DEPARTMENT OF PLANNING, INDUSTRY & ENVIRONMENT

Climate change impacts in the NSW and ACT Alpine region

Impacts on water availability

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ACT	Australian Capital Territory
ALUM	Australian Land Use and Management Classification
ANN	Annual
AWAP	Australian Water Availability Project
CAP	Catchment Action Plan
CMIP	Coupled Model Intercomparison Project
DJF	December January February
DPIE	NSW Department of Planning, Industry and Environment
ET	evapotranspiration
FPC	foliage projective cover
GCM	Global Climate Model
GSG	Great Soil Groups classification
HGL	hydrogeological landscape (HGL)
JJA	June July August
MAM	March April May
MCAS-S	Multi-Criteria Analysis Shell for Spatial Decision Support
mm	millimetre
MM	Murray-Murrumbidgee state planning region
NARCliM	NSW/ACT Regional Climate Modelling project
NetCDF	Network Common Data Form
NSW	New South Wales
NVAT	Native Vegetation Assessment Tool
OEH	Office of Environment and Heritage
RCM	Regional Climate Model
SET	South East and Tablelands
SON	September October November
SRES	Special Report on Emissions Scenarios
SRTM	Shuttle Radar Topography Mission
WRF	Weather Research and Forecasting
WDM5	WRF Double Moment 5-class

Summary of findings

Impacts on water availability in the NSW and ACT Alpine region

1. Impacts of climate change on water availability affect water quality, salinity and aquatic biodiversity. Climate change is projected to affect water availability through changes in surface runoff and recharge to groundwater.
2. In the near future (2020 to 2039), most of the study area is likely to have less surface runoff, while areas from Balranald to Deniliquin, Griffith and northern parts from West Wyalong to Goulburn are likely to experience increased surface runoff. In the far future (2060 to 2079), reductions in surface runoff of more than 40 millimetres/year are projected for higher alpine areas, generally bounded by the NSW and ACT Alpine region, from Tumut to Canberra to the Victorian border in the south.
3. Changes in recharge to groundwater in near future projections are slightly less than changes in the far future projections. Both scenarios project reduced recharge. For both near future and far future projections, areas bounded by the NSW and ACT alpine park reserves are significantly impacted, with a substantial reduction in recharge.
4. In the near future, most of the study area is likely to have less recharge, except for some areas west of Deniliquin and Griffith that show a slight increase. Far future projections predict less recharge in summer, winter and autumn, with the largest decreases during in spring.
5. For the near future, most Catchment Action Plan (CAP) regions currently designated as low salinity hazard show no change in hazard. There is potential for less dilution flow from low hazard CAP regions in alpine areas, which could increase downstream catchment-scale salinity. Most CAP regions with moderate, high or very high salinity hazard show either no change in hazard or lower salinity hazard in the near future. The only exceptions are CAP regions west of Deniliquin that show an increase in salinity hazard.
6. For the far future, most CAP regions currently designated as low salinity hazard show no change in hazard. Some low hazard areas north of Griffith show the potential for higher dilution flows that could be beneficial for catchment-scale salinity. CAP regions that are currently moderate, high or very high salinity hazard show either no change in hazard or higher salinity hazard in the far future. CAP regions west of Narrandera consistently show an increase in salinity hazard.
7. All CAP regions with high irrigation land use (e.g. Griffith, Leeton) have a potential for high salinity hazard.

1. Introduction

1.1 Background

The New South Wales (NSW) and Australian Capital Territory (ACT) Alpine region is located in the south-eastern corner of mainland Australia and is the highest mountain range in Australia. Though it comprises only about 0.16% of Australia in size, it is an important region for ecosystems, biodiversity, energy generation and winter tourism. It forms the southern end of the Great Dividing Range, covering a total area of 1.64 million hectares that extend over 500 kilometres. The highest peak, Mount Kosciuszko, rises to an altitude of 2228 metres.

This report is part of a larger project delivered by the NSW Department of Planning, Industry and Environment on the various impacts from climate change on the NSW and ACT Alpine region, hereafter referred to as the Alpine region. The full study region covers the Murray-Murrumbidgee region (MM), South East and Tablelands (SET) and the ACT, bordering the Victorian border in the south (Figure 1).

The Alpine region is vulnerable to climate change. Observations have shown substantial changes in precipitation and temperature for this area (Di Luca et al. 2018), which have already impacted biodiversity and ecosystems (Hughes 2011). In 2014, the NSW/ACT Regional Climate Modelling (NARCliM) project was delivered. Climate snapshots for each of the 11 NSW planning regions and the ACT were developed to demonstrate observed and projected climate change; however, the snapshots only show changes for some variables and focus on each planning region.

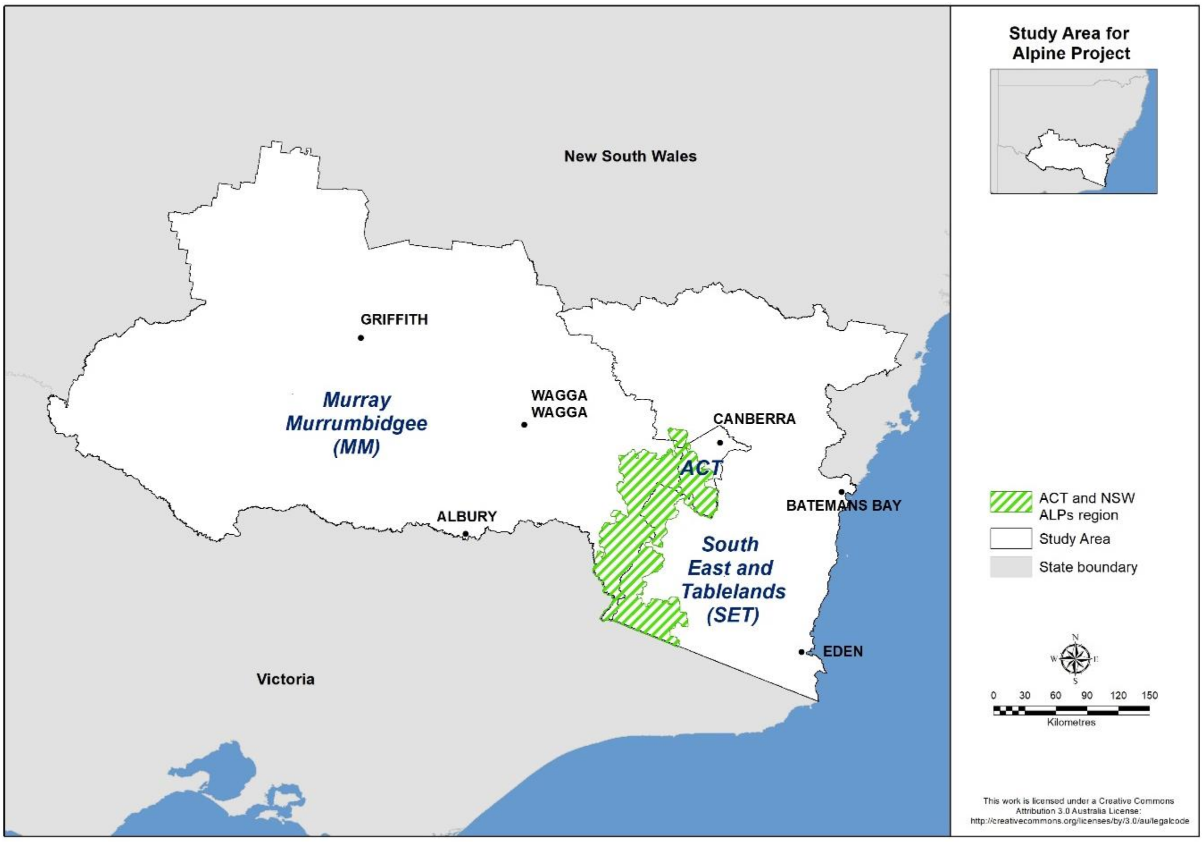

Figure 1 **The study area for the Alpine project, including the NSW and ACT Alpine region, Murray-Murrumbidgee region and South East and Tablelands**

1.2 Objectives

This study provides projections for potential impacts of climate change on the surface runoff and recharge to groundwater within the MM region, ACT and SET areas of New South Wales. Surface flow and groundwater recharge projections can assist decisions on adaptation options for managing water resources, water quality and waterway health that affect the ecosystem services our waterways provide. Combining surface runoff and recharge projections allows us to explore changes in landscape water movement and its impact on salinity hazard and dilution flows within sub-catchments.

We used the NARCliM ensemble of climate projections for south-east Australia. This ensemble is designed to provide robust projections that span the range of likely future changes to climate (Evans et al. 2014). NARCliM projections over three climate time periods were used as inputs to a water balance model, PERFECT (Littleboy et al. 1992). The three time periods consisted of a baseline (1990 to 2009), near future (2020 to 2039) and far future (2060 to 2079).

Unlike the hydrological assessment for New South Wales in 2010 (Vaze et al. 2010), which used a conceptually lumped rainfall–runoff model (Chiew et al. 2002), this impact assessment applies a daily time-step, one-dimensional model to each grid cell. Using rainfall and areal potential evapotranspiration (Morton 1983; Ji et al. 2015) as inputs, the model partitions non-transpired water into surface flows and groundwater recharge. This partitioning is driven by soil properties, land use and topography. The major benefit of this type of modelling is that results are not constrained to catchment boundaries and impacts on surface flows and recharge can be obtained for individual parts of the landscape. However, a change in surface runoff does not directly correlate to a similar change in streamflow at the catchment outlet. Not all surface runoff will flow into the river itself, flowing instead into farm dams, wetlands and other waterbodies.

Changes in surface runoff and recharge to groundwater can also be used to explore hydrological changes at a landscape scale. Salinity and landscape water movement are inextricably linked. Salinity is the accumulation of salt in the landscape. It can be mobilised by surface runoff, subsurface flow, groundwater recharge or groundwater discharge.

Salinity is an important variable in landscape systems and is often a determining factor in the capacity of the landscape to absorb change (Smithson et al. 2004). It has a three-pronged impact on landscapes namely land salinisation, in-stream salt load and in-stream salt concentration. Any of these impacts can themselves or together affect landscape resilience.

In New South Wales, Salinity Hazard for Catchment Action Plans (CAP) provides a framework to better understand how salinity influences landscape resilience. Catchment Action Plan products are appropriate for planning at a catchment scale. This existing mapping provides a consistent salinity mapping product that covers the entire study area.

1.3 Outputs

Raster format spatial data, maps and graphs from this modelling form part of this climate impact profile to assess projected biophysical changes across the study area. Maps show central estimates or arithmetic means of near and far future projections. Bar graphs are used to present projections as ranges of plausible change, illustrating the projections from the 12 individual simulations as well as the central estimate.

Output	Details	Key users
Report	This report	Researchers
Maps	.jpg	Councils, etc.
Data	geoTIFF format rasters, .csv	Spatial analysts

1.4 Focus region

The study area covers an area of more than 171,000 square kilometres and extends across the SET, ACT and MM catchments, bordering the Victorian border in the south. It spans three distinct physiographic provinces (Pain et al. 2011):

- Kosciuszkan Uplands Province 107, (mountains and plateaus ranging from the highest point in Australia to the coast) covering most of the catchment
- a small coverage of Macquarie Uplands Province 106, (dissected plateaus on sub-horizontal resistant sandstones, mainly of the Sydney Basin) to the north of Goulburn, and Cootamundra
- Murray Lowlands Province 203 (more-or-less coincident with the Murray sedimentary basin, consisting of flat alluvium with aeolian cover in places) to the western third of the catchment from Corowa in the south to Leeton in the north.

The area falls completely within the temperate climatic zone (BoM 2006) and mean annual temperatures of –0.4°C to 21.1°C and annual rainfall averages of 313–1828 millimetres span this climatic zone.

2. Method

2.1 Source of data

NARCliM simulations from four Coupled Model Intercomparison Project phase 3 (CMIP3) Global Climate Models (GCMs) were used to drive three Regional Climate Models (RCMs) to form a 12-member GCM/RCM ensemble (Evans et al. 2014). The four selected GCMs are MIROC3.2, ECHAM5, CCCMA3.1 and CSIRO-MK3.0. For future projections, the Special Report on Emissions Scenarios (SRES) business-as-usual A2 scenario was used (IPCC 2000). The three selected RCMs are three physics scheme combinations of the Weather Research and Forecasting (WRF) model. Each simulation consists of three 20-year runs (1990 to 2009, 2020 to 2039, and 2060 to 2079). The four GCMs were chosen based on a number of criteria: i) adequate performance when simulating historic climate; ii) most independent; iii) cover the largest range of plausible future precipitation and temperature changes for Australia. The three RCMs correspond to three different physics scheme combinations of the WRF V3.3 model (Skamarock et al. 2008), which were also chosen for adequate skill and error independence, following a comprehensive analysis of 36 different combinations of physics parameterisations over eight significant East Coast Lows (ECLs) (Evans et al. 2012; Ji et al. 2014). For the selected three RCMs, the WRF Double Moment 5-class (WDM5) microphysics scheme and NOAH land surface scheme are used in all cases. Refer to Evans et al. (2014) for more details on each physics scheme.

We acknowledge that the results are model dependent (as all model studies are) but through the use of this carefully selected ensemble we have attempted to minimise this dependence. By using this model selection process, we have shown that it is possible to create relatively small ensembles that are able to reproduce the ensemble mean and variance from the large parent ensemble (i.e. the many GCMs) as well as minimise the overall error (Evans et al. 2013a).

Some initial evaluation of NARCliM simulations shows that they have strong skill in simulating the precipitation and temperature of Australia, with a small cold bias and overestimation of precipitation on the Great Dividing Range (Evans et al. 2013b, Ji et al. 2016). The differing responses of the different RCMs confirm the utility of considering model independence when choosing the RCMs. The RCM response to large-scale modes of variability also agrees well with observations (Fita et al. 2016). Through these evaluations we found that while there is a spread in model predictions, all models perform adequately with no single model performing the best for all variables and metrics. The use of the full ensemble provides a measure of robustness such that any result that is common through all models in the ensemble is considered to have higher confidence.

In total, there were four same GCM driven simulations (average of three members) and three same RCM used simulations (average of four members). The analyses in this study are based on the ensemble mean of these simulations.

2.2 Climate projections

While the climate models produce a range of variables, only daily maximum temperature, daily minimum temperature, precipitation and evapotranspiration (ET) are required to drive the water balance model. Bias-corrected precipitation was considered, but due to incomplete spatial coverage was not used. Cell resolution of the NARCliM domain is at 10 kilometres, data is WGS84 regular grid.

2.3 Water balance model

This work has been undertaken using the application of the water balance model PERFECT (Littleboy et al. 1992) using spatially specific key input drivers of land use, foliage projective cover, soils, and the NARCliM ensemble of climate projections for south-east Australia (Evans et al. 2014). Outputs are presented for the near future (2020 to 2039) and far future (2060 to 2079), of annual and seasonal surface runoff and recharge in comparison to a baseline period (1999 to 2009) for a high emissions scenario – the A2 scenario from the Special Report on Emissions Scenarios (SRES) (IPCC 2000). Changes under lower emissions are likely to be similar in nature but weaker in magnitude than these projections; also, changes outside those contained in the NARCliM projections are also possible.

The water balance model used daily time-series of NARCliM non-bias-corrected rainfall and areal potential evapotranspiration (Morton 1983; Ji et al. 2015) modelled by each GCM/RCM as inputs. Actual ET was calculated daily using areal potential ET and seasonal crop factors. Crop factors varied by land-use category and foliage projective cover (FPC). Using FPC to disaggregate land-use categories to account for different levels of tree cover was crucial to account for spatial variability within a single land-use polygon.

Partitioning between surface flow and recharge is driven by soil properties and topography for each ~90 metre (3 arc-second) cell within a NARCliM 10 kilometre cell. Volumes of surface flow are governed by model parameters and variables describing potential infiltration, antecedent soil water, surface and vegetative cover and slope. Volumes of recharge are controlled by parameters and variables quantifying drainage rates through the soil profile, soil depth and slope.

PERFECT is a one-dimensional, daily time-step water balance model which predicts the water balance in a single column of soil. It does not predict lateral subsurface movement of water. Any excess soil water is assumed to move vertically as deep drainage to groundwater. Therefore, estimates of drainage from PERFECT are a combination of subsurface lateral flow and vertical drainage. To partition excess soil water moving laterally and vertically, the HYDRUS 2D model (Simunek et al. 1999) was applied to develop a generic model of lateral water movement (Rassam & Littleboy 2003).

2.4 Salinity analysis

The salinity assessment is based on existing salinity hazard mapping undertaken in NSW Catchment Action Plans (CAPs). These maps were designed to be appropriate for planning at a catchment scale as they show the broad salinity hazard distribution across the study area. They are fully documented and represent the only consistent salinity dataset currently available across the entire study area. The maps depict the potential severity of salinity underpinned by a practical understanding of the factors that cause salinity at the time.

Each salinity hazard map defines spatial units based on relevant biophysical datasets including groundwater flow systems mapping, depth to water table maps, soil mapping and terrain. Each spatial unit has been assigned a salinity hazard ranking – Very High, High, Moderate, Low and Very Low. Hazard ratings were derived from other statewide and catchment data sets that influence salinity. In addition, consideration was given to the presence or absence of known dryland salinity outbreaks, influence of local or regional groundwater systems, climatic impacts and any other relevant modifiers impacting on the hazard area. Existing hydrogeological landscape (HGL) hazard information was integrated in areas where it was available.

Salt mobilisation occurs when movement of water within a landscape intercepts a salt store, producing saline discharge. Changes to the volume of water added to the natural system intensify the processes that cause salinity as the water cycle tries to find a new balance. As such, any increases in landscape water movement inputs due to climate change may intensify salinity impacts. Conversely, less movement of water within landscapes may reduce the impacts of salinity.

Volumes of surface runoff and recharge to groundwater can be used to quantify the surplus water movement in a landscape that could potentially mobilise salt. In this study, changes in runoff and recharge were combined to calculate the change in surplus water.

These changes were split into three categories, namely: greater than 10% drier, greater than 10% wetter or no change (Table 1). The impacts of changes in surplus water on salinity vary depending on the likely salt stores.

For areas with low salinity hazard, changes in surplus water will mainly affect freshwater flows or dilution flows within the catchment. Dilution flows from non-saline areas are crucial for catchment salt export because they dilute salt water from saline areas. More dilution flow is usually seen as beneficial because it provides more fresh water into the catchment. Less dilution flow can cause higher stream salinity concentrations at the end of the catchment.

For areas with moderate to high salinity hazard, it is more likely that salt stores are currently being intercepted by water moving through the landscape. If the climate change analysis is forecasting less water movement, then salinity hazard will be reduced. Conversely, more water movement through higher salinity hazard areas is likely to mobilise additional salt and hence increase salinity hazard.

Table 1 **Categories of potential salinity hazard/dilution flow change**

Blue and red colours denote low and high CAP hazard, respectively.

Change in surplus water (runoff + recharge)		CAP hazard				
		Very Low	**Low**	**Moderate**	**High**	**Very High**
Drier	< –10%	Potential for lower dilution flows		Lower salinity hazard		
No change	–10% to +10%	No change to salinity hazard				
Wetter	> +10%	Potential for higher dilution flows		Higher salinity hazard		

2.5 Spatial datasets

PERFECT requires spatial data for land use, soil and slope. Land use, soil type and slope vary significantly and spatially over the study area and are assumed to be static through time. Other inputs (NARCliM projections) do vary over time and space. In this study, the spatial resolution is 3 arc-seconds for land use, soil, slope, predRH (Rassam & Littleboy 2003), and ~10 kilometres for NARCliM grid.

Land use and foliage projective cover

Land use, land management and foliage cover have major effects on the water balance, with impacts on water infiltration, evapotranspiration, soil water-holding capacity, nutrients, plants and animals. Detailed land-use mapping shown in Figure 2 was derived from the NSW Land use v1 and ACT ACLUMP. The combined attributes, derived from Australian Land Use and Management Classification (ALUM), were allocated to nine simplified categories (Conservation, Forest, Grazing, Cropping, Horticulture, Tree Horticulture, Cleared, Urban, Irrigation and Water; water areas were excluded from this modelling). These categories were selected to better reflect hydrological response across different land-use types.

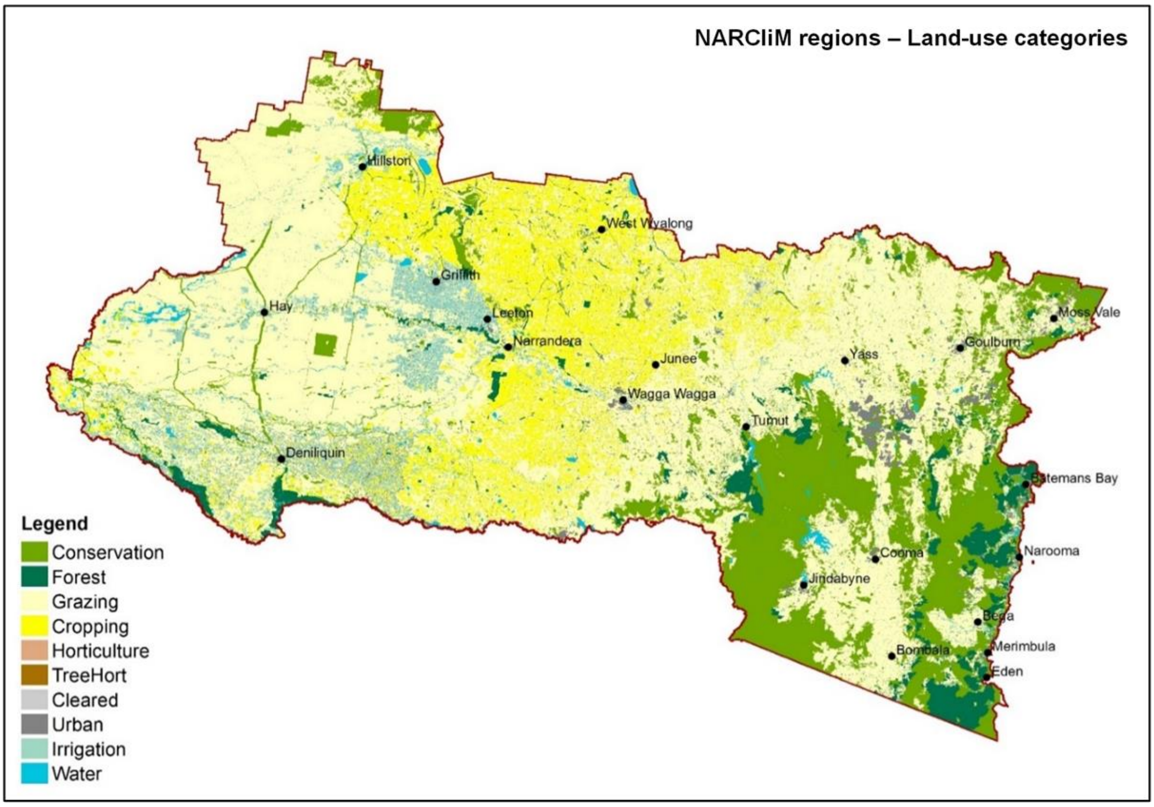

Figure 2 **Detailed land-use categories derived from the DPIE NSW Land use v1 and Sydney 1:100k mapping**

To better model hydrology within the land-use categories, foliage projective cover (FPC) shown in Figure 3 was derived from the NSW woody vegetation and FPC 2011 statewide dataset and categorised to four classes (0–20%, 20–40%, 40–65%, ≥65%). The categorised FPC layer was intersected with the land-use layer to create hydrological response units. Using FPC was crucial for land-use categories such as grazing because it allowed us to separate grazing areas into open grasslands, open woodlands and closed woodlands. In that way, we captured the varying hydrological responses that are inherent within a single and generic land-use category.

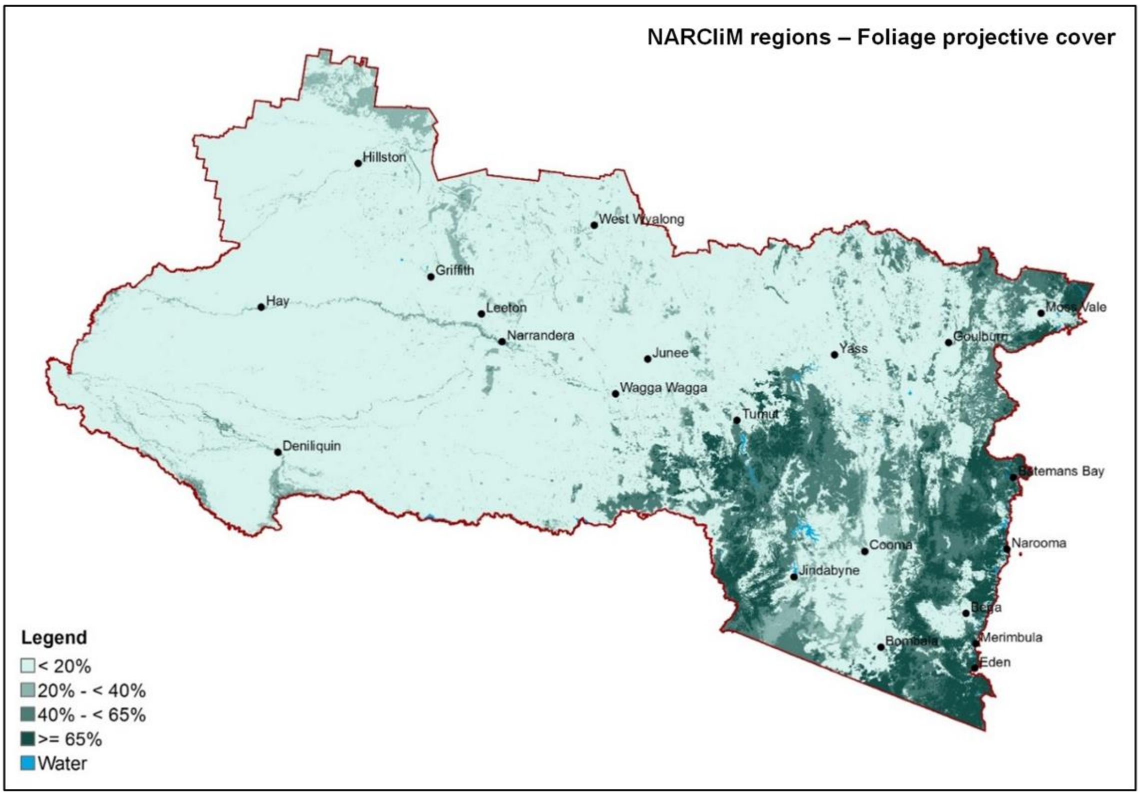

Figure 3 **Percentage of foliage projective cover derived from the DPIE NSW woody vegetation and FPC 2011 statewide dataset**

Soil types (Great Soil Groups of NSW)

The nature and conditions of the underlying soils (depth, type, texture, chemical composition, physical properties, available moisture content, hydraulic conductivity, and bulk density) all affect the water balance within a catchment.

Soil types across the region are shown in Figure 4 and have been classified using a modified version of the Great Soil Groups (GSG) classification. It uses the best available soils and natural resource mapping coverage provided by the NSW Government.

The dominant soil type for each ~90 metre cell within the study area was determined. Soil hydraulic properties (water content, wilting point, field capacity, saturation, and hydraulic conductivity) for each GSG as compiled by (Littleboy et al. 2003, 2009) were used to define soil hydraulic parameters. These parameters are input files to the PERFECT model.

Lateral flow partitioning coefficient (Rh)

Mean slope for each ~90 metre (3 arc-second) cell and values for lateral flow partitioning coefficient (Rassam & Littleboy, 2003) were calculated from the Shuttle Radar Topography Mission (SRTM) 30 metre resolution Digital Elevation Model.

Modelling environment (Python 2.7)

Modelling was performed using a Python-based system, backed by the core PERFECT water balance model, implemented in FORTRAN and compiled to executable (exe) format. The Python software managed the various spatial and temporal data inputs and pre-processed this data for input to the point-based PERFECT model, before assembling the outputs into spatial and aggregate output files as ESRI raster format. At its core, the system manages unique ‘scenarios’, which describe a set of PERFECT model runs based on three key information sources for the area of interest: climate, soil and land-use/foliage cover inputs. The intersection of these three information sources identifies a unique spatial area and determines the corresponding PERFECT model inputs and parameters required for the unit to be modelled. To minimise run times, only unique combinations of land use and soil within a single 10 kilometre NARCliM cell were processed.

For the simulations presented in this report, the multi-step system was configured to:

- read the post-processed NARCliM netCDFs containing daily data for rainfall and evapotranspiration, convert to PERFECT model input file type
- index 10 kilometre NARCliM cell and determine the number of unique combinations of 100 metre drivers (land use, soil) and execute PERFECT for each unique driver combination
- compile modelled outputs as ESRI raster format for input to ArcGIS
- provide post-processing of drainage partitioning. For each GCM/RCM scenario (annual and monthly), combine lateral flow and recharge to define total drainage and using lateral flow partitioning coefficient (Rassam & Littleboy 2003), partition to groundwater recharge and surface runoff
- generate seasonal grids by combining each GCM/RCM scenario. Summer is December, January, February (DJF), autumn is March, April, May (MAM), winter is June, July, August (JJA), and spring is September, October, November (SON)
- extract annual and seasonal means for each period (1990 to 2009, 2020 to 2039 and 2060 to 2079) as input .csv for R scripts. The R scripts produce the relevant graph-based outputs of absolute change.

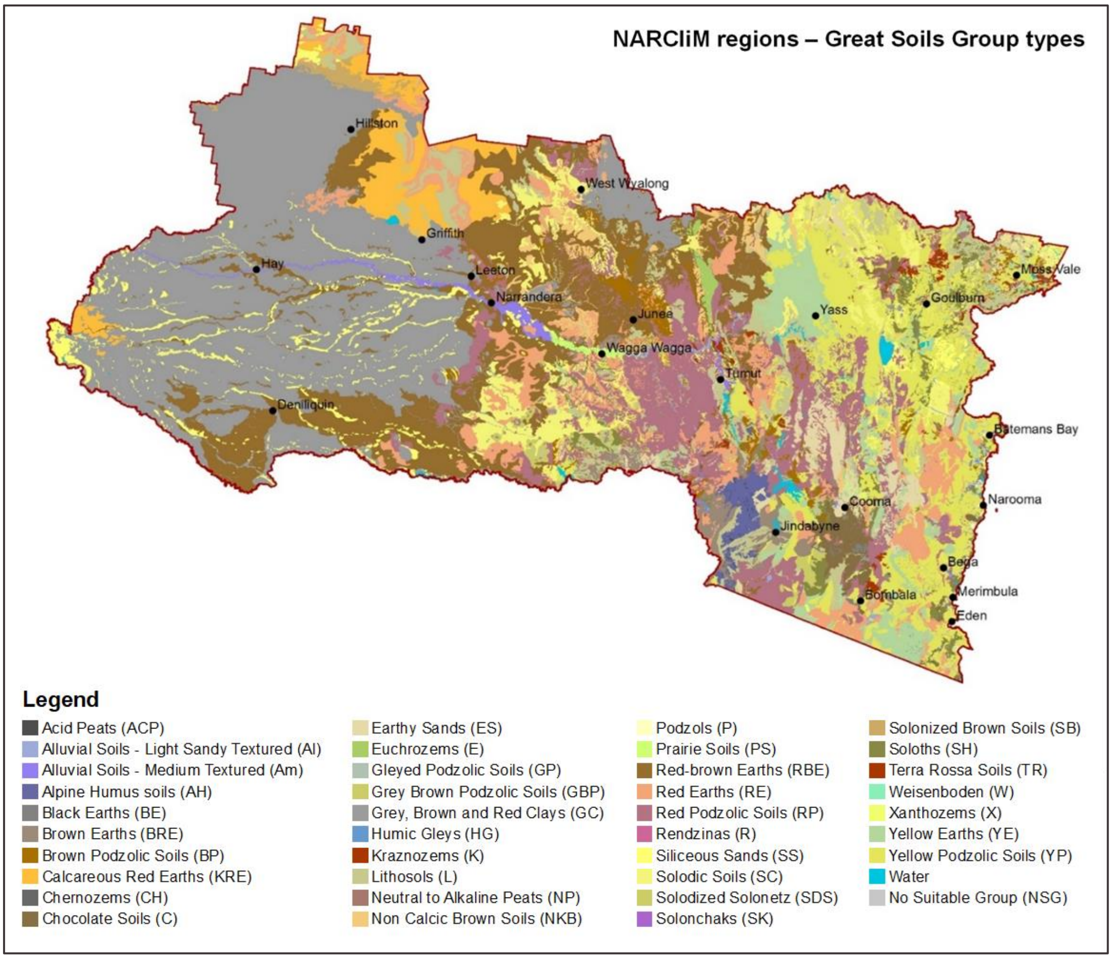

Figure 4 **Dominant soil type distribution derived from the DPIE NSW Great Soil Groups statewide dataset**

2.6 Quality control

Datasets

Using the Department of Planning, Industry and Environment (DPIE) corporate licensed spatial software (ArcGIS 10.x), spatial datasets as inputs to the modelling are a by-product of existing corporate and external sources. The quality of the by-product datasets is at least as good as the source data. All data has been converted to raster format, projected to WGS 84 at a resolution of 3 arc-seconds (approx. 90 m) and aligned to SRTM DEM. Stored data is in ESRI TIFF, GCS WGS84, 3 arc-second format and is available as individual files or zipped. Dataset completeness is study area; MM, ACT, South East and Tablelands as a single coverage, extent boundary top: –32.671254 dd, left: 143.317445 dd, right: 150.745676 dd, bot: –37.505077dd.

Output files (.tif, .csv, .jpg) are named using the standard NARCliM convention:

{Version}_{Domain}_{Model}_{Measure}_{Actual/Change}_
{time period_{Variable}_{Unit}_{Annual/Season}_{region prefix}_{region}.{ext}

i.e. v001_20170907_d02_multimodel_mean_chg_2060_2079_Recharge_mm_SON_ALPINE_0.jpg

where:

- {Ver} is used for version control (version: vxxx + date: yyyymmdd)
- {Domain} is d02 and indicates the 10 kilometre resolution NARCliM domain
- {Model} is the combination of GCMs (reanalysis, MIROC3.2, ECHAM5, CCCMA3.1, CSIRO-MK3.0) and RCMs (R1, R2, R3). Multi-model represents the mean of all model combinations
- {Measure} is the representation of the method of combining data from multiple models (i.e. mean, median, mode)
- {Actual/Change} represents whether it is the actual value for the time period or the difference between the 1990 to 2009 baseline period and 2020 to 2039 or 2060 to 2079 near and far future time periods (i.e. the change)
- {Epoch} is one of the three temporal periods: 1990 to 2009, 2020 to 2039 and 2060 to 2079
- {Variable} is the name of the output modelled variable – Recharge, Surface Flow
- {Unit} is the unit of measure for the variable
- {Annual/Season} can be ANN, DJF, MAM, JJA, SON; for annual and seasonal time periods
- {region prefix} ALPINE = Alpine Project
- {region} is 0 = ALPINE (MM, ACT and SET).

Water balance model PERFECT 3.0

The water balance model used in this study is the PERFECT model (Littleboy et. al. 1992). It was developed as a cropping systems model to predict the water balance (runoff, infiltration, soil evaporation, transpiration and recharge) for crop/fallow sequences. It has been previously applied to estimate water balance for a range of perennial pasture systems and tree water use in eastern Australia. A major strength of PERFECT is that it contains robust and well-tested algorithms, often based on proven water balance models developed by the United States Department of Agriculture. Many examples of previous model validation in Eastern Australia are documented (e.g. Abbs & Littleboy 1998).

The modelling used in this study is consistent with other modelling activities across New South Wales including:

- coastal estuarine monitoring, evaluation and reporting modelling (Littleboy et al. 2009; Roper et al. 2011)
- future salinity-trend modelling for the 2009 Salinity Audit (DECC 2009)
- salinity tools used in the Native Vegetation Assessment Tool or NVAT (DECCW 2011) and enhancements proposed under the Environmental Outcomes Assessment Methodology (OEH 2012)
- previous statewide assessments for the impacts of climate change on hydrology (Littleboy et al. 1992, 2003, 2009).

Salinity hazard

A meeting was held on Thursday 31 August 2017 at the NSW Office of Environment and Heritage (now DPIE) Cowra office to expertly review the potential impact of change to salinity hazard under future climate projections. Present at the meeting to discuss the outputs were Allan Nicholson (NSW Department of Primary Industries (DPI), Principal Salinity Officer), Andrew Wooldridge (NSW DPI, Salinity Officer), Rob Muller (NSW OEH, Senior Scientist) and John Young (NSW OEH, Scientist) who presented the results based on modelling criteria (Wooldridge et al. 2012).

Expert knowledge of salinity hazard across the area comes from previous and continued work in hydrogeological landscapes in: Central West, ACT, Yass, Jugiong, Tumut, Bega, Cooma and Wagga, and work completed for the Salinity Hazard for Catchment Action Plans (CAP) program.

With an understanding that CAP mapping is the only dataset currently available for entire coverage of the study area and is a broad-scale salinity hazard spatial coverage, findings from modelling of potential change in salinity hazard were positive:

- Based on geological parameters, the interpretation of the hazards using the +/–10% was deemed reasonable.
- Salinity hazard mapping was not consistent across the whole study area. There is greater confidence in areas where more information was available, and where HGL mapping was able to be incorporated.
- The main limitation stems from how irrigation areas are attributed. In the CAP hazard mapping, any polygon that has significant irrigation automatically becomes high hazard for the whole polygon. Key examples can be seen around Griffith and Leeton. Irrigation was not specifically modelled as a land-use category.

2.7 Data storage and access

All output data were converted to raster format (ArcGIS ESRI grid) and supplied to the MCAS-S (Multi-Criteria Analysis Shell for Spatial Decision Support) datapacks for distribution and storage. All input data to the model and by-products are stored on hard disk drives. All data are in the NARCliM coordinate system. The extent of the datasets includes the MM region, ACT and SET with the boundary at top: –32.671254, left: 143.317445, right: 150.745676, and bottom: –37.505077.

3. Results

3.1 Surface runoff

Changes in surface runoff – entire study area

Over most of the study area, surface runoff is likely to decrease (drying) in the near future (Figure 5). An increase in surface runoff (wetting) is evident in the far future (Figure 6) based on the multi-model mean of simulations. There is a large variation in likely changes across the 12 different GCM/RCM model simulations however; some combinations suggest more runoff while others suggest less runoff. Largest increases (wetting) are projected in areas from Balranald to Deniliquin, and around West Wyalong and south of Griffith. In the far future, reductions in surface runoff of more than 40 millimetres/year are projected for higher alpine areas, generally bounded by the Alpine region, from Tumut to Canberra to the Victorian border in the south.

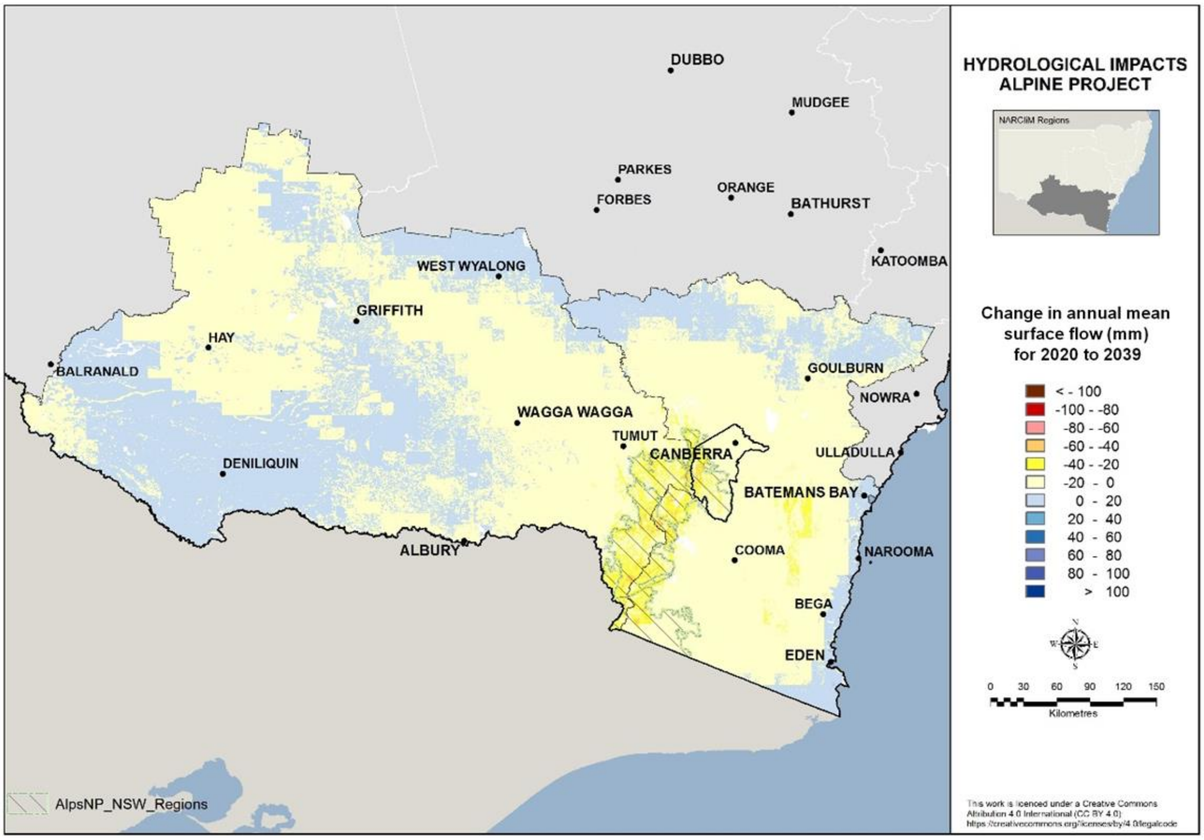

Figure 5 **Changes in mean annual surface runoff (mm) across the study area for 2020 to 2039 relative to the 1990 to 2009 baseline period**

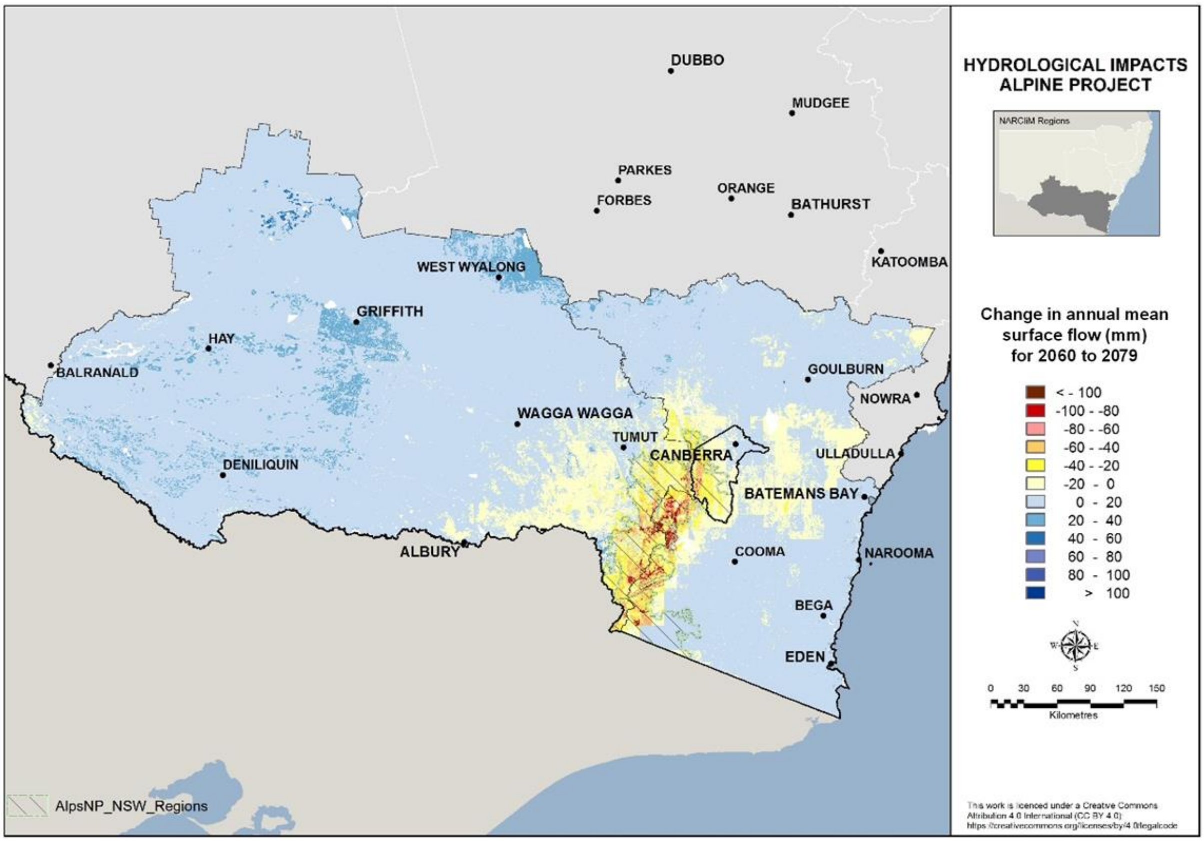

Figure 6 Changes in mean annual surface runoff (mm) across the study area for 2060 to 2079 relative to the 1990 to 2009 baseline period

As noted above, there are a range of projections for mean annual surface runoff ranging from a decrease of 13.0 millimetres (drying) to an increase of 10.8 millimetres (wetting) for the near future, and drying of 5.4 millimetres to wetting of 15.9 millimetres for the far future (Figure 7).

Near future scenario projections show surface runoff in summer ranging from –11.2 to +4.3 millimetres, autumn ranging from –5.3 to +8.5 millimetres, winter ranging from –2.1 to +1.9 millimetres, and spring ranging from –3.6 to +0.6 millimetres. For the far future scenario, summer surface runoff ranges from –2.5 to +14.2 millimetres, autumn –2.2 to +8.1 millimetres, winter –3.7 to +4.0 millimetres, and spring –7.4 to +2.2 millimetres (Figure 7).

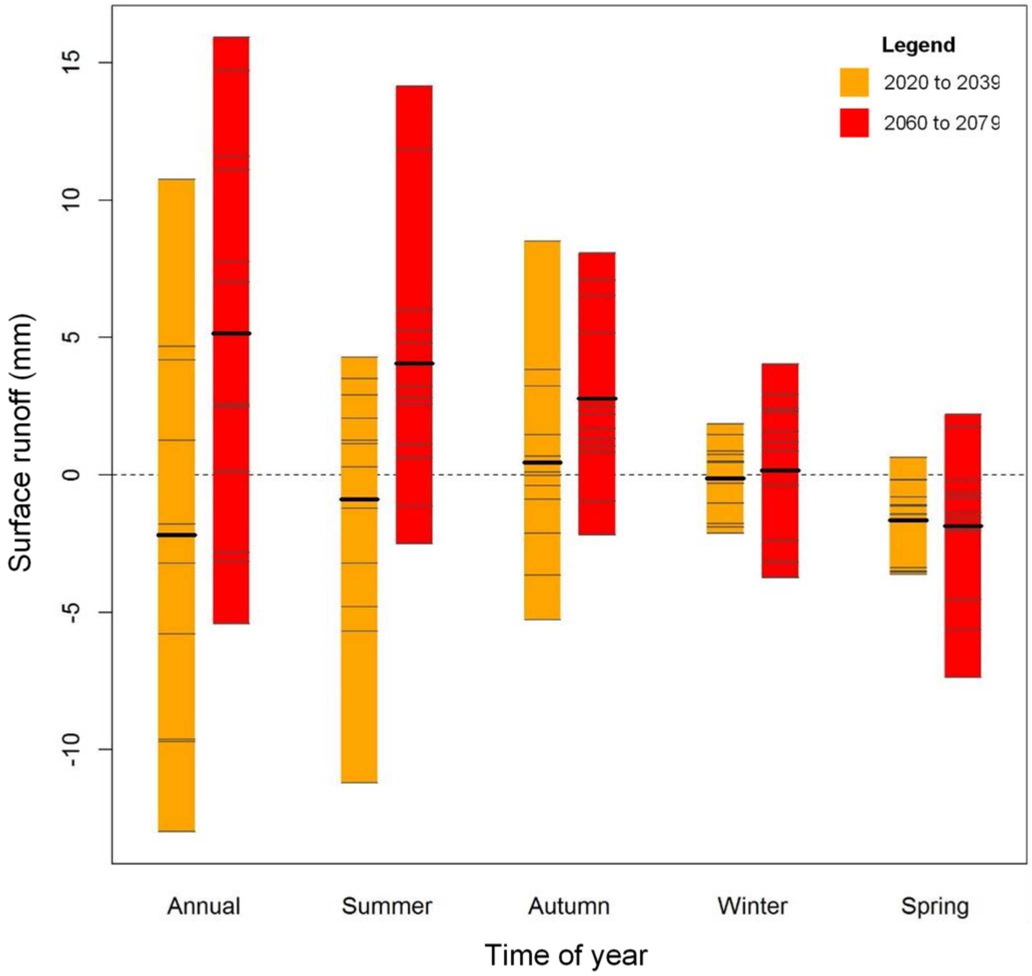

Figure 7 **Absolute change in seasonal and annual surface runoff (mm) across the study area**

Colours denote the near future (2020 to 2039) and far future (2060 to 2079) NARCliM projection periods.

For the near future, the NARCliM simulations using CCCMA3.1 and MIROC3.2_R3 as hosts forecast a slight increase in surface runoff (wetting), whereas those using CSIRO-MK3.0, ECHAM5 and MIROC3.2_R1/R2 project less surface runoff (drying). For the far future, nine of the 12 NARCliM simulations project higher surface runoff, and those using CSIRO-MK3.0 project less surface runoff. The largest variability across GCM/RCM combinations on a seasonal basis occurs for summer and autumn periods in both the near future and far future (Table 2).

Table 2 presents mean annual and seasonal surface runoff predictions and Table 3 provides changes in annual and seasonal surface runoff for each GCM/RCM combination across the entire region. Change is calculated from the climate baseline (1990 to 2009) to the near future (2020 to 2039) and far future (2060 to 2079).

Table 2 **Mean annual and seasonal surface runoff (mm) across the study area for each GCM/RCM combination**

Pink and green colours denote maximum and minimum changes in surface runoff, respectively. ANN = annual, DJF = summer, MAM = autumn, JJA = winter and SON = spring.

	Baseline 1990 to 2009					Near future 2020 to 2039					Far future 2060 to 2079				
GCM/RCM model	ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON
MIROC3.2_R1	72.9	21.9	14.7	17.7	18.7	71.1	23.1	14.8	18.2	15.1	87.6	36.0	15.7	21.7	14.2
MIROC3.2_R2	64.7	16.0	11.3	19.9	17.5	62.9	18.9	10.5	19.6	14.0	64.8	13.5	18.4	22.8	10.1
MIROC3.2_R3	72.8	16.8	15.4	20.1	20.5	74.1	21.1	15.0	20.9	17.0	88.7	28.7	23.5	21.7	14.9
ECHAM5_R1	53.6	23.3	7.5	17.2	5.6	40.6	12.1	9.0	15.1	4.5	64.7	29.3	10.0	18.1	7.4
ECHAM5_R2	38.2	9.9	7.8	15.3	5.2	36.0	10.2	5.6	15.2	5.0	45.2	12.5	10.0	17.8	5.0
ECHAM5_R3	53.1	18.0	10.0	17.5	7.6	47.3	16.7	10.7	15.6	4.2	64.7	23.2	16.6	15.1	9.8
CSIRO-MK3.0_R1	55.5	21.2	12.5	14.2	7.6	45.9	16.4	7.2	16.1	6.2	52.4	26.0	10.4	10.5	5.5
CSIRO-MK3.0_R2	35.0	9.8	4.7	14.5	6.0	31.8	6.6	4.7	16.0	4.6	29.6	8.6	5.5	10.8	4.6
CSIRO-MK3.0_R3	48.8	20.5	9.9	11.7	6.8	39.1	14.8	6.2	12.4	5.7	46.0	23.7	8.9	8.6	4.8
CCCMA3.1_R1	19.8	4.8	2.9	7.7	4.2	30.5	6.0	11.5	8.2	4.9	27.5	6.0	8.1	10.0	3.4
CCCMA3.1_R2	17.4	1.6	1.9	9.3	4.6	22.1	3.6	5.7	8.3	4.4	19.8	2.2	3.2	10.5	3.9
CCCMA3.1_R3	20.1	2.4	4.8	8.1	4.7	24.3	5.9	8.0	6.4	3.9	22.6	5.2	6.4	7.8	3.2
Maximum:	72.9	23.3	15.4	20.1	20.5	74.1	23.1	15.0	20.9	17.0	88.7	36.0	23.5	22.8	14.9
Minimum:	17.4	1.6	1.9	7.7	4.2	22.1	3.6	4.7	6.4	3.9	19.8	2.2	3.2	7.8	3.2
Range:	55.5	21.7	13.5	12.3	16.3	52.0	19.5	10.4	14.5	13.1	68.9	33.8	20.3	15.0	11.7

Table 3 **Changes in mean annual and seasonal surface runoff (mm) across the study area for each GCM/RCM combination**

Grey and blue colours denote maximum and minimum changes in surface runoff, respectively. ANN = annual, DJF = summer, MAM = autumn, JJA = winter and SON = spring.

	Near future (2020 to 2039)					Far future (2060 to 2079)				
GCM/RCM model	**ANN**	**DJF**	**MAM**	**JJA**	**SON**	**ANN**	**DJF**	**MAM**	**JJA**	**SON**
MIROC3.2_R1	–1.8	1.3	0.1	0.5	–3.6	14.7	14.2	1.1	4.0	–4.5
MIROC3.2_R2	–1.8	2.9	–0.9	–0.3	–3.5	0.1	–2.5	7.1	2.9	–7.4
MIROC3.2_R3	1.3	4.3	–0.4	0.9	–3.5	15.9	11.9	8.1	1.6	–5.6
ECHAM5_R1	–13.0	–11.2	1.5	–2.1	–1.1	11.1	6.0	2.5	0.9	1.8
ECHAM5_R2	–2.2	0.3	–2.1	–0.2	–0.2	7.0	2.6	2.2	2.4	–0.2
ECHAM5_R3	–5.8	–1.2	0.7	–1.9	–3.4	11.6	5.3	6.5	–2.4	2.2
CSIRO-MK3.0_R1	–9.6	–4.8	–5.3	1.9	–1.4	–3.1	4.8	–2.2	–3.7	–2.0
CSIRO-MK3.0_R2	–3.2	–3.2	0.0	1.5	–1.4	–5.4	–1.1	0.8	–3.7	–1.4
CSIRO-MK3.0_R3	–9.7	–5.7	–3.6	0.7	–1.1	–2.8	3.2	–0.9	–3.2	–1.9
CCCMA3.1_R1	10.8	1.1	8.5	0.5	0.6	7.8	1.1	5.2	2.3	–0.8
CCCMA3.1_R2	4.7	2.1	3.8	–1.0	–0.2	2.5	0.6	1.3	1.2	–0.7
CCCMA3.1_R3	4.2	3.5	3.2	–1.8	–0.8	2.6	2.8	1.7	–0.4	–1.6
Maximum:	10.8	4.3	8.5	1.9	0.6	15.9	14.2	8.1	4.0	2.2
Minimum:	–13.0	–11.2	–5.3	–2.1	–3.6	–5.4	–2.5	–2.2	–3.7	–7.4
Scenarios > 0:	4	7	6	6	1	9	10	10	7	2
Scenarios ≤ 0:	8	5	6	6	11	3	2	2	5	10
Range:	23.7	15.5	13.8	4.0	4.3	21.3	16.7	10.3	7.8	9.6

Changes in surface runoff – NSW and ACT Alpine region

Surface runoff is projected to decrease (drying) in the near future (2020 to 2039) across much of the NSW and ACT Alpine region based on the multi-model mean of the 12 GCM/RCM simulations (Figure 8). In the far future (2060 to 2079), surface runoff is also projected to decrease for most areas in the region except for a slight increase in runoff projected for a small area east of Thredbo (Figure 9). This increase is relatively small and less than 20 millimetres/year.

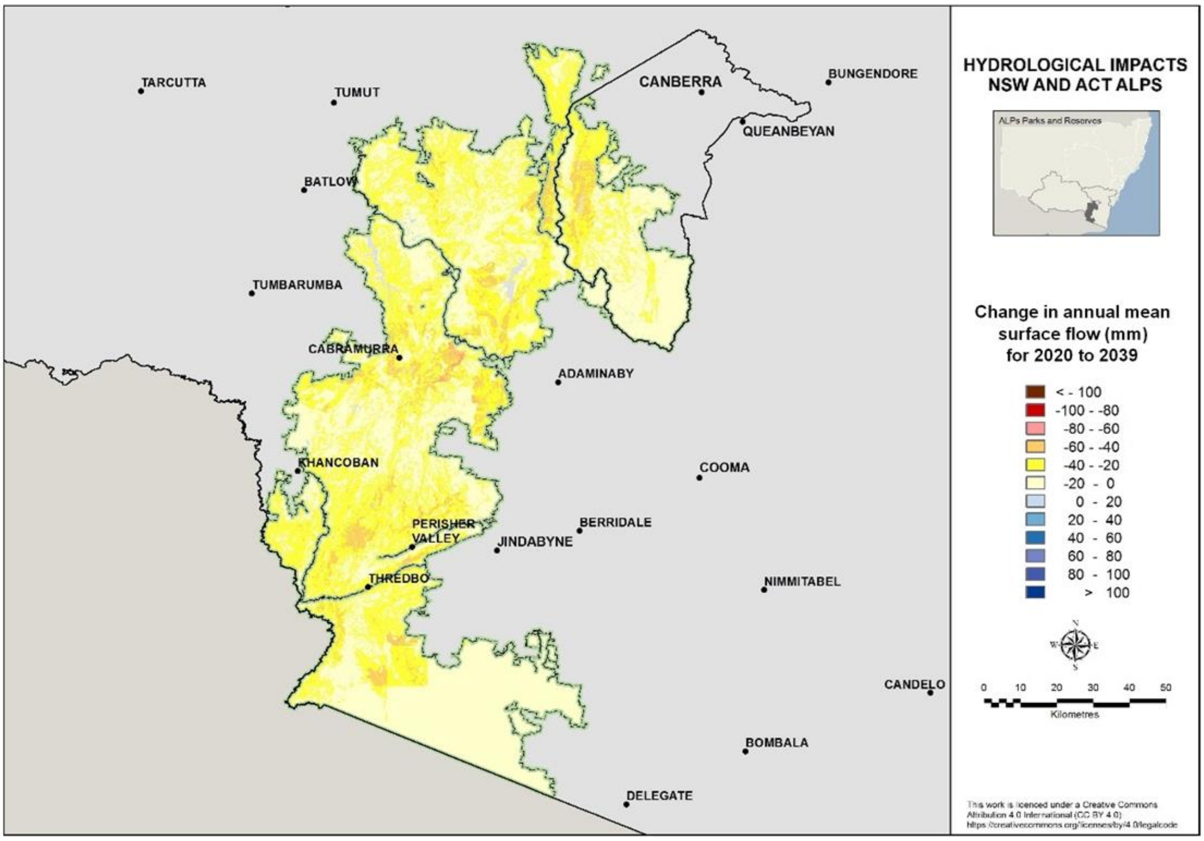

Figure 8 **Changes in mean annual surface runoff (mm) in the NSW and ACT Alpine region for 2020 to 2039 relative to the 1990 to 2009 baseline period**

The multi-model mean is the average of a range of different model forecasts. Near future projections for changes in mean annual runoff range from a decrease (drying) of –51.7 millimetres to an increase (wetting) of +22.5 millimetres (Figure 10). For the far future, forecasts also span both drying and wetting scenarios (–72.0 mm to +16.6 mm) (Figure 10).

Figure 10 and Table 4 show seasonal changes in surface runoff for the near future that include both increases and decreases in summer (–18.5 to +9.3 mm), autumn (–11.3 to +13.7 mm), winter (–17.3 to +18.9 mm) and spring (–28.9 to +7.7 mm). For the far future, the changes in surface runoff in summer range from –14.8 to +22.5 millimetres, in autumn –4.5 to +10.9 millimetres, winter –35.8 to +39.6 millimetres, while projected surface runoff in spring shows a decrease only, ranging from –65.8 to –4.6 millimetres.

Based on mean annual runoff for the near future, simulations excluding CCCMA3.1_R1 tend to project less recharge (drying). For the far future, nine of the 12 NARCliM ensembles forecast a decrease in surface runoff and three show more surface runoff. Most variability across the GCM/RCM combinations is evident during the winter and spring periods for the near future, and winter for the far future (Table 5).

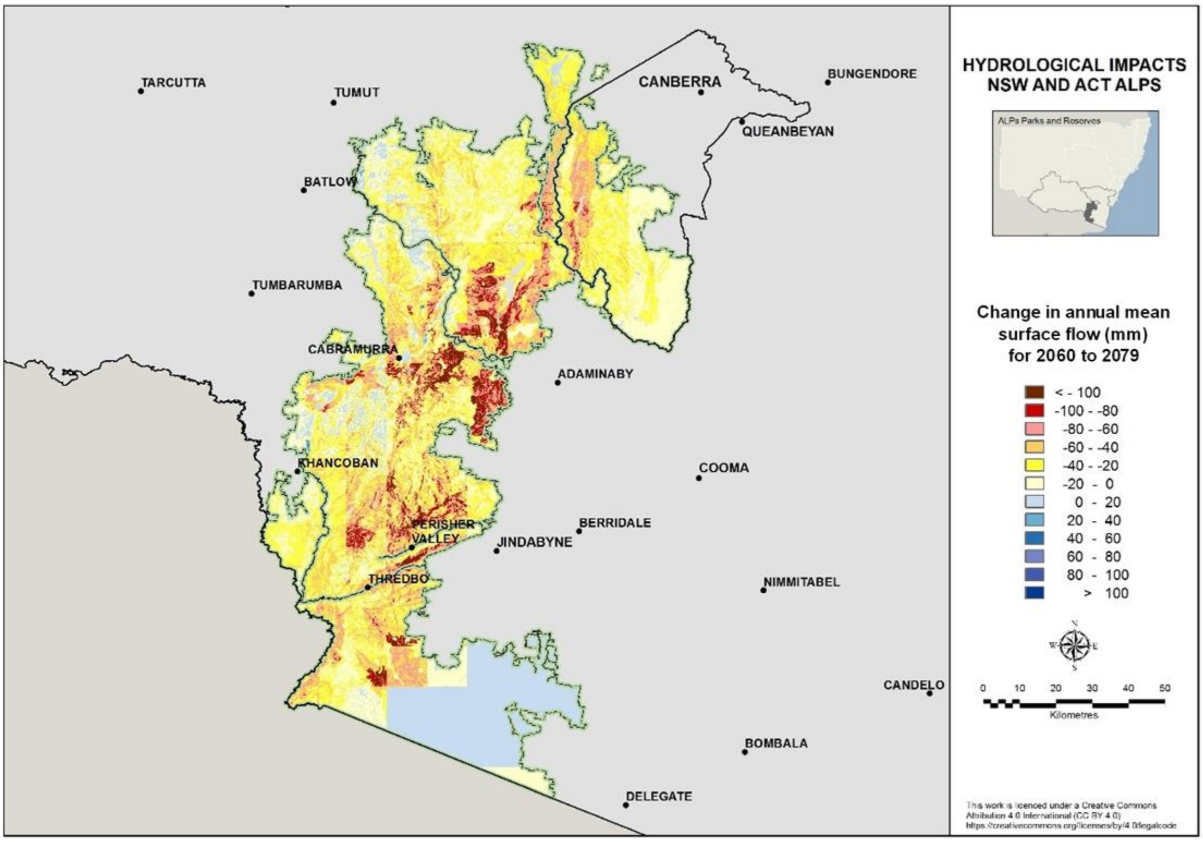

Figure 9 **Changes in mean annual surface runoff (mm) in the NSW and ACT Alpine region for 2060 to 2079 relative to the 1990 to 2009 baseline period**

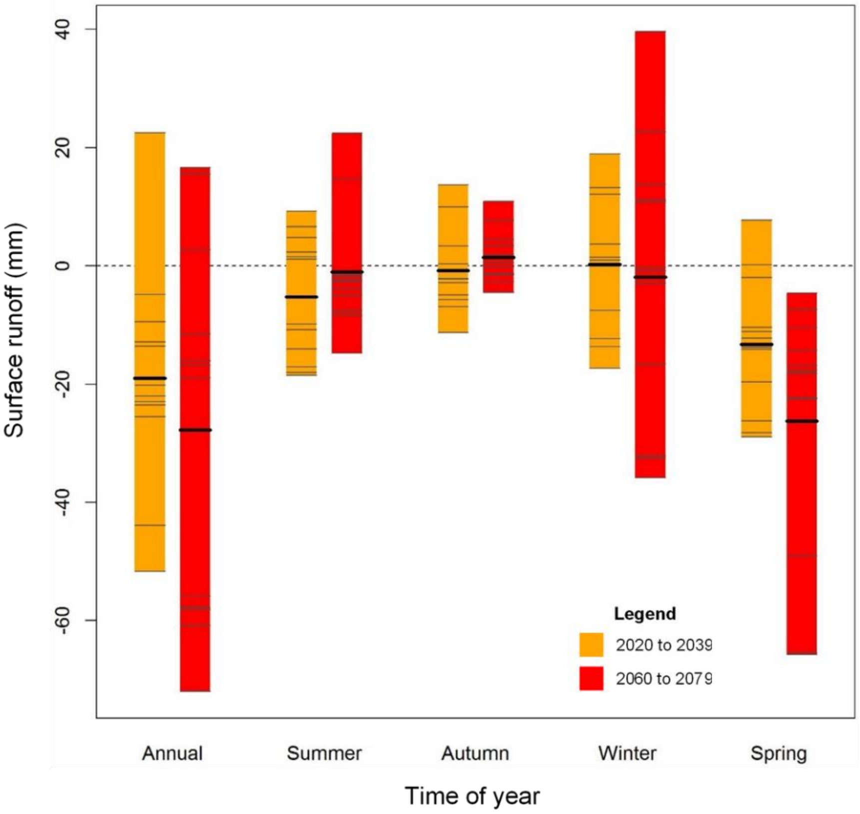

Figure 10 **Absolute change in seasonal and annual surface runoff (mm) in the NSW and ACT Alpine region**

Colours denote the near future (2020 to 2039) and far future (2060 to 2079) NARCliM projection periods.

Table 4 **Mean annual and seasonal surface runoff (mm) in the NSW and ACT Alpine region for each GCM/RCM combination**

Pink and green colours denote maximum and minimum changes in surface runoff, respectively. ANN = annual, DJF = summer, MAM = autumn, JJA = winter and SON = spring.

	Baseline 1990 to 2009					Near future 2020 to 2039					Far future 2060 to 2079				
GCM/RCM model	ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON
MIROC3.2_R1	454.2	56.2	76.3	175.5	146.3	432.2	60.9	74.0	179.2	118.0	437.4	78.6	75.0	186.6	97.2
MIROC3.2_R2	462.4	47.2	69.0	195.9	150.3	439.5	56.4	62.1	196.8	124.1	401.6	44.7	76.8	195.6	84.6
MIROC3.2_R3	474.1	49.5	75.4	193.3	155.8	450.5	56.1	70.5	197.0	126.9	402.0	64.1	70.9	176.7	90.3
ECHAM5_R1	298.5	41.2	32.8	161.5	62.9	246.8	23.2	27.1	147.7	48.8	301.2	38.5	33.4	184.1	45.2
ECHAM5_R2	277.8	27.8	29.9	156.6	63.5	257.7	18.0	29.3	158.0	52.4	294.4	23.9	33.3	196.2	41.0
ECHAM5_R3	284.2	42.6	27.3	148.0	66.4	240.3	25.5	27.6	140.5	46.8	265.3	27.8	31.7	161.7	44.0
CSIRO-MK3.0_R1	351.7	63.4	48.0	167.7	72.7	338.7	44.9	45.1	186.5	62.3	293.8	55.0	47.8	135.1	55.9
CSIRO-MK3.0_R2	303.2	27.6	33.7	177.9	64.1	289.6	16.8	31.5	191.1	50.2	247.4	20.1	35.6	142.0	49.7
CSIRO-MK3.0_R3	288.0	43.8	38.4	144.0	61.8	262.5	29.7	27.1	156.1	49.5	229.9	38.7	35.7	111.8	43.5
CCCMA3.1_R1	163.8	11.8	12.3	95.6	44.1	186.3	13.0	26.0	95.5	51.8	179.3	10.2	23.2	106.4	39.5
CCCMA3.1_R2	188.2	6.0	11.8	119.0	51.3	183.4	8.4	21.8	101.7	51.5	176.7	4.1	10.5	118.2	43.9
CCCMA3.1_R3	156.6	7.9	13.7	90.4	44.6	147.1	9.4	17.1	78.0	42.6	140.5	6.8	12.2	87.4	34.1
Maximum:	474.1	63.4	76.3	195.9	155.8	450.5	60.9	74.0	197.0	126.9	437.4	78.6	76.8	196.2	97.2
Minimum:	156.6	6.0	11.8	90.4	44.1	147.1	8.4	17.1	78.0	42.6	140.5	4.1	10.5	87.4	34.1
Range:	317.5	57.3	64.5	105.5	111.7	303.5	52.6	57.0	119.0	84.3	296.9	74.5	66.3	108.8	63.1

Table 5 **Changes in mean annual and seasonal surface runoff (mm) in the NSW and ACT Alpine region for each GCM/RCM combination**

Grey and blue colours denote maximum and minimum changes in surface runoff, respectively. ANN = annual, DJF = summer, MAM = autumn, JJA = winter and SON = spring.

	Near future 2020 to 2039					Far future 2060 to 2079				
GCM/RCM model	ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON
MIROC3.2_R1	–22.0	4.8	–2.3	3.7	–28.3	–16.8	22.5	–1.3	11.1	–49.1
MIROC3.2_R2	–23.0	9.3	–6.9	0.9	–26.3	–60.9	–2.5	7.7	–0.3	–65.8
MIROC3.2_R3	–23.5	6.6	–4.9	3.7	–28.9	–72.0	14.6	–4.5	–16.6	–65.4
ECHAM5_R1	–51.7	–18.1	–5.8	–13.7	–14.2	2.7	–2.7	0.5	22.7	–17.8
ECHAM5_R2	–20.2	–9.8	–0.6	1.4	–11.1	16.6	–3.9	3.4	39.6	–22.5
ECHAM5_R3	–43.9	–17.1	0.4	–7.5	–19.6	–19.0	–14.8	4.4	13.7	–22.4
CSIRO-MK3.0_R1	–12.9	–18.5	–2.9	18.9	–10.4	–57.8	–8.3	–0.2	–32.5	–16.8
CSIRO-MK3.0_R2	–13.6	–10.8	–2.2	13.2	–13.8	–55.8	–7.5	1.9	–35.8	–14.3
CSIRO-MK3.0_R3	–25.5	–14.1	–11.3	12.1	–12.3	–58.1	–5.0	–2.7	–32.2	–18.2
CCCMA3.1_R1	22.5	1.2	13.7	–0.1	7.7	15.5	–1.6	10.9	10.8	–4.6
CCCMA3.1_R2	–4.9	2.3	9.9	–17.3	0.1	–11.6	–1.9	–1.4	–0.8	–7.4
CCCMA3.1_R3	–9.5	1.5	3.3	–12.4	–2.0	–16.0	–1.1	–1.5	–2.9	–10.5
Maximum:	22.5	9.3	13.7	18.9	7.7	16.6	22.5	10.9	39.6	–4.6
Minimum:	–51.7	–18.5	–11.3	–17.3	–28.9	–72.0	–14.8	–4.5	–35.8	–65.8
Scenarios > 0:	1	6	4	7	2	3	2	6	5	0
Scenarios ≤ 0:	11	6	8	5	10	9	10	6	7	12
Range:	74.2	27.8	25.0	36.2	36.6	88.6	37.2	15.4	75.4	61.1

3.2 Recharge to groundwater

Changes in recharge to groundwater – entire study area

Recharge is a vital component of the total water balance of a catchment and changes in recharge can influence the availability and vulnerability of groundwater resources and the volumes of base flow in streams. Secondary impacts such as salinity and water quality with subsequent impacts on aquatic biodiversity can also occur.

For the near future, less recharge (drying) is projected across much of the study area based on the multi-model mean of the 12 GCM/RCM simulations. Areas bounded by the Alpine region and areas of higher elevation near Batemans Bay to the south-east show reductions of more than 40 millimetres/year (Figure 11). For some areas along the western part of the study area, west of Griffith, higher recharge is projected, but these increases are relatively small.

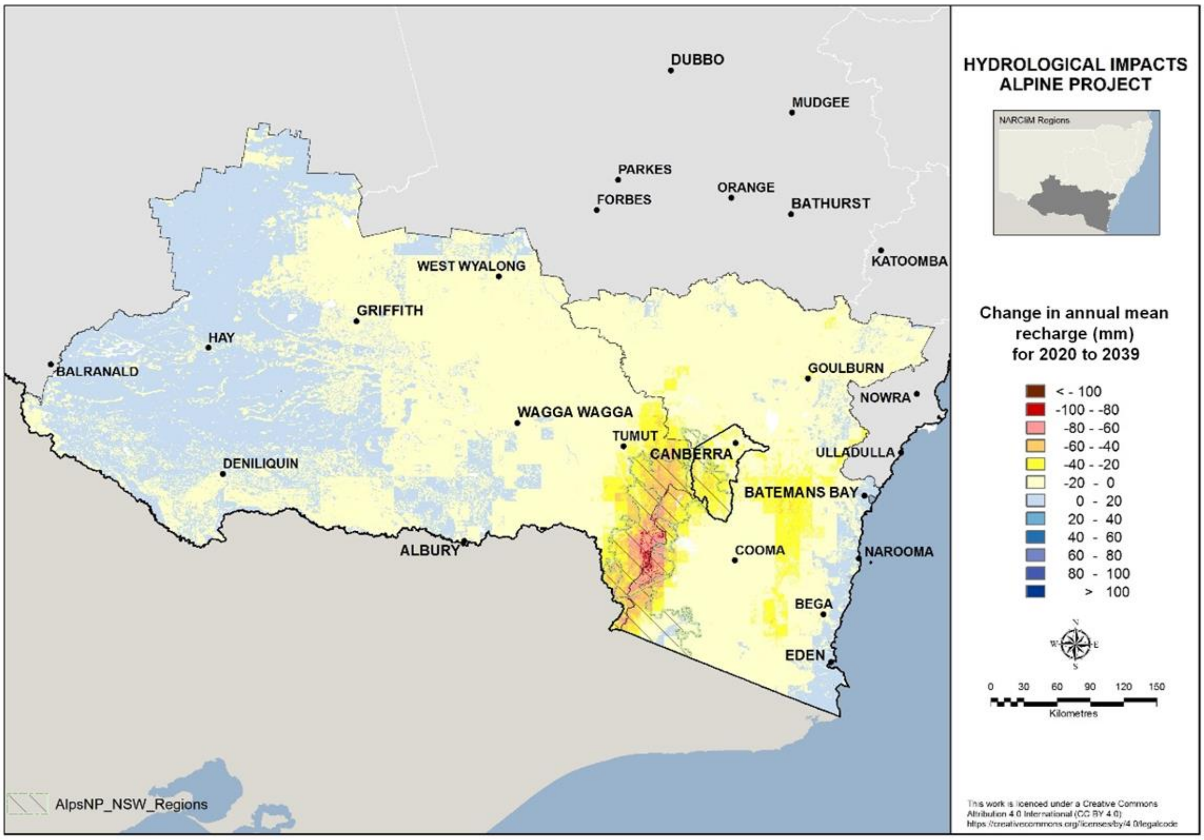

Figure 11 Changes in mean annual recharge (mm) across the study area for 2020 to 2039 relative to the 1990 to 2009 baseline period

In the far future, recharge is projected to decrease across many parts of the study area (Figure 12), with highest the reductions within the ACT and Alpine region. A slight increase in recharge is projected in areas west of Wagga Wagga, north of Griffith, and between Balranald and Deniliquin. Areas along the eastern boundary of the region and Cooma to the south show an increase in recharge.

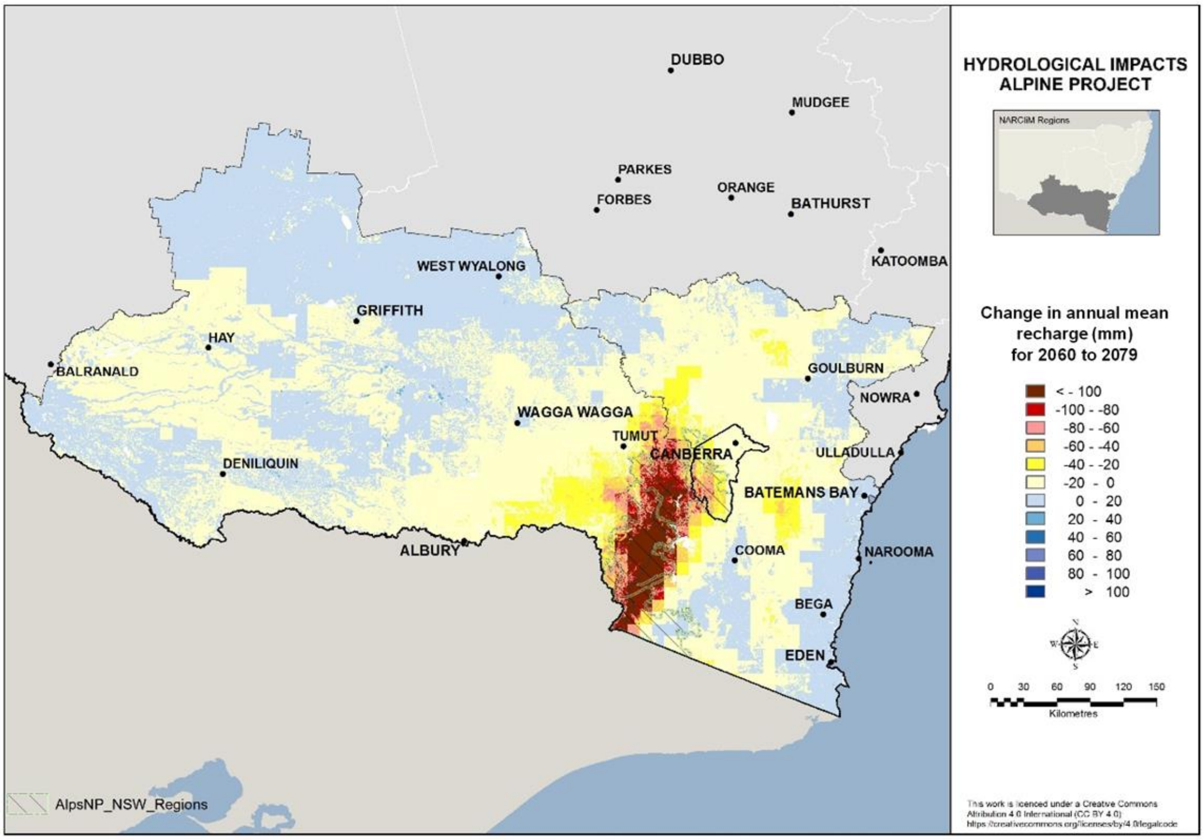

Figure 12 **Changes in mean annual recharge (mm) across the study area for 2060 to 2079 relative to the 1990 to 2009 baseline period**

As for surface runoff, the multi-model mean is the average of a large range of model forecasts. Changes in mean annual recharge range from a decrease (drying) of –14.6 millimetres to an increase (wetting) of +5.5 millimetres for the near future (Figure 13, Table 6), and still span both drying and wetting scenarios (–20.9 to +3.9 mm) for the far future (Figure 13, Table 6).

Mean seasonal projections for the near future include both increases and decreases in recharge during summer (–7.2 to +2.7 mm), autumn (–5.1 to +3.6 mm), winter (–2.5 to +3.4 mm), and spring (–7.7 to +1.2 mm). For the far future, the projections for recharge in summer range from –4.6 to +4.4 millimetres, autumn –2.9 to +4.9 millimetres, winter –10.8 to +5.4 millimetres, and spring –17.5 to –0.3 millimetres.

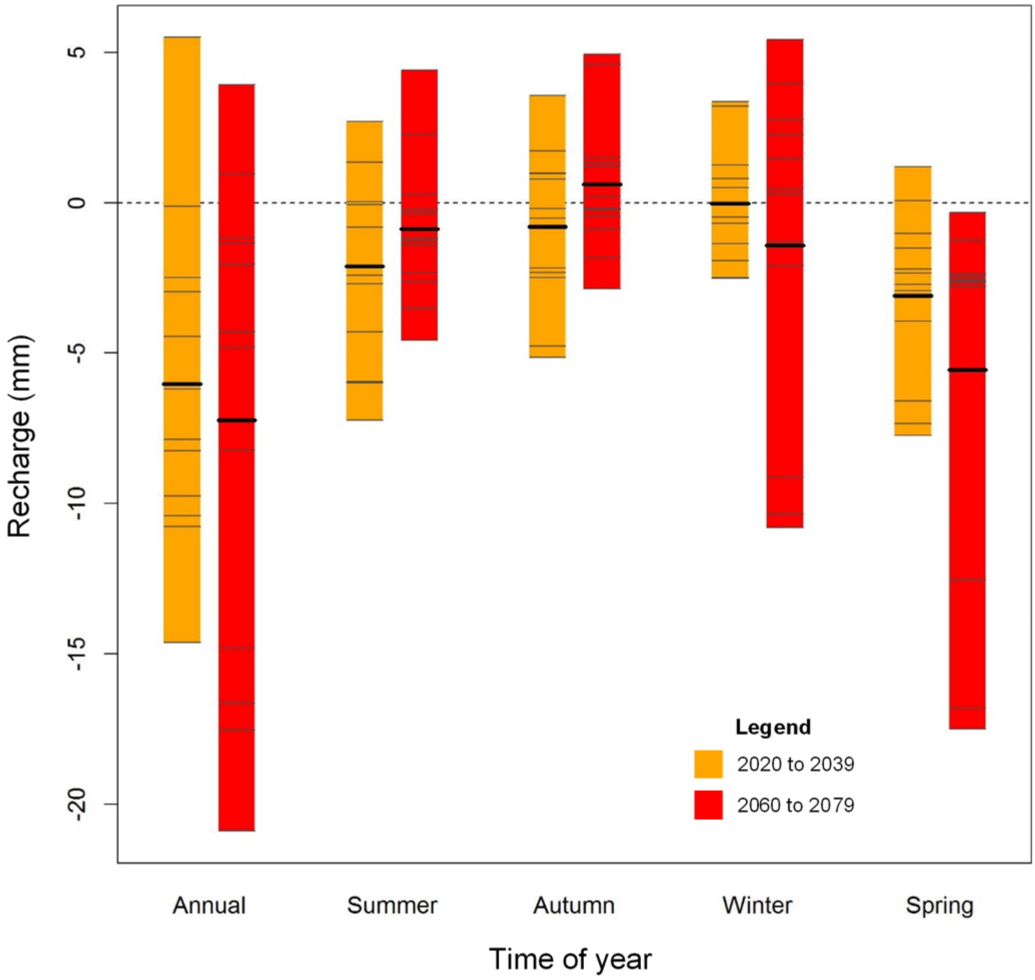

Figure 13 **Absolute change in seasonal and annual recharge (mm) across the study area**

Colours denote the near future (2020 to 2039) and far future (2060 to 2079) NARCliM projection periods.

Table 7 presents annual mean recharge for the near future, simulations using MIROC3.2, ECHAM5, CSIRO-MK3.0 and CCCMA3.1_R2/R3, which all tend to forecast less recharge (drying). In contrast, the simulation using CCCMA3.1_R1 tends to project more recharge (wetting). For the far future, 10 of the 12 NARCliM ensembles forecast a decrease in recharge and two project an increase in recharge. Most variability across the 12 GCM/RCM combinations is evident during summer for the near future, and spring for the far future.

Table 6 **Mean annual and seasonal recharge (mm) across the study area for each GCM/RCM combination**

Pink and green colours denote maximum and minimum changes in recharge, respectively. ANN = annual, DJF = summer, MAM = autumn, JJA = winter and SON = spring.

GCM/RCM model	Baseline 1990 to 2009					Near future 2020 to 2039					Far future 2060 to 2079				
	ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON
MIROC3.2_R1	105.4	14.2	15.8	43.3	32.0	97.1	13.4	16.6	42.8	24.3	100.6	16.5	17.4	47.2	19.5
MIROC3.2_R2	102.9	10.3	13.6	47.3	31.7	95.1	11.7	13.1	46.0	24.4	85.4	6.8	14.9	48.8	14.9
MIROC3.2_R3	110.7	10.5	16.6	48.8	34.8	107.8	13.2	17.5	48.8	28.2	102.5	15.0	21.2	49.1	17.3
ECHAM5_R1	63.3	11.2	7.3	34.4	10.5	48.7	4.0	5.1	31.9	7.8	61.3	9.8	6.8	36.6	8.1
ECHAM5_R2	54.5	5.4	7.3	32.2	9.5	48.3	2.7	4.8	32.7	8.0	55.4	3.1	7.5	37.7	7.1
ECHAM5_R3	62.8	11.2	7.2	33.1	11.3	52.0	5.2	7.0	32.4	7.4	61.7	10.0	12.1	31.0	8.5
CSIRO-MK3.0_R1	79.7	17.9	14.1	34.4	13.3	69.9	11.9	9.3	37.8	10.9	58.8	13.3	11.2	23.6	10.6
CSIRO-MK3.0_R2	58.8	6.3	7.1	34.3	11.2	54.4	3.9	4.8	37.5	8.3	42.2	3.7	6.2	23.9	8.4
CSIRO-MK3.0_R3	66.7	15.1	12.1	28.0	11.5	56.3	10.8	6.9	29.3	9.3	51.9	13.8	10.2	18.9	8.9
CCCMA3.1_R1	26.4	1.5	1.7	16.2	7.0	31.9	1.4	5.3	17.0	8.2	30.3	1.8	2.9	19.0	6.7
CCCMA3.1_R2	30.7	0.7	1.5	20.0	8.4	30.5	0.7	3.3	18.1	8.5	29.3	0.3	1.3	20.5	7.2
CCCMA3.1_R3	27.3	1.2	2.6	15.6	8.0	24.8	1.2	3.5	13.1	7.0	23.0	0.9	2.3	14.3	5.4
Maximum:	110.7	17.9	16.6	48.8	34.8	107.8	13.4	17.5	48.8	28.2	102.5	16.5	21.2	49.1	19.5
Minimum:	26.4	0.7	1.5	15.6	7.0	24.8	0.7	3.3	13.1	7.0	23.0	0.3	1.3	14.3	5.4
Range:	84.3	17.2	15.0	33.2	27.8	83.0	12.7	14.3	35.7	21.2	79.5	16.2	19.8	34.8	14.0

Table 7 **Changes in mean annual and seasonal recharge (mm) across the study area for each GCM/RCM combination**

Grey and blue colours denote maximum and minimum changes in surface runoff, respectively. ANN = annual, DJF = summer, MAM = autumn, JJA = winter and SON = spring.

	Near future 2020 to 2039					Far future 2060 to 2079				
GCM/RCM model	ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON
MIROC3.2_R1	–8.3	–0.8	0.8	–0.5	–7.7	–4.8	2.3	1.5	4.0	–12.5
MIROC3.2_R2	–7.9	1.3	–0.5	–1.4	–7.3	–17.5	–3.5	1.3	1.5	–16.8
MIROC3.2_R3	–3.0	2.7	1.0	0.0	–6.6	–8.2	4.4	4.6	0.3	–17.5
ECHAM5_R1	–14.6	–7.2	–2.2	–2.5	–2.7	–2.0	–1.4	–0.5	2.3	–2.4
ECHAM5_R2	–6.2	–2.7	–2.5	0.5	–1.5	0.9	–2.3	0.2	5.4	–2.4
ECHAM5_R3	–10.8	–6.0	–0.2	–0.7	–3.9	–1.2	–1.2	4.9	–2.1	–2.8
CSIRO-MK3.0_R1	–9.8	–6.0	–4.8	3.4	–2.3	–20.9	–4.6	–2.9	–10.8	–2.7
CSIRO-MK3.0_R2	–4.4	–2.4	–2.3	3.2	–2.9	–16.6	–2.6	–0.9	–10.4	–2.8
CSIRO-MK3.0_R3	–10.4	–4.3	–5.1	1.2	–2.2	–14.8	–1.3	–1.8	–9.1	–2.6
CCCMA3.1_R1	5.5	–0.1	3.6	0.8	1.2	3.9	0.3	1.2	2.8	–0.3
CCCMA3.1_R2	–0.1	0.0	1.7	–1.9	0.1	–1.3	–0.4	–0.2	0.5	–1.2
CCCMA3.1_R3	–2.5	0.0	1.0	–2.5	–1.0	–4.3	–0.2	–0.2	–1.3	–2.5
Maximum:	5.5	2.7	3.6	3.4	1.2	3.9	4.4	4.9	5.4	–0.3
Minimum:	–14.6	–7.2	–5.1	–2.5	–7.7	–20.9	–4.6	–2.9	–10.8	–17.5
Scenarios > 0:	1	4	5	5	2	2	3	6	7	0
Scenarios ≤ 0:	11	8	7	7	10	10	9	6	5	12
Range:	20.1	9.9	8.7	5.9	8.9	24.8	9.0	7.8	16.2	17.2

Changes in recharge to groundwater – NSW and ACT Alpine region

Less recharge to groundwater (drying) is likely in the near future across the Alpine region, based on the multi-model mean of the 12 GCM/RCM simulations (Figure 14). For the far future, the recharge is predicted to decrease further (up to –100 mm/year) (Figure 15).

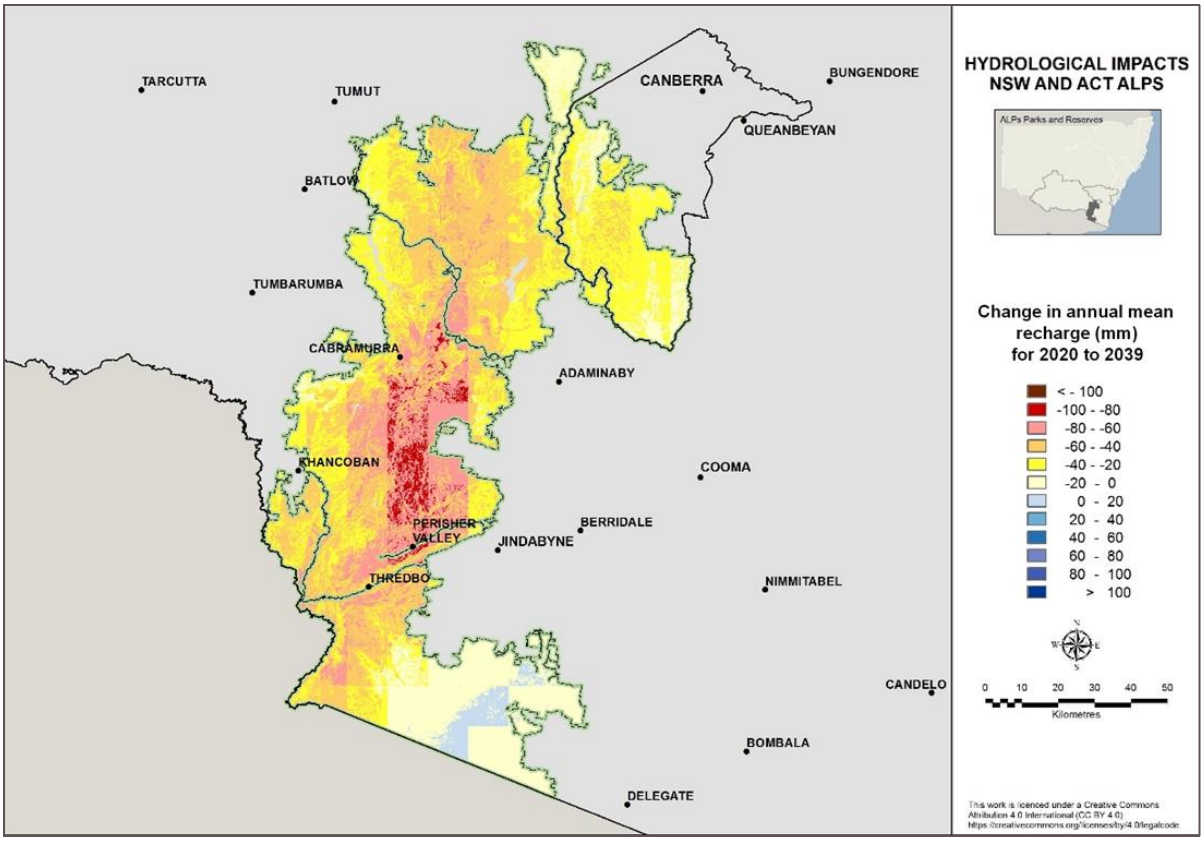

Figure 14 **Changes in mean annual recharge (mm) in the NSW and ACT Alpine region for 2020 to 2039 relative to the 1990 to 2009 baseline period**

In both the near future and far future projections, the variability across the individual models is large (Figure 16, Table 8 and Table 9). For the near future, the annual means range from drying of –67.7 millimetres/year to an increase (wetting) of 17.5 millimetres/year, with 11 of the 12 models predicting less recharge. For the far future, all 12 models predict less recharge ranging from –170.3 millimetres/year to –0.6 millimetres/year.

For the near future, most models show less recharge for summer, autumn and spring. In winter, the predicted changes in mean annual recharge range from –33.5 to +33.9 millimetres. For the far future projections, most models forecast less recharge in summer, autumn and winter. For spring, all 12 models predict less mean annual recharge (–118.8 to –11.4 mm) (Table 9).

Based on annual mean recharge for the near future (Table 8, Table 9), NARCliM simulations using MIROC3.2, ECHAM5, CSIRO-MK3.0 and CCCMA3.1_R2/R3 as hosts all tend to project less recharge (drying), while simulations using CCCMA3.1_R1 as host tend to project more recharge (wetting). For the far future, all 12 NARCliM ensembles project a decrease in recharge.

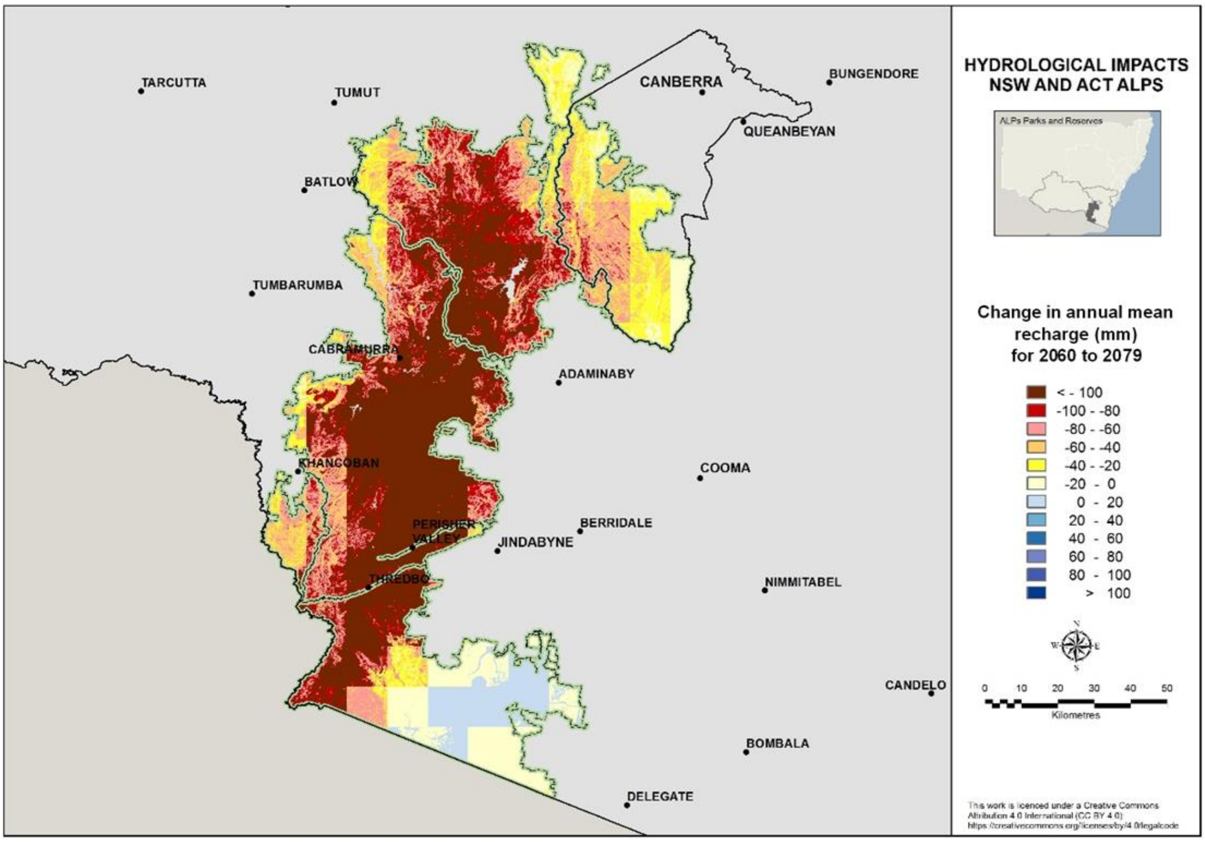

Figure 15 **Changes in mean annual recharge (mm) in the NSW and ACT Alpine region for 2060 to 2079 relative to the 1990 to 2009 baseline period**

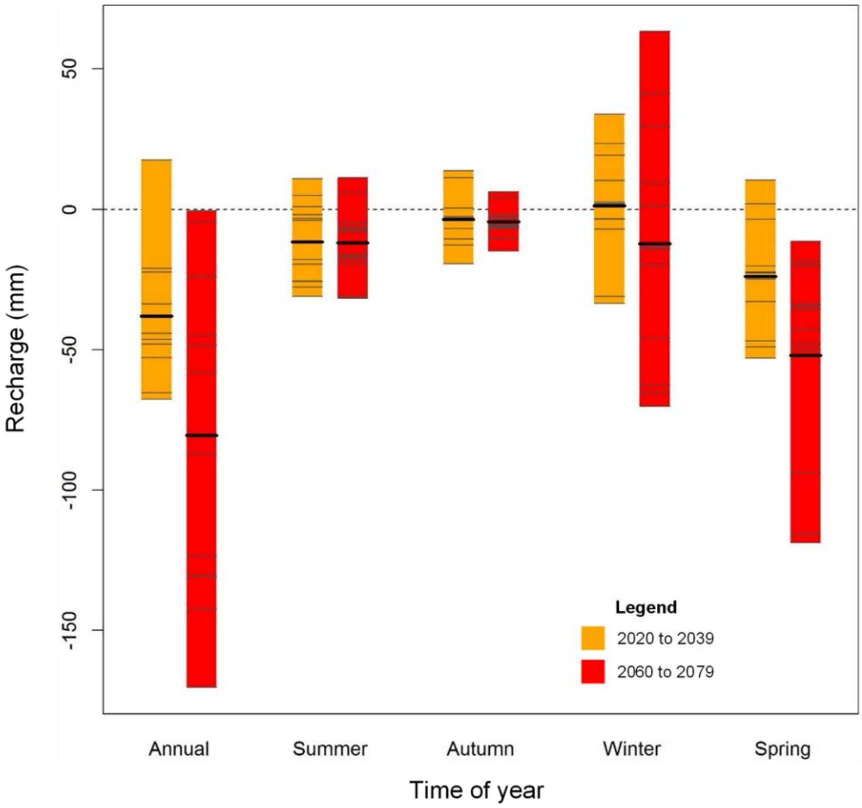

Figure 16 **Absolute change in seasonal and annual recharge (mm) in the NSW and ACT Alpine region**

Colours denote the near future (2020 to 2039) and far future (2060 to 2079) NARCliM projection periods.

Table 8 **Mean annual and seasonal recharge (mm) in the NSW and ACT Alpine region for each GCM/RCM combination**

Pink and green colours denote maximum and minimum changes in recharge, respectively. ANN = annual, DJF = summer, MAM = autumn, JJA = winter and SON = spring.

	Baseline 1990 to 2009					Near future 2020 to 2039					Far future 2060 to 2079				
GCM/RCM model	ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON
MIROC3.2_R1	816.0	82.7	131.7	336.9	264.6	763.2	87.7	124.9	339.0	211.6	728.8	94.0	125.8	338.1	170.9
MIROC3.2_R2	844.2	74.6	119.1	373.4	277.1	800.0	85.4	116.6	369.8	228.2	701.8	66.7	123.1	353.7	158.3
MIROC3.2_R3	845.6	77.1	125.4	364.7	278.3	799.3	78.1	122.3	367.4	231.5	675.2	83.2	110.5	318.8	162.7
ECHAM5_R1	526.2	53.9	51.4	297.8	123.1	458.5	28.2	40.8	290.8	98.7	502.1	37.2	45.7	339.0	80.2
ECHAM5_R2	514.9	40.1	50.2	299.4	125.2	481.3	22.3	46.9	309.6	102.4	510.4	23.9	46.8	362.7	77.1
ECHAM5_R3	496.5	57.1	43.5	270.5	125.4	431.1	26.0	40.1	272.5	92.5	438.4	25.5	37.6	300.0	75.3
CSIRO-MK3.0_R1	653.6	91.3	88.8	329.9	143.7	632.6	63.5	81.8	363.7	123.6	523.0	60.1	86.1	267.3	109.4
CSIRO-MK3.0_R2	594.3	44.1	70.1	349.5	130.7	560.6	24.6	57.3	372.9	105.9	470.7	26.4	68.2	279.3	96.8
CSIRO-MK3.0_R3	543.5	64.3	68.7	287.9	122.6	495.5	38.8	49.3	307.2	100.2	412.7	45.0	58.3	222.6	86.8
CCCMA3.1_R1	321.1	16.0	17.6	195.9	91.6	338.6	12.8	31.3	192.5	102.0	320.5	11.2	23.8	205.3	80.2
CCCMA3.1_R2	377.7	10.4	18.4	240.6	108.2	355.3	8.5	29.6	207.1	110.1	332.8	4.0	12.0	227.2	89.5
CCCMA3.1_R3	306.1	11.8	19.2	184.5	90.6	268.1	7.9	19.5	153.5	87.1	257.5	4.3	12.4	170.3	70.5
Maximum:	845.6	91.3	131.7	373.4	278.3	800.0	87.7	124.9	372.9	231.5	728.8	94.0	125.8	362.7	170.9
Minimum:	306.1	10.4	17.6	184.5	90.6	268.1	7.9	19.5	153.5	87.1	257.5	4.0	12.0	170.3	70.5
Range:	539.5	80.8	114.1	188.9	187.7	531.9	79.8	105.3	219.4	144.4	471.3	90.1	113.7	192.4	100.3

Table 9 **Changes in mean annual and seasonal recharge (mm) in the NSW and ACT Alpine region for each GCM/RCM combination**

Grey and blue colours denote maximum and minimum changes in surface runoff, respectively. ANN = annual, DJF = summer, MAM = autumn, JJA = winter and SON = spring.

	Near future 2020 to 2039					Far future 2060 to 2079				
GCM/RCM model	ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON
MIROC3.2_R1	–52.8	5.0	–6.9	2.1	–53.1	–87.2	11.3	–6.0	1.2	–93.8
MIROC3.2_R2	–44.2	10.9	–2.5	–3.6	–48.9	–142.4	–7.9	4.0	–19.8	–118.8
MIROC3.2_R3	–46.3	0.9	–3.1	2.7	–46.8	–170.3	6.1	–14.9	–45.9	–115.7
ECHAM5_R1	–67.7	–25.7	–10.5	–7.0	–24.4	–24.1	–16.8	–5.7	41.2	–42.8
ECHAM5_R2	–33.7	–17.8	–3.3	10.2	–22.8	–4.5	–16.3	–3.5	63.3	–48.1
ECHAM5_R3	–65.4	–31.1	–3.4	1.9	–32.9	–58.2	–31.7	–5.9	29.5	–50.1
CSIRO-MK3.0_R1	–21.0	–27.8	–6.9	33.9	–20.2	–130.6	–31.1	–2.6	–62.5	–34.3
CSIRO-MK3.0_R2	–33.7	–19.5	–12.8	23.4	–24.8	–123.5	–17.7	–1.8	–70.2	–33.9
CSIRO-MK3.0_R3	–48.0	–25.5	–19.3	19.3	–22.4	–130.8	–19.3	–10.4	–65.4	–35.8
CCCMA3.1_R1	17.5	–3.2	13.7	–3.4	10.4	–0.6	–4.8	6.2	9.4	–11.4
CCCMA3.1_R2	–22.3	–1.9	11.2	–33.5	1.9	–44.9	–6.4	–6.3	–13.4	–18.7
CCCMA3.1_R3	–38.0	–3.8	0.4	–31.0	–3.6	–48.6	–7.5	–6.8	–14.3	–20.1
Maximum:	17.5	10.9	13.7	33.9	10.4	–0.6	11.3	6.2	63.3	–11.4
Minimum:	–67.7	–31.1	–19.3	–33.5	–53.1	–170.3	–31.7	–14.9	–70.2	–118.8
Scenarios > 0:	1	3	3	7	2	0	2	2	5	0
Scenarios ≤ 0:	11	9	9	5	10	12	10	10	7	12
Range:	85.2	41.9	33.1	67.4	63.5	169.7	43.0	21.1	133.5	107.4

3.3 Impact on salinity hazard potential

For the near future, changes in salinity hazard are shown in Figure 17. Areas that are currently described as low salinity hazard are shown in blue. Less dilution flow is likely from some low salinity hazard areas, especially in the higher elevation Alpine region. Less dilution flow from alpine areas could increase catchment-scale salinity further downstream.

Most CAP regions with moderate, high or very high salinity hazard (yellow, pink and red) show no change in salinity hazard or a lowering of salinity hazard. Of interest are areas around Cootamundra, Yass and Young which contain some of the highest dryland salinity in the state. However, some high hazard areas west of Deniliquin do show an increase in salinity hazard.

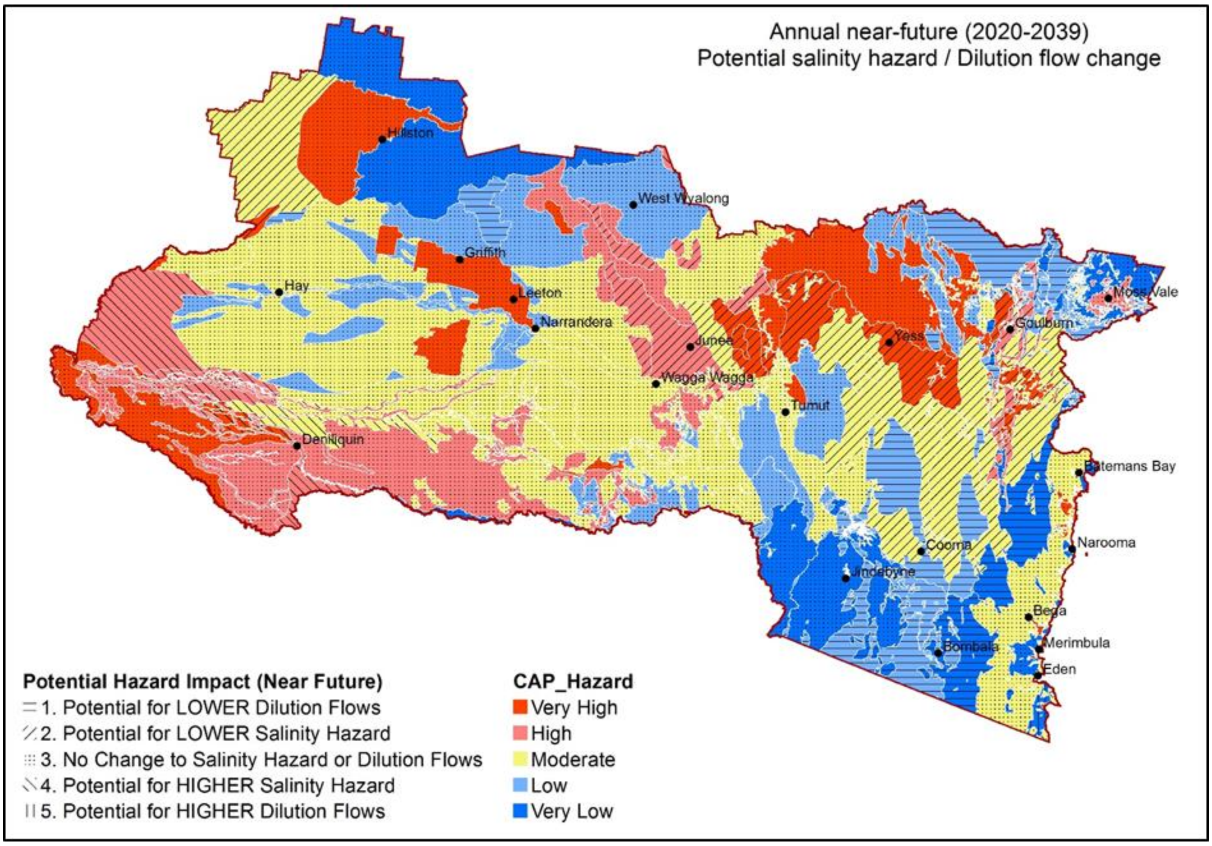

Figure 17 Potential impact on salinity hazard and dilution flow in the near future (2020 to 2039)

For the far future, changes are shown in Figure 18. Many areas that are currently low salinity hazard (blue), show no change in hazard. Some low hazard areas north of Griffith and along the Murrumbidgee River as it crosses the Riverina show the potential for higher dilution flows that could be beneficial for catchment scale salinity.

CAP regions that are currently moderate, high or very high salinity hazard (yellow, pink and red) show either no change in hazard or higher salinity hazard. CAP regions west of Corowa to Balranald consistently show an increase in salinity hazard, as do areas around Griffith and Leeton. Of interest, are the areas around Cootamundra, Yass and Young, which contain some of the highest dryland salinity in the state. Salinity hazard is not forecast to get worse in the near or far future in these catchments (Yass River, Jugiong Creek and Muttama Creek).

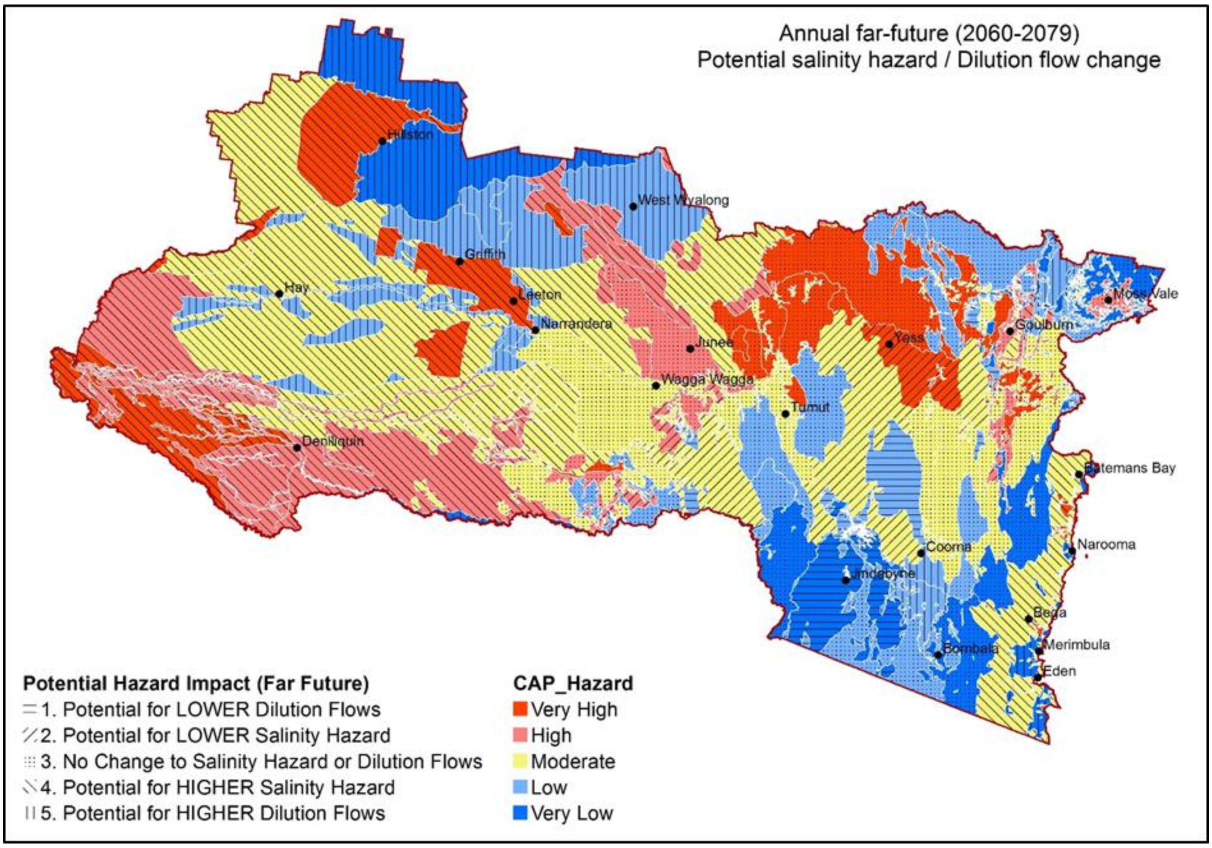

Figure 18 **Potential impact on salinity hazard and dilution flow in the far future (2060 to 2079)**

4. Discussion

4.1 Key findings

Decreases in surface runoff can impact high mountain wetlands that are highly dependent on the surface hydrology. In the near future most of the study area is likely to have less surface runoff while in the far future, reductions in surface runoff of more than 40 millimetres/year are projected for higher alpine areas.

The biggest hydrological impact of these decreases in surface runoff is the reduction in recharge in alpine areas, especially in the far future. Most of the study area is likely to have less recharge in the near future, while far future projections predict less recharge in summer, winter and autumn, with the largest decreases during in spring.

While salinity hazard potential is sensitive to changes in climate, at a whole-of-catchment scale, decreases in hazard (e.g. around Cootamundra) may be offset by increased hazard in other areas.

4.2 Limitations and further research

The following factors influence the interpretation of these results:

- The daily time-step NARCliM projections are only available at a 10 kilometre spatial resolution. Local variations due to topography that can occur at a finer resolution cannot be captured.
- The bias-corrected rainfall could not be used due to missing data along eastern parts of the study area.
- Snow formation and snow melt were not considered within water balance modelling. Similarly, hydrological effects of frozen soil preventing infiltration was not modelled.
- Salinity hazard products were catchment-specific and used data sources available for that catchment. Data sources vary and discrepancies in ratings may occur on some boundaries.

Further investigation into snow conditions and their effects on surface runoff and recharge would be beneficial.

A finer-scale assessment of salinity impacts would require new hydrogeological landscape mapping. Improved salinity modelling using this new mapping could be integrated with river flow and management models to quantify salinity impacts at mid-valley and end-of-valley salinity target sites.

5. Conclusion

Previous impact analyses on the AdaptNSW webpage are at a statewide scale and showed the impacts of climate change on surface runoff and groundwater recharge at a 10 kilometre resolution. This study overcame this limitation by using finer-scale information for soil type, topography and land use (100 m resolution) and producing maps showing changes in surface runoff and recharge to groundwater at a landscape scale rather than a lumped 10 kilometre pixel resolution. These new datasets can identify those landscapes most affected by climate change.

This study produced the first salinity impact assessment based on the NARCliM projections by combining projected changes in surface runoff and recharge with catchment-scale salinity data.

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