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Modelling hydrological changes in New South Wales under future climate change

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Abstract: Within New South Wales, the Office of Environment and Heritage (OEH) supports climate-change adaptation by working with communities, agencies and other stakeholders to identify and understand regional vulnerabilities. Scientific impact assessments for bushfires, biodiversity, sea level and coasts, floods, soil, human health and water resources have been undertaken.

In this study, impacts of climate change on the water cycle and hydrology is investigated. Assessing the impacts of climate change on hydrology is important because changes to the water cycle influence water security, water quality, salinity and groundwater availability.

We use the NARCliM (**N**SW / **A**CT **R**egional **Cli**mate **M**odelling) ensemble of climate projections for south-east Australia. This ensemble is designed to provide robust projections that span the range of likely near and future changes in climate *(Evans et. al. 2014).*The water balance was simulated using the PERFECT model *(Littleboy et al. 1992)* which is a daily time-step model that predicts surface runoff, infiltration, soil evaporation, transpiration, profile drainage and recharge. PERFECT was applied at a 10km resolution across NSW to predict surface flows and groundwater recharge.

Maps and graphs from this modelling form part of the NSW Climate Impact Profile which provides an assessment of projected biophysical changes across the State. Maps presented show central estimates or arithmetic means of future projections. Bar graphs are used to present projections as ranges of plausible change, illustrating the projections from the twelve individual simulations as well as the central estimate.

In the near future, less recharge is predicted across much of NSW, especially in the south east of the State. Considerably less recharge is likely in alpine areas. Some areas of western NSW do show a slight increase in recharge but these increases are considered relatively small. In the far future, recharge is expected to increase across many parts of NSW. Some areas along the Great Dividing Range are likely to experience less recharge to groundwater. The largest impact is the dramatic reduction in recharge in alpine areas.

Across much of NSW, surface runoff is projected to increase in both the near and far future. Largest increases are evident in the central west through to the northern tablelands. Largest reductions in surface runoff are projected in both the near and far future for alpine areas in the south of the State.

More complex analyses at a resolution on 100m are underway for the ACT and coast catchments of NSW. This analysis will permit allow spatial variability in land use and soils to be taken into consideration in the climate impact assessments. This is not represented in this paper.

Keywords: *Climate change, hydrology, soil water balance, PERFECT model, NARCliM*

1. INTRODUCTION

The hydrological cycle is essential for all forms of life. We must understand how to protect, sustain and manage this resource now and into the future; and this is driven by the pressures of urbanisation, water and food security, and declining environmental ecosystems under a changing climate.

Effects of climate change on the hydrological cycle has become an area of research priority, and will be one of the most vital issues for the future *(IPCC 2013)*. New South Wales Office of Environment and Heritage (OEH), has undertaken a study of the impacts of global climate change projections on the hydrology across New South Wales (NSW). Providing scientific valued information on potential future change in the hydrological cycle enables informed policy decisions and adaptation strategies.

This study was instigated to report on the potential impact of climate change on the hydrology of NSW. We use projections produced using Global Climate Models (GCMs) and then downscaled using Regional Climate Models (RCMs). This paper describes the application of the water balance model PERFECT *(Littleboy et. al. 1992)* using spatially specific key input drivers of land use, soil, and the NARCliM projections. We present near future (2020-2039) and far future (2060-2079) projections of annual and seasonal surface runoff and recharge in comparison to baseline (1999-2009) period for a high emissions scenario – the A2 scenario from the Special Report on Emission Scenarios (SRES) of Nakicenovic et al. (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.

New South Wales (Study Area)

The study area (Figure 1) extends across NSW and the ACT, and covers an area of more than 800 000km^2 with some 2000km of coastline.

NSW has a diverse topography and hydrography. It includes extensive rangelands, the largest expanse of Alpine regions *(Mt Kosciuszko, 2228m)*, and some of the most productive agricultural/horticulture land in Australia such as Liverpool Plains *(Abbs et. al. 1998)*.

NSW includes three of the largest hydrological zones in Australia, Lake Eyre, Murray-Darling and South East Coast. These hydrological zones contain more than 20,000 coastal and inland wetlands, over 1 million km of drainage systems and 69 major water storage systems.

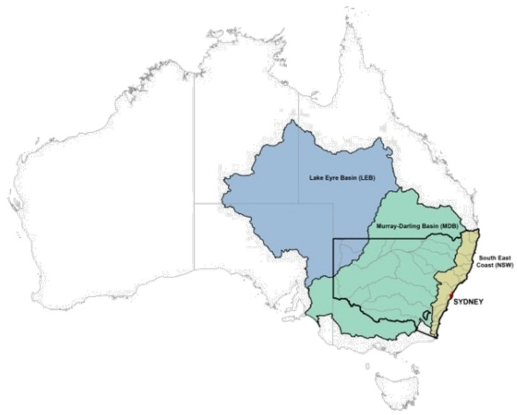

Figure 1. Major hydrological zones

2. METHODS AND DATA

Climate Projections (NARCliM)

Climate inputs come from the NARCliM simulations *(Evans et al., 2014)* using the Weather and Regional Forecasting (WRF) modelling system *(Skamarock et al., 2008)*. 12 ensemble members are used which consist of all combinations of four Global Climate Models (CGM) and three Regional Climate Models (RCM). For each combination of GCM and RCM, three time periods are simulated: Current climate (1990-2009), near future (2020-2039) and far future (2060-2079), assuming a high emissions scenario (A2). While the climate models produce a range of variables, only daily maximum temperature, daily minimum temperature, precipitation and evapotranspiration are required to drive the water balance model.

Water balance modelling

The water balance model used daily time-series of NARCliM rainfall and actual evapotranspiration (ET) modelled by each GCM/RCM as inputs. Actual ET data from NARCliM was compared against areal actual evapotranspiration surface from the Bureau of Meteorology (Data not presented). There was good agreement with the magnitude and spatial patterns of actual ET across NSW on an average annual basis. By using actual ET, this analysis is static in nature in that it partitions the surplus and non-transpired water from NARCliM into surface flows and recharge. By using actual ET, we also ensure that the RCM water balance is maintained in the impact modelling.

Partitioning between surface flow and recharge is driven by soil properties and topography for each NARCliM 10km cell. Volumes of surface flow are governed by model parameters describing potential infiltration, antecedent soil water, surface and vegetative cover and slope. Volumes of recharge are controlled by parameters quantifying drainage rates through the soil profile, soil depth and slope.

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. Many examples of previous model validation in Eastern Australia are documented in Abbs and Littleboy *(Abbs et. al. 1998)*. 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.

PERFECT is a one-dimensional water balance model in that it 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 actually 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 and Littleboy, 2003)*.

Spatial datasets

PERFECT requires spatial data for land use, soil and slope. Dominant land use, soil type and slope vary significantly and spatially over the study area and are assumed as static through time. Other inputs (NARCliM projections) do vary over time and space. In this study, the spatial resolution is the10km NARCliM grid.

Land Use

Land use and management have major effects on natural resources with impacts on water, soil, nutrients, plants and animals.

The Weather Research ad Forecasting Model (WRF) default land use data set was used in this analysis (Figure 2). It is provided as part of the WRF Pre-processing System.

For this analysis, the land use was assigned USGS-24 category *(WRF 2015)* land use classes. The dominant land use for each NARCliM 10km cell was used.

The 10km land use data is inherent in the pattern of actual evapotranspiration modelled by RCM, so it must be used for consistency in model inputs.

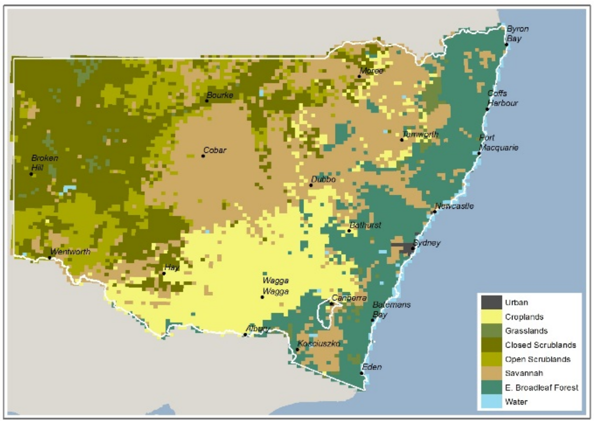

Figure 2. Dominant land use categories

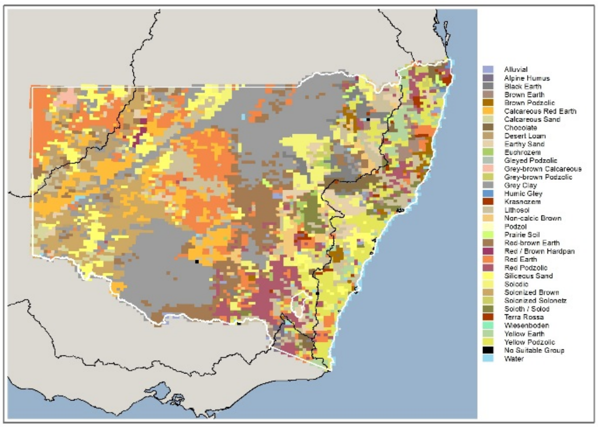

Figure 3. Dominant soil types

Dominant Soils (Great Soils Groups)

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 NSW have been classified using a modified version of the Great Soil Groups (GSG) classification. It uses the best available soils natural resource mapping coverage.

The dominant soil type for each 10km cell was determined (Figure 3). Soil hydraulic properties for GSG as compiled by *(Littleboy et. al. 2003, 2009)* were used to assign soil hydraulic properties for each 10km cell.

Lateral Flow Partitioning Coefficient (Rh)

Values for lateral flow partitioning coefficient *(Rassam and Littleboy, 2003)* were derived for each 10km cell (Figure 4). Mean slope for each 10km cell was calculated from 30m resolution Digital Elevation Model.

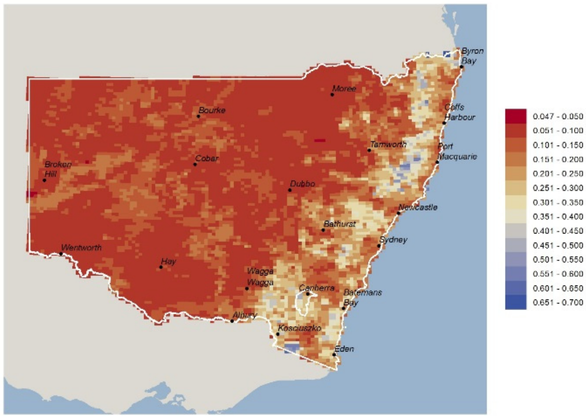

Figure 4. Lateral flow partitioning coefficient

Modelling environment

Modelling was performed using a Python based system, backed by the core PERFECT water balance model, implemented in FORTRAN. 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 from many point based runs into spatial and aggregate output files in netCDF and CSV formats. At its core, the system manages '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 inputs. The intersection of these three information sources identifies a spatial area to be modelled and the corresponding PERFECT model inputs and parameters required for the individual spatial unit to be modelled.

Users currently interact with the modelling system through a command-driven interface hosted in the web-based IPython Notebook environment. This interface presented a series of 'top level' commands, which were backed by detailed Python modules representing the spatial modelling approach, and links to the underlying PERFECT model. The Notebook environment allows users to mix modelling commands, with documentation and visualisation, and the resulting ‘notebook’ files represent a record of the modelling workflow. This command driven approach leads to reproducibility, while also giving users the ability to create short scripts to automate repetitive operations.

For the simulations presented in this report, the system was configured to

1. Read the post-processed NARCliM netCDFs containing daily data for rainfall and evapotranspiration
2. For each 10km cell, run PERFECT using the land use type, great soil group and lateral flow partitioning coefficient (Rh) shown in Figures 2, 3 and 4, for that cell
3. Extract model output as netCDFs and ASCII comma separated files and for input to ArcGIS and Excel for further analysis

3. RESULTS

Changes in Surface Runoff

Changes in surface runoff influence the availability of water resources, flows into natural and man-made major water bodies, and the design and operation of rural and urban stormwater drainage systems. Secondary impacts such as salinity, erosion, water quality and aquatic biodiversity can also occur as a result of changes in surface runoff.

Across much of NSW, surface runoff (mm/yr.) is likely to increase in both the near and far future in the multi-model mean of simulations. However, there is a large spread between different model simulations (see below). The largest increases are projected in the central west through to the northern tablelands. Reductions of greater than 40mm/yr. in surface runoff are projected in for alpine areas in the south of the State.

As noted above, there is a spread between different models. This can be seen in the range of projections for the NSW annual mean surface flow, ranging from a decrease (drying) of -23.3mm/yr. to an increase (wetting) of +12.1mm/yr. for the near future (2020-2039), Figure 5. There is also a large range from drying to wetting

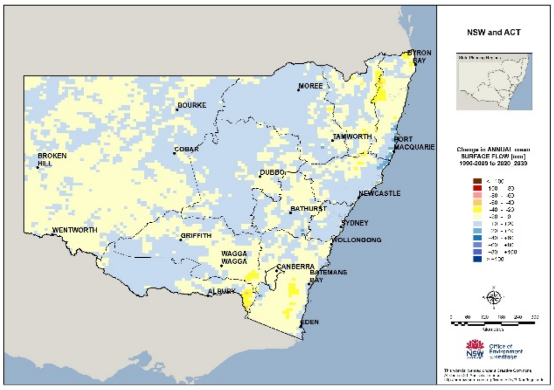

Figure 5. Annual mean change in Surface Runoff 1990-2009 to 2020-2039

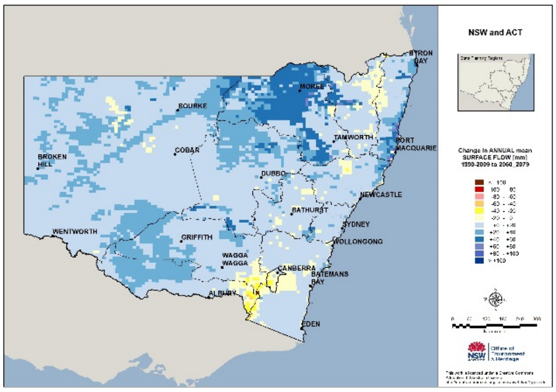

Figure 6. Annual mean change in Surface Runoff 1990-2009 to 2060-2079

(-7.9mm/yr. to +45.7mm/yr.) for the far future (2060-2079), Figure 6.

Mean seasonal projections for the near future (2020-2039) also show a range that includes both increases and decreases for summer (-16.2 to +5.9mm), autumn (-6.0 to +11.3mm), winter (-1.4 to +1.8mm), and spring (-2.0 to +2.0mm). For far future (2060-2079) the changes are: Summer (-4.5 to +26.2mm), autumn (-0.4 to +10.0mm), winter (-3.3 to +4.4mm), and spring (-1.8 to +6.9mm) Figure 7. There is a greater increase in the far future period than the near future period in each season.

For near future (2020-2039), the NARCliM simulations using MIROC3.2 and CCCMA3.1 GCMs as hosts all tend to project an increase in annual surface flow (wetting), whereas those using CSIROMK3.0 and ECHAM5 project a decrease in surface flow (drying). For the far future (2060-2079), 9 of the 12 NARCliM simulations project an increase >5mm in surface runoff, and 3 (those using CSIROMK3.0) project no change or a decrease in surface runoff. The largest range between models are present during summer and autumn periods.

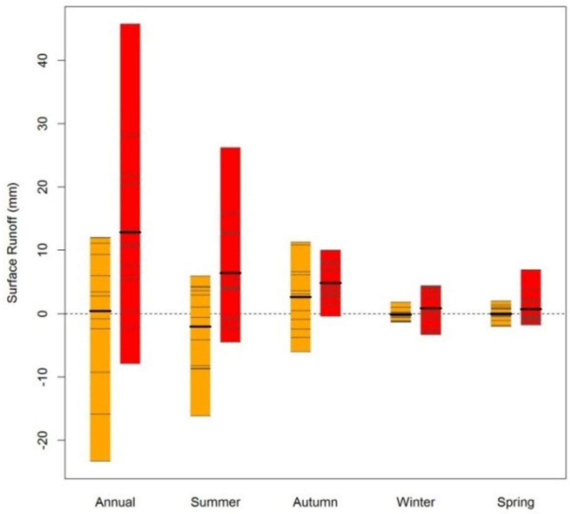

Figure 7. Change in mean Surface Runoff Orange: Near (2020-2039) Red: Far (2060-2079)

Changes in Recharge

Changes in recharge can influence the availability 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.

In the near future (2020-2039), less recharge is projected across much of NSW in the multi-model mean of the 12 simulations, especially in the south east and northwest of the State (Figure 8). Some areas of western NSW do show a slight projected increase in recharge but these increases are relatively small. In the far future (2060-2079), Figure 10, recharge is projected to increase across many parts of NSW. Considerably less recharge is projected in alpine areas for both near and far future scenarios.

However, as for runoff, this multi-model mean is the mean of a large model range. Projections for the NSW annual mean recharge range from a decrease (drying) of -29.9mm/yr. to an increase (wetting) of +14.6mm/yr. for near future (2020-2039) Figure 9, and still span both drying and wetting scenarios (-2.1 to +16.7mm/yr.) for far future (2060-2079) Figure 10.

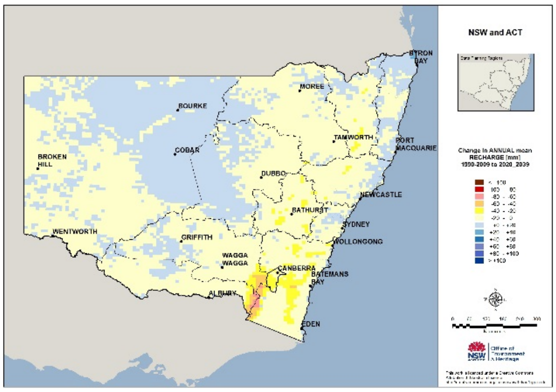

Figure 8. Annual mean change in Recharge 1990-2009 to 2020-2039

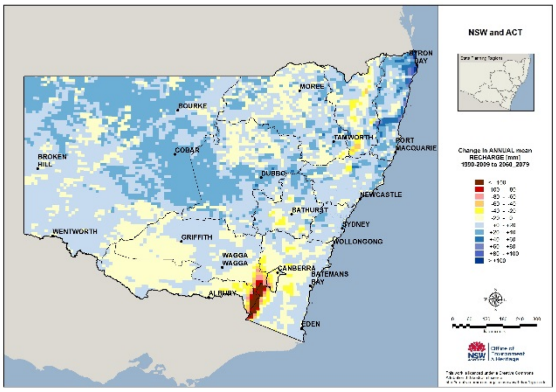

Figure 9. Annual mean change in Recharge (2070) 1990-2009 to 2060-2079

Mean seasonal projections for the near future (2020-2039) span both increases and decreases for summer (-15.1 to +8.8mm), autumn (-8.8 to +7.4mm), winter (-4.8 to +3.1mm), and spring (-2.6 to +0.8mm). For far future (2060-2079) the projections are: Summer (-6.2 to +26.0mm), autumn (-2.1 to +16.7mm), winter (-11.1 to +12.9mm), and spring (-3.8 to +0.3mm) Figure 11.

Based on annual mean recharge, for near future (2020-2039), NARCliM simulations using MIROC3.2 and CCCMA3.1 as hosts tend to project an increase in recharge (wetting), whereas simulations using CSIROMK3.0 and ECHAM5 as hosts tend to project a decrease in recharge (drying). For far future (2060-2079), 9 (MIROC3.2, ECHAM5, CCCMA3.1) of the 12 NARCliM ensembles project an increase in recharge and 3 (CSIROMK3.0) project a decrease to recharge. The largest spread between models are evident during summer and autumn periods.

4. CONCLUSION

This study applied a 1-dimensional water balance for each grid cell using rainfall and actual evapotranspiration as inputs.

In the near future, projected changes in either runoff or recharge are generally small, with the multi-model mean projection showing a small reduction in mean annual runoff in southern areas of NSW, but a small increase in central and northern areas. However, there is a large model spread around this mean, with both increases and decreases projected by different simulations for the state-wide mean change.

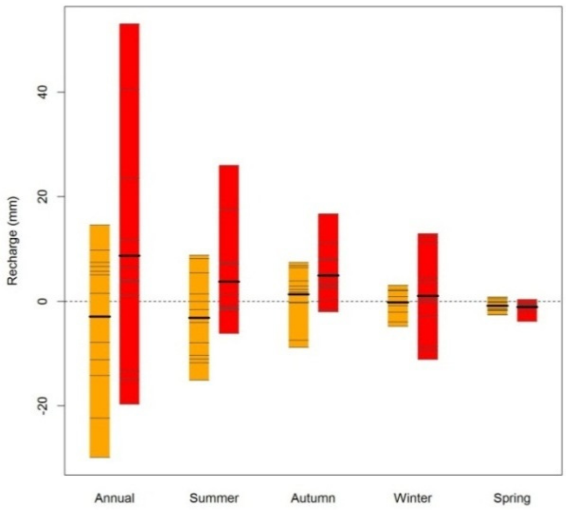

Figure 10. Change in mean Recharge
Orange: Near (2020-2039) Red: Far (2060-2079)

Projected changes in the far future are larger than for near future, with more surface runoff and recharge projected across much of the State in the multi-model mean. However, there is also a wide spread between models for this period too, ranging from decrease to increase for the state-wide mean However, there is higher model agreement for the southern areas of NSW, which are projected to have less runoff and recharge.

Across most of NSW, higher runoff and recharge in the autumn months is projected due to higher autumn rainfall in many simulations (but not all). In southern parts of the State, there is higher model agreement for a marked drying during spring months resulting in less spring runoff and recharge.

More complex analyses at a resolution on 100m are underway for the ACT and coast catchments of NSW. This analysis will permit allow spatial variability in land use and soils to be taken into consideration in the climate impact assessments.

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