribed NY (Carribie basin)	Unconfined aquifer (Quaternary)	3	3	3	Yes	**9**
Unprescribed NY (Para-Wurlie basin)	Unconfined aquifer (quaternary limestone)	3	3	3	Yes	**9**
South Australian Arid Lands						
Unprescribed SAAL(Nepabunna)	Unconfined aquifer (Quaternary)	3	3	3	Yes	**9**
Far North PWA	Unconfined aquifer (fractured rock aquifer)	3	3	3	Yes	**9**
Far North PWA	Unconfined aquifer (TLA)	2	3	1.5	Yes	**6.5**
Far North PWA	Confined aquifer (GAB artesian)	0	1	0	Yes	**1**
Unprescribed SAAL	Unconfined aquifer	3	3	3	Yes	**9**
South Australian Murray-Darling Basin						
Angas-Bremer PWA	Unconfined aquifers (fractured rock, sedimentary and palaeo-channels)	3	3	2	Yes	**8**
Eastern Mount Lofty Ranges PWRA	Groundwater(Permian sand unconfined/confined	3	3	1.5	Yes	**7.5**

	aquifer system)					
Marne Saunders Prescribed Water Resources Area	Unconfined aquifer (TLA and fractured rock aquifer)	3	3	3	Yes	**9**
Peake Roby and Sherlock PWA	Unconfined aquifer (Tertiary limestone and Quaternary limestone)	3	2.5	1.5	Yes	**7**
Western Mount Lofty Ranges PWRA	Unconfined aquifer (Southern Fleurieu - Sedimentary)	3	3	2	Yes	**8**
Mallee PWA	Tertiary limestone aquifer (unconfined portion)	3	0	1.5	No	**4.5**
South East						
Lower Limestone Coast PWA	Unconfined aquifer (Tertiary Limestone Aquifer)	3	3	3	Yes	**9**
Padthaway PWA	Unconfined aquifer (Tertiary Limestone Aquifer)	3	3	3	Yes	**9**
Tatiara PWA	Unconfined Aquifer (Tertiary Limestone Aquifer)	3	3	3	Yes	**9**
Tintinara-Coonalpyn PWA	Unconfined aquifer (Tertiary Limestone Aquifer)	3	3	3	Yes	**9**

Source: Appendix B, Wood & Green 2011.

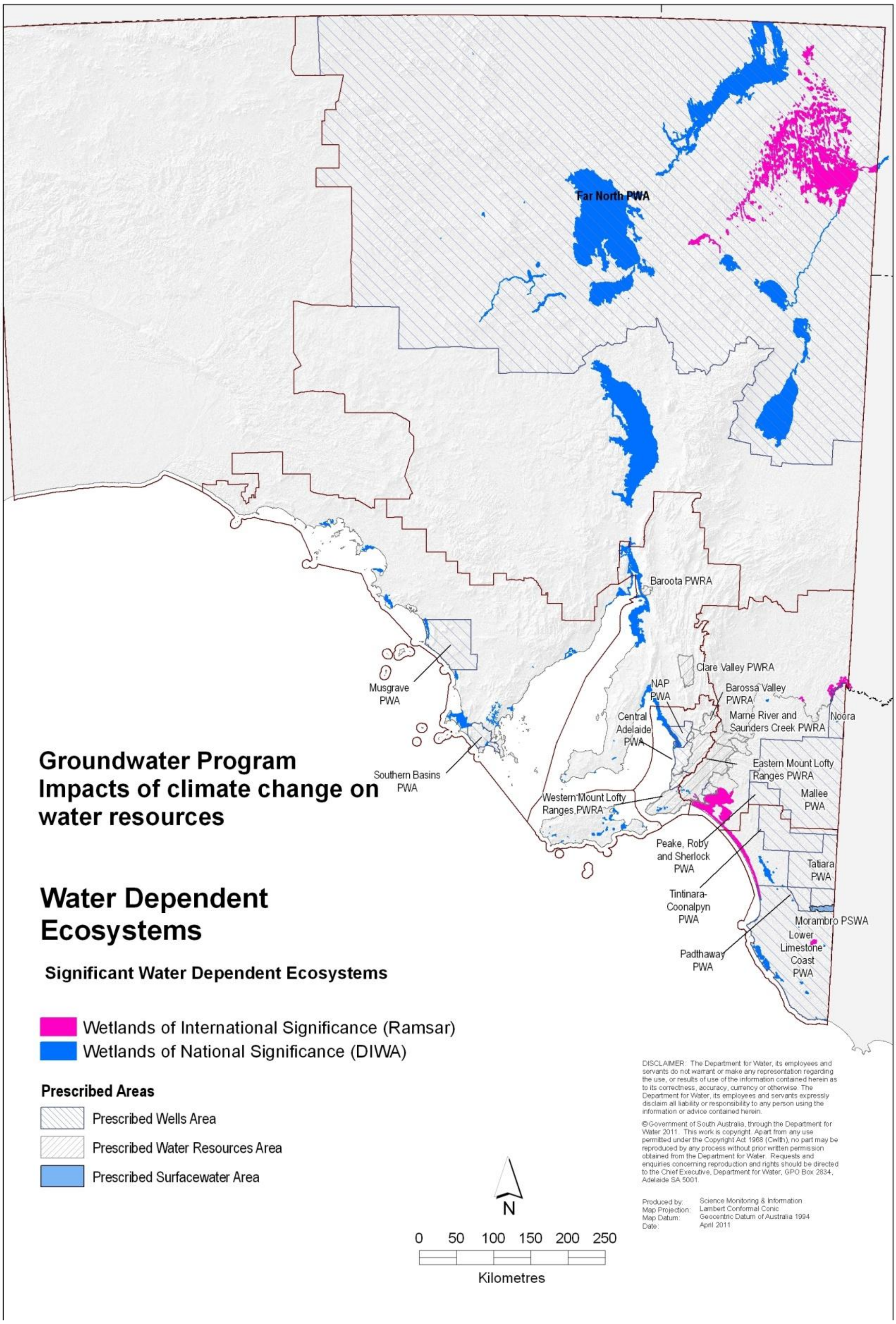
Note –In many cases Wood and Green 2011 assessed multiple aquifers within one prescribed area however for the assessment of climate change impacts on WDEs only those aquifers with the potential to support dependent ecosystems were considered.

B. SURFACE WATER RESOURCE USAGE SCORES

NRM Region / Prescribed Water Resource	Resource Description	Water Resource Usage Rating Scores				
		Surface water use Public Water Supply	Irrigation and industrial	Environmental Water Requirements	Catchment within area	**Surface Water Resource Usage Total Score**
SURFACE WATER RESOURCES						
Baroota PWRA	Surface water / watercourse	0	2	2	Yes	**4**
Clare Valley PWRA	Surface water / watercourse	0	3	3	Yes	**6**
Unprescribed Kangaroo Island	Surface water / watercourse	3	2.5	3	Yes	**8.5**
Barossa Valley PWRA	Surface water / watercourse	1	3	1.5	Partial	**5.5**
Marne Saunders PWRA	Surface water / watercourse	1	2	3	Yes	**6**
Central Adelaide PWA	Surface water / watercourse	0	1	2	Partial	**3**
Eastern Mount Lofty Ranges PWRA	Surface water / watercourse	1	2	3	Yes	**6**
Morambro Creek	Surface water / watercourse	1	1	3	No	**5**

Source: Appendix B, Wood & Green 2011

C. NATIONALLY AND INTERNATIONALLY IMPORTANT WETLANDS – SOUTH AUSTRALIA



GLOSSARY

AETG - Aquatic Ecosystems Task Group (AETG)

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

Arid lands — In South Australia, arid lands are usually considered to be areas with an average annual rainfall of less than 250 mm and support pastoral activities instead of broadacre cropping

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

Basin — The area drained by a major river and its tributaries

Bayesian Belief Network (BBN) – Probabilistic graphical model (a type of statistical model) that represents a set of random variables and their conditional dependencies via a graphical interpretation (directed graph).

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

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

CSIRO — Commonwealth Scientific and Industrial Research Organisation

DENR – Department for Environment and Natural Resources (SA)

DFW — Department for Water (Government of South Australia)

Domestic purpose — The taking of water for ordinary household purposes; includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares

DIWA – Directory of Important Wetlands in Australia (ANCA 1996). Identifies wetlands on national significance in Australia.

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

EC — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS

Ecological values — The habitats, natural ecological processes and biodiversity of ecosystems

Ecosystem — Any system in which there is an interdependence upon and interaction between, living organisms and their immediate physical, chemical and biological environment

Eco-Modeller – Tool for building, storing and running quantitative models of ecological responses to physical and biological factors, for use in comparing the merits of alternative natural resource management solutions (eWater CRC 2011).

Environmental values — The uses of the environment that are recognised as being of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

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

GLOSSARY

Ephemeral streams or wetlands — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

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

GAB — Great Artesian Basin

GDE — Groundwater-dependent ecosystem

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

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

HEVAE - High Ecological Value Aquatic Ecosystems

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'

ICCWR – Impacts of Climate Change on Water Resources (Department for Water project)

Impact — A change in the chemical, physical, or biological quality or condition of a water body caused by external sources

IPCC – Intergovernmental Panel on Climate Change

Irrigation — Watering land by any means for the purpose of growing plants

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

LLC – Lower Limestone Coast (Prescribed Wells Area)

Low flows – The water in a stream that maintains flows during seasonal dry periods and has important ecological functions (see also 'Baseflow')

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

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

NWI - National Water Initiative

Perennial streams — Permanently inundated surface stream courses. Surface water flows throughout the year except in years of infrequent drought.

PET – Potential Evapotranspiration

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

PWA — Prescribed Wells Area

PWRA — Prescribed Water Resources Area

GLOSSARY

Ramsar – The Ramsar Convention on Wetlands (1971). An intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

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

SAAE – South Australia Aquatic Ecosystem Classification

SAMDB – South Australian Murray-Darling Basin

SD – Standard Deviation

SRES – Special Report on Emission Scenarios (IPCC 2000)

Stock use — The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act)

Sub-catchment — The area of land determined by topographical features within which rainfall will contribute to run-off at a particular point

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

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

Water Resource – For the purposes of this report, a water resource is defined in terms of a management unit for consumption as presented in *Impacts of Climate Change on Water Resources – Phase 1: First Order Risk Assessment & Prioritisation* (Wood & Green 2011). This includes broad scale groundwater resources, often identified as a particular aquifer unit (ie unconfined or confined aquifer) and surface water resources (ie catchment area).**Water-dependent ecosystems** — Those parts of the environment, the species composition and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground; the in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems

WDE — Water-dependent ecosystem

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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