



# Design rainfalls under climate change scenarios in South East Queensland, Australia: A Brisbane River case study

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## ARTICLE INFO

### Keywords:

Precipitation  
Floods  
Design storms  
GCMs  
AEP

## ABSTRACT

This study updates design rainfalls for the Brisbane River Basin, Australia, employing rainfall data from eight CMIP5 General Circulation Models (GCMs) across two Representative Concentration Pathways (RCP 4.5 and RCP 8.5) and four future timeframes (2016–2045, 2036–2065, 2056–2085, and 2075–2104), totalling 64 climate futures. Future design rainfalls were computed for Annual Exceedance Probabilities (AEPs) of 1%, 2%, 5%, and 10%, spanning durations from 1 to 7 days. For each climate future, an Annual Maximum Series was established, and a Gumbel distribution was applied to estimate precipitation for various AEPs. Comparisons were made with baseline (stationary) design rainfalls and those derived from Australian Rainfall & Runoff (AR&R) methodology based on temperature scale factors. GCM-derived design rainfalls indicate a general reduction in depths for most durations and AEPs under both RCP scenarios. Specifically, RCP 4.5 demonstrated significant reductions in design rainfalls for the 1% AEP, ranging from −9.61% (1-day duration) to −21.40% (7-day duration). Similarly, RCP 8.5 showed decreased depths, except for 1-day, 2-day, and 3-day design rainfalls in the 2075–2104 timeframe, which exhibited marginal increases. AR&R methodology yielded substantially higher design rainfalls, with increases reaching +11.6% for 1% AEP and 10% AEP. While GCM-derived rainfalls imply adequacy of current drainage infrastructure, AR&R methodology suggests a more conservative estimate, emphasizing the need for cautious climate data interpretation.

## 1. Introduction

Design rainfalls are defined as precipitation events characterized by diverse intensities, durations, and frequencies of occurrence. These events play a pivotal role in engineering, guiding the design of infrastructure to ensure they can effectively withstand extreme weather conditions. Typically derived from statistical analyses of historical rainfall data, design rainfall values are usually represented by Intensity-Duration-Frequency (IDF) or Depth-Duration-Frequency (DDF) curves or equations (Jiang and Tung, 2015). The ‘frequency’ characteristic of design rainfalls is typically represented by an Annual Exceedance Probability (AEP) (Dingman, 2015). The AEP describes the probability of a given rainfall event of certain duration and intensity being exceeded in any one year and is often expressed as a percentage. Exceedances per Year (EY) is another term commonly used to describe design rainfall frequencies. EY represents the number of times that a rainfall event is expected to be exceeded in a year, and it is usually applied to very frequent rainfall events (AEP 50% or higher).

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Design rainfalls can be divided into five classes according to their probability of occurrence: 1) very frequent; 2) frequent; 3) infrequent; 4) rare; and 5) extreme (Green et al., 2019). Very frequent design rainfalls may occur more than once a year with a probability range from 12 EY to 1 EY. These rainfalls are typically used for water sensitive urban design. Frequent design rainfalls (1 EY to 10% AEP) and infrequent design rainfalls (10% to 1% AEP) are commonly used for stormwater, pit and pipe design. Rare design rainfalls (1% to 0.05% AEP) are widely used in floodplain management and waterway design; and extreme design rainfalls (<0.05% AEP) are inputs for the design of critical infrastructure, like reservoirs and bridges.

The derivation of design rainfalls follows a systematic procedure, incorporating statistical analysis of historical rainfall observations. This procedure involves utilizing a sufficiently extended period of data, typically exceeding 30 years, to encompass a diverse range of rainfall events. During this process, frequency distributions like the Gumbel distribution or the Pearson Type III distribution are employed to fit the data. This fitting allows for the modeling of the frequency and magnitude of rainfall events, aiding in the determination of the relationship between rainfall intensity, duration, and frequency.

Importantly, the derivation of design rainfalls hinges on the critical assumption of “stationarity”, which suggests that the statistical properties of rainfall, including mean, variance, and probability distribution, remain constant over time. This assumption has come under significant scrutiny in the past decade. Debates surrounding its validity have intensified based on the growing recognition of climate change’s influence on precipitation patterns (Salas et al., 2018). Over time, as climate shifts occur, the constancy of rainfall characteristics may no longer hold true, underlining the need to reevaluate the accuracy of current design rainfalls, established under the stationarity assumption.

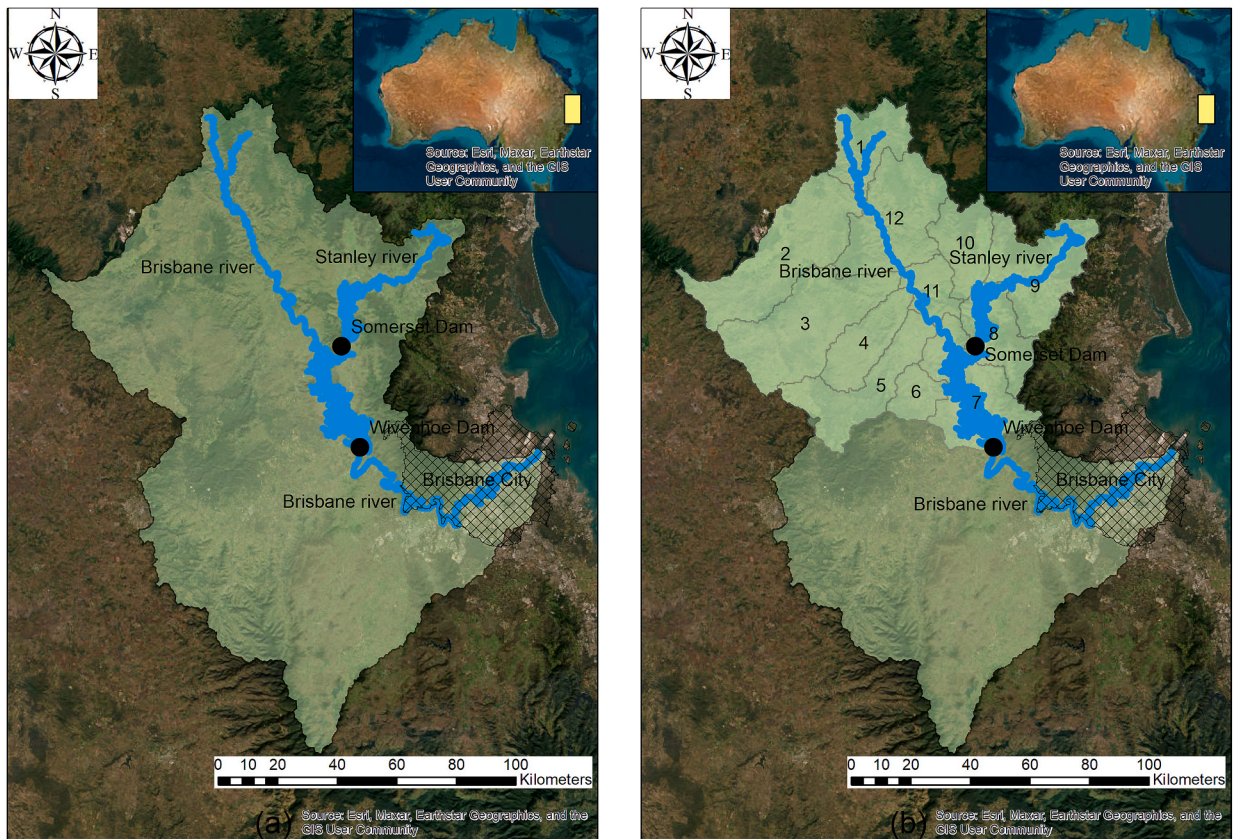
In Australia, significant shifts in precipitation patterns over the years have been documented (Li et al., 2005; Lough, 1991; Hennessy et al., 1999). Hennessy et al. (1999) conducted a comprehensive analysis using 379 rainfall stations, spanning from 1910 to 1995, revealing a substantial 10% increase in the annual average number of rainy days in Australia. Moreover, certain states, such as South Australia, Northern Territory and New South Wales, experienced noteworthy increases ranging from 20% to 50%. In Queensland, the focus of the current study, Lough (1991) examination of rainfall records from 1891 to 1986 suggests a declining trend in mean summer rainfall. Conversely, an analysis of 191 rainfall stations from 1910 to 1988 by Nicholls and Lavery (1992) indicates an increasing trend in summer rainfall across much of eastern Australia. The same study notes a decrease in winter rainfall over the south-west of Western Australia. Corroborating this finding, Li et al. (2005), using a daily rainfall dataset from 1930 to 2001, found that winter daily rainfall extremes in Western Australia are lower post-1965 compared to earlier periods. These diverse observations emphasize the notable and regionally varying changes in precipitation patterns across Australia over the years, suggesting that the assumption of stationarity is no longer valid. Therefore, it is highly probable that design rainfalls established under the stationarity assumption will not be valid in the future, a hypothesis that we will endeavour to assess in this study.

Understanding future changes in design rainfalls is important for predicting reservoir inflows, and thus help quantify and manage flood risks more effectively. Despite the recommendation in Australia being the use of ‘climate change factors’ to adjust current (stationary) design rainfalls for use in climate change scenarios (Bates et al., 2019), these factors are based on temperature changes, rather than precipitation changes. Furthermore, they do not account for the actual uncertainty of climate change predictions, as they only consider changes in temperature related to the highest level of ‘consensus’ among the models. Climate change impact studies should, instead, be conducted with the use of multi-model approaches (Medellin-Azuara et al., 2008; Kloster et al., 2010; Abrishamchi et al., 2012), considering available model predictions, and using the variables of interest (precipitation in this case), rather than a proxy.

General Circulation Models (GCMs) are one of the best available tools for predicting changes in future precipitation (IPCC, 2007). These models are complex computer-based systems designed to represent and simulate the Earth’s climate. They integrate mathematical equations to compute the interactions between the atmosphere, oceans, land surface, and ice. GCMs are used to study and predict climate patterns, understand the dynamics of the climate system, and assess the potential impacts of various factors, such as greenhouse gas emissions and changes in land use (Srivastav et al., 2015).

Numerous studies involving the use of GCM data to assess the impacts of climate change on precipitation patterns have been conducted in Australia, revealing the substantial and varied impacts across the continent. For example, Feng et al. (2019) used 28 GCM precipitation datasets to analyze changes in droughts across the New South Wales Wheat Belt region in the southeast of Australia. One of the main findings was that spring and winter droughts are expected to become more severe over this region in the next years, while summer and autumn droughts are expected to change slightly. Irving et al. (2012) analyzed some GCM data in terms of the simulated present climate and projected future climate for Australia, and the results showed that rainfall is predicted to decline in winter and spring in the southwest of Western Australia and, to a lesser extent, in the southeast of Australia. Jenkins and Warren (2015) quantified the potential consequences of climate change on precipitation in several regions of the world, including Australia. Based on the results of two selected GCMs, the authors identified that drought frequency will increase in the northwest and southwest of Australia. Also, Christensen et al. (2007) projected an increased risk of droughts in southern Australia. The authors also concluded that precipitation is very likely to decrease in winter in southwestern Australia. Examining the Brisbane region, where this study is based, Webb and Hennessy (2015) analysis, employing 40 CMIP5 models, revealed a projected decline in both average annual and seasonal rainfall across all seasons up to the year 2090 compared to 1986–2005 baseline. These collective findings highlight the diverse impacts of climate change on precipitation throughout the country, suggesting a need for re-evaluating design rainfalls to mitigate future climate effects on hydraulic infrastructure design.

The Brisbane River Basin, located in the region of South-East Queensland (SEQ), Australia (description provided in section 2.1), is a flood and drought prone region, which is expected to be significantly affected by climate change (Helfer et al., 2012; Webb and Hennessy, 2015; Ramezani et al., 2023). This basin contains two important reservoirs for flood mitigation: Wivenhoe Dam and Somerset Dam, which are the third and fourth largest reservoirs in Queensland, respectively. Depending on the future DDF curves



**Fig. 1.** Location of the Brisbane River Basin in Australia and its two main reservoirs (Wivenhoe Dam and Somerset Dam) (a) and the 12 sub-basin division adopted in this study (b).

projections for this region, it might be necessary to update the operational strategies of these reservoirs.

As such, the objective of this study is to assess the impacts of climate change on DDF curves of long durations (1 to 7 days) and AEP 10 to 1% (rare occurrence) in the Brisbane River Basin. The specific steps to achieve this objective are:

1. To obtain 1, 2, 3, 4, 5, 6 and 7-day DDF curves for probabilities from 10% to 1% AEP, for the baseline period in the studied basin.
2. To obtain 1, 2, 3, 4, 5, 6 and 7-day DDF curves for probabilities from 10% to 1% AEP, for 64 climate futures in the studied basin.
3. To obtain 1, 2, 3, 4, 5, 6 and 7-day DDF curves for probabilities from 10% to 1% AEP, for future climate, using the simplified method recommended by the Australian Rainfall & Runoff (AR&R), which is based on temperature projections (Bates et al., 2019).
4. To analyze and discuss the changes between the DDF curves found in (1), (2) and (3).
5. To make recommendations for updating design rainfalls in response to climate change scenarios.

The results of this study can assist governmental planners and engineers to predict future design rainfalls in the Brisbane River Basin and take more robust decisions regarding reservoir design, operation, and flood mitigation strategies. For example, they will have more reliable information about future rainfall probabilities and spatial distribution in this important basin. This, in turn, will help them better predict future runoff and inflows into the two reservoirs of the basin. Ultimately, the findings will contribute to better reservoir management and operation and flood control in Southeast Queensland.

## 2. Methodology

### 2.1. Study area

Located in Southeast Queensland (SEQ), Australia, the Brisbane River Basin covers a total area of 13,570 km<sup>2</sup>. The Brisbane River has a length of 344 km and an average stream gradient of 0.62 m/km. The river is fed by numerous tributaries, including the Stanley River, Moggill Creek and Breakfast Creek on the northside, and Bremer River, Lockyer Creek, Bulimba Creek and Oxley Creeks on the southside, where the Brisbane metropolitan area is located. The Brisbane River travels mostly from Mount Stanley to Moreton Bay – an inlet of the Pacific Ocean.

The Brisbane River Basin is home to over 3.27 million people, constituting nearly 14% of the Australian population (Australian

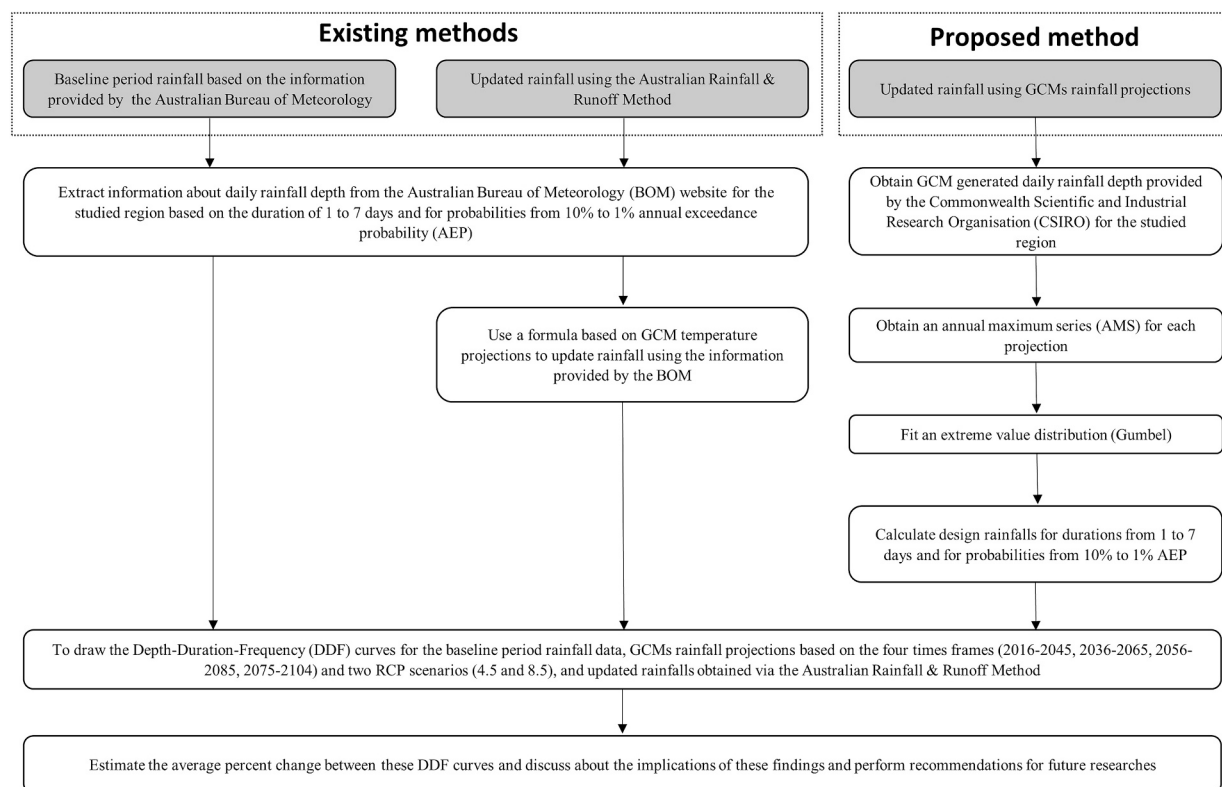


Fig. 2. Flowchart of the proposed methodology to assess how design rainfalls will be affected by climate change.

Bureau of Statistics, 2016). It is an economically significant basin, currently experiencing large economic and population growth. The Brisbane City population, for example, has increased from 957,900 to 2,568,927 from 1971 to 2021, with an average increase of 1.49% per year from 2018 to 2021 (Australian Bureau of Statistics, 2022).

In the upper part of the Brisbane River Basin, two large reservoirs were constructed to meet the region's growing water demands and serve as flood mitigation strategies. Wivenhoe Dam, built in 1984 on the Brisbane River, has a full storage capacity of 3.13 million megalitres and a drainage area of 7020 km<sup>2</sup>. Upstream of Wivenhoe Dam lies Somerset Dam, constructed in 1953 on the Stanley River, a main tributary of the Brisbane River. Somerset Dam has a full storage capacity of 0.9 million megalitres and a drainage area of 1340 km<sup>2</sup> (Fig. 1a). These dams operate as a unified system, with Wivenhoe Dam receiving flows from both Somerset Dam to the east and the Brisbane River to the west.

Despite the presence of these dams, the Brisbane River Basin remains highly sensitive to climate extremes and has faced significant impacts from historical flood events, such as those in 1893, 1974, and 2011. The 2011 floods alone caused damages exceeding \$4 billion (Honert and McAneney, 2011). Although the dams helped minimize the flood consequences, the aftermath prompted the implementation of costly measures, including the installation of backflow prevention devices and a comprehensive review of dam operational strategies (BMT, 2017).

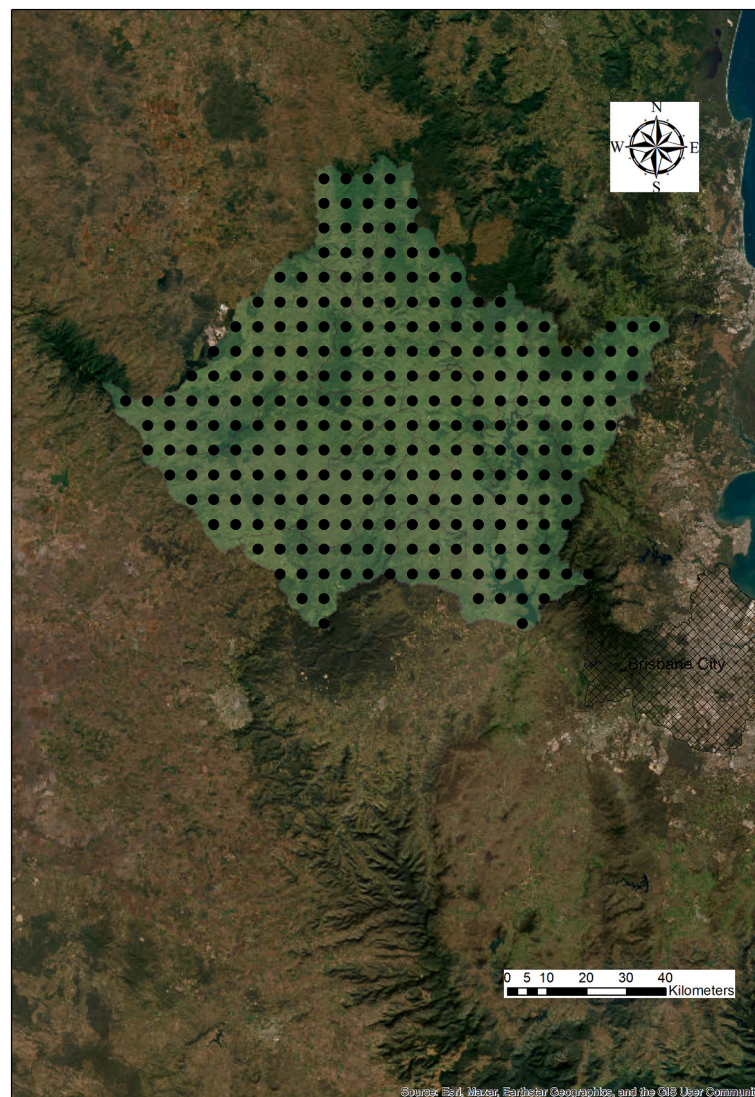
Various flood mitigation structures, including culverts and stormwater pipes, have been installed along the Brisbane River to reduce the impact of its high velocities and limited overbank storage (BMT, 2017). The critical structure in this context is Wivenhoe Dam, which plays a pivotal role in flood mitigation by allowing controlled release of the river's water during heavy rains, providing a safe environment downstream for approximately 150 km until it reaches Moreton Bay, adjacent to the Brisbane metropolitan area.

This study focused on the examination of this important segment of the Brisbane River Basin — the Wivenhoe Dam basin — which also includes the drainage area of Somerset Dam (1340 km<sup>2</sup>) in the northeast of the catchment (refer to Fig. 1). The study area covers 7020 km<sup>2</sup> — approximately half of the total area of the Brisbane River Basin. The predominant land use in the Wivenhoe Dam basin is grazing and forestry, with predominantly friable loamy soils or hard-setting loamy soils (Ruffini et al., 1994). The altitude varies from 70 m in the lowest portion of the basin (at Wivenhoe Dam) to approximately 700 m on the highest portion (north boundary). Brisbane's annual average rainfall is around 1200 mm, with higher rainfall in the wet season from October to March receiving around 800 mm, and the dry season from April to September receives only a half (about 400 mm) of the wet season (Enviro Friendly, 2024).

To facilitate the assessment of spatial changes in design rainfall patterns within this region, the studied area was subdivided into 12 sub-basins, ranging from 202.12 to 1039.69 km<sup>2</sup>. These sub-basins are depicted in Fig. 1b.

**Table 1**  
Summary of GCMs selected for the current study.

| Model      | Research Center                                                                                                                        | Spatial Grid Resolution (in degrees) |
|------------|----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|
| ACCESS1-0  | The Centre for Australian Weather and Climate Research, Australia                                                                      | $1.9 \times 1.2$                     |
| CANESM2    | Canadian Centre for Climate Modeling and Analysis, Canada                                                                              | $2.8 \times 2.8$                     |
| CESM1-CAM5 | National Center of Atmospheric Research, USA                                                                                           | $1.2 \times 0.9$                     |
| CNRM-CM5   | Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique, France | $1.4 \times 1.4$                     |
| GFDL-ESM2M | National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory, USA                                            | $2.5 \times 2.0$                     |
| HadGEM2-CC | Met Office Hadley Centre, United Kingdom                                                                                               | $1.9 \times 1.2$                     |
| MIROC5     | Japan Agency for Marine-Earth Science and Technology                                                                                   | $1.4 \times 1.4$                     |
| NorESM1-M  | Norwegian Climate Center, Norway                                                                                                       | $2.5 \times 1.9$                     |



**Fig. 3.** Location of the GCM data grid in the study area. Black dots represent the GCM grid points.

## 2.2. DDF curves for the baseline period

Fig. 2 shows the overall framework of the methodology adopted in this study, and this and the subsequent sections will elaborate on each specific step.

The initial phase of the methodology involved acquiring DDF curves and design rainfall values for durations ranging from 1 to 7 days, and AEPs of 1%, 2%, 5%, and 10% for the baseline period, reflecting the current climate conditions. This data was sourced using the Australian Bureau of Meteorology (BOM) IDF system (Bureau of Meteorology, 2020). The BOM curves were constructed based on observed rainfall data from BOM sites and other organizations, primarily representing the climate of the 20th century without factoring in the impacts of future climate change.

To ensure the reliability of the statistics derived from the data, the BOM set minimum record lengths for inclusion of rainfall sites. The BOM IDF system is freely available for public use, enabling the determination of AEP rainfall depths for any given latitude and longitude within Australia at a grid resolution of  $0.025^\circ$ , approximately  $2.7 \text{ km} \times 2.7 \text{ km}$  at the equator (Bureau of Meteorology, 2016). In the context of this study, for each of the 12 sub-basins defined within the Wivenhoe Dam basin, a single point of DDF information, closest to the centroid of each sub-basin, was obtained. Subsequently, baseline period rainfalls were acquired for durations ranging from 1 to 7 days and for probabilities from 10% to 1% AEP.

## 2.3. Design rainfalls for future periods using GCM data

The Commonwealth Scientific and Industrial Research Organization (CSIRO) and Australian Bureau of Meteorology (BoM) provided daily rainfall projections for the studied region. The daily rainfall projections were obtained from eight CMIP5 GCMs: ACCESS1-0, CANESM2, CESM1-CAM5, CNRM-CM5, GFDL-ESM2M, HadGEM2-CC, MIROC5, NorESM1-M (see Table 1). CSIRO and BoM's selection of these GCMs (out of a total of 40 GCMs) was guided by various criteria, including their effectiveness in representing historical climate, capability to model extreme El Niño and La Niña events, and ability in simulating the Australian monsoon, among other factors. Further details on the evaluation and selection process of these models can be found in Chapter 5 of the CSIRO and Bureau of Meteorology (2015) report.

It is widely known that raw GCM data, characterized by low spatial resolution, cannot be directly employed for regional impact assessments, particularly for evaluating impacts on hydrological processes (IPCC, 2007; Feng et al., 2019; Patil et al., 2018). To overcome this limitation, downscaling techniques must be applied to achieve a finer scale resolution (Patil et al., 2018). The GCMs data provided by the CSIRO were downscaled using the Delta Change method. In this method, the raw GCM projected rainfall changes are applied to observed rainfall data in the form of a multiplicative factor (CSIRO and Bureau of Meteorology, 2015). The downscaled GCM data was provided in a  $5 \times 5 \text{ km}$  grid, totalling 257 points within the studied basin (Fig. 3).

The GCM projections used in this study were based on two RCP scenarios: 4.5 and 8.5. Scenario RCP 4.5 was chosen because it has been considered a reasonable greenhouse gas emission pathway considering the latest worldwide climate policies (Khan et al., 2018). Scenario RCP 8.5 is considered the worst-case climate change scenario (Korell et al., 2020; Yanahan and Moore, 2019). Thus, these two scenarios can provide a feasible range of climate change impacts. Furthermore, they are the recommended scenarios to be used in hydraulic infrastructure design in Australia, as per the AR&R guidelines (Bates et al., 2019).

The considered timeframes were 2016–2045, 2036–2065, 2056–2085 and 2075–2104. For each timeframe, and considering an average value of the grid data for each sub-basin, an Annual Maximum Series (AMS) was obtained. An AMS is a set of data consisting of the maximum values of daily rainfall observed each year. Then, a Generalised Extreme Value (GEV) frequency distribution was fitted to each AMS. As it is widely used in the analysis of hydrological events, the Gumbel distribution was fitted to the AMSs of the GCMs. The cumulative distribution function (CDF) of the Gumbel distribution is expressed by the following equation (Gumbel, 1935, 1941):

$$F(y) = \exp \left[ - \exp \left( - \frac{y - \beta}{\mu} \right) \right] \quad (1)$$

where  $F(y)$  represents the cumulative probability of occurrence of a specific event;  $\beta$  represents the shape parameter of the Gumbel distribution; and  $\mu$  represents the scale parameter of the Gumbel distribution.

Like the baseline period, design rainfalls were determined for durations from 1 to 7 days and for probabilities from 10% to 1% AEP.

## 2.4. Design rainfalls for future periods using the AR&R method

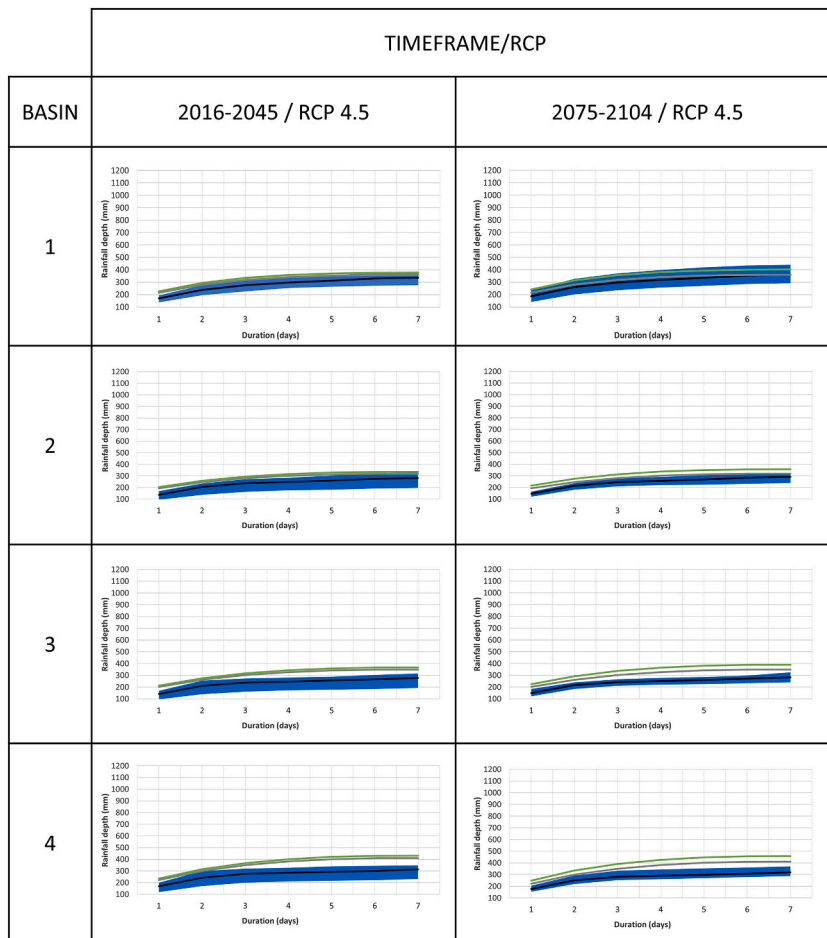
In this study, future design rainfalls of 1, 2, 3, 4, 5, 6 and 7-day durations, and for probabilities from 10% to 1% AEP were obtained using the method recommended by the AR&R (Bates et al., 2019). The method is based on the Effective Service Life (ESL) of the structure to be designed and in GCM projections of temperature. If the ESL is shorter than 20 years, a stationary climate is considered, which means using the existing design rainfalls derived for the 20th century (current climate) without considering the effects of climate change. If the ESL is between 20 and 50 years, a non-stationary climate (i.e., with consideration of climate change) is assumed, except in region where there is a low probability of occurrence of changes in land use. For last, if the ESL is  $>50$  years, a non-stationary climate is considered, meaning that the following method should be applied.

The method of incorporating climate change in design rainfalls using a non-stationarity assumption, as proposed by the AR&R is based on the following formula (Bates et al., 2019):

**Table 2**

Baseline design rainfalls (mm) for the Wivenhoe Dam Basin (Source: BoM IDF data system).

|          | AEP    | 10%    | 5%     | 2%     | 1%     |
|----------|--------|--------|--------|--------|--------|
| Duration | 1 day  | 163.33 | 192.67 | 232.58 | 264.33 |
|          | 2 days | 212.33 | 253.25 | 310.50 | 356.58 |
|          | 3 days | 241.75 | 290.42 | 358.67 | 414.25 |
|          | 4 days | 260.17 | 313.58 | 389.00 | 450.58 |
|          | 5 days | 271.92 | 328.00 | 406.92 | 472.17 |
|          | 6 days | 279.17 | 336.42 | 417.00 | 483.42 |
|          | 7 days | 283.17 | 340.33 | 421.00 | 487.50 |



**Fig. 4.** Current climate DDF curves and future climate DDF curves for different rainfall durations (1 to 7 days) and for 1% AEP. The gray lines represent current climate DDF curves, whereas the black lines represent the average curves of the eight future climate curves. The blue shaded area represents the range of the maximum and minimum value of the future climate DDF curves. The green lines represent the future climate DDF curves obtained using the Australian & Rainfall Runoff Method. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

$$I_p = I_{ARR} \times 1.05^{T_m} \quad (2)$$

where  $I_p$  is the projected rainfall intensity or equivalent depth;  $I_{ARR}$  is the design rainfall intensity (or depth) for current climate conditions (refer to [section 2.2](#));  $T_m$  is the temperature at the midpoint (or median) of the selected class interval. The  $T_m$  can be obtained from the Climate Futures Webtool Website ([CSIRO and Bureau of Meteorology, 2015b](#)). The class interval is a range of possible future temperatures which is provided by the Climate Futures Webtool Website.

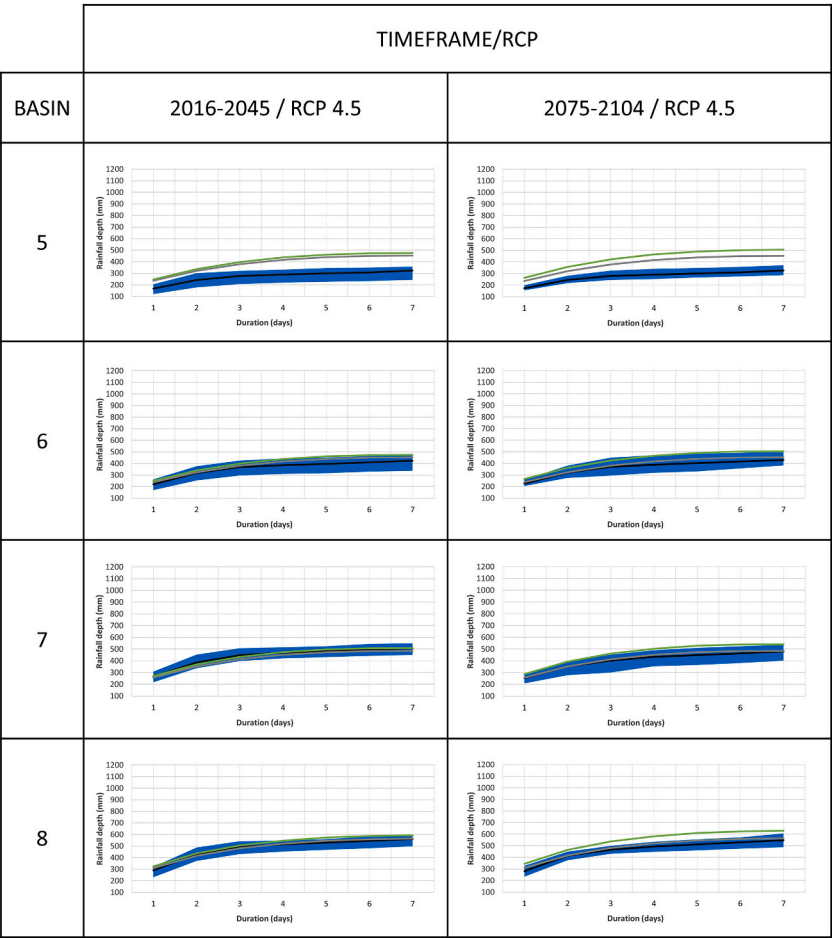


Fig. 4. (continued).

2.5. Effects of climate change on design rainfalls

Firstly, the graphs of the current DDF curves and future climate DDF curves were compared for the short-term timeframe (2016–2045) and long-term timeframe (2075–2104) for all the 12 sub-basins of the Wivenhoe Dam basin. Also, the results for the four timeframes 2016–2045, 2036–2065, 2056–2085, 2075–2104 and the two RCP scenarios (4.5 and 8.5) were analyzed. Secondly, an assessment of the average percent change was performed in all sub-basins for the 1-day and 7-day rainfalls, considering the four timeframes and the two RCP scenarios. Finally, area-weighted average changes were obtained for the four timeframes, the two RCP scenarios and different durations of rainfall, to obtain representative values for the whole study area.

2.6. Assessment of the AR&R climate change method

The climate change design rainfalls obtained via the AR&R method (section 2.4) were then compared with the design rainfalls obtained via the GCM method (section 2.3). Also, the results provided by the AR&R method were compared with the baseline design rainfalls (section 2.2). This comparison allowed us to determine whether the simplified temperature-based method proposed by the AR&R could lead to a design rainfall that could potentially result in overdesign or underdesign of infrastructure compared to the design rainfall derived from GCM data series.

2.7. Implications and recommendations

After summarizing the findings from the above steps, a discussion about the implications of these findings was performed. Moreover, some important observations were detailed and further recommendations for future research were provided.

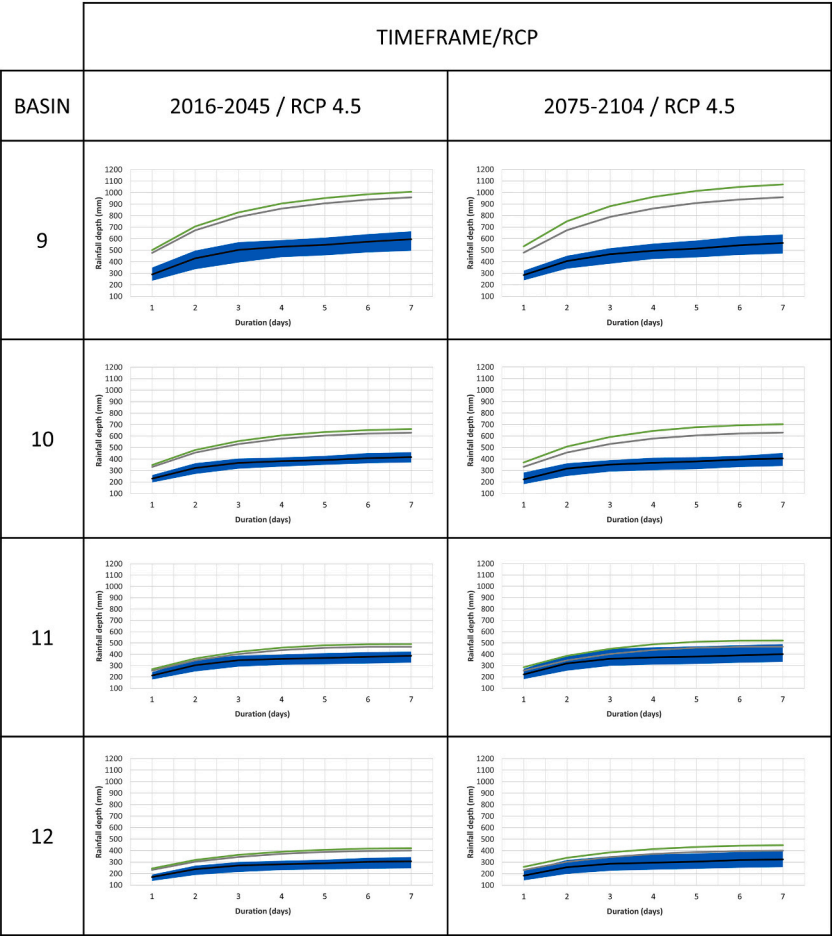


Fig. 4. (continued).

3. Results and discussion

3.1. Baseline design rainfalls

Table 2 illustrates the baseline design rainfalls obtained from the BOM data system, as detailed in section 2.2. It can be observed that the rainfall depths range from 163.3 mm for the highest AEP (10%) and the shortest duration (1 day) considered, to 487.5 mm for the lowest AEP (1%) and the longest duration (7 days). As anticipated, there is an upward trend in design rainfall depths as probabilities decrease. Additionally, design rainfall depths show an increasing pattern with longer rainfall durations. Conversely, intensities decrease as durations increase. The rainfall intensities vary between 1.7 mm/h for a 7-day duration at 10% AEP and 11 mm/h for a 1-day duration at 1% AEP. The gray curves in Fig. 4 represent the baseline design rainfall curves for each sub-basin in the study area.

3.2. GCM-derived design rainfalls

Table 3 presents the anticipated percentage changes in design rainfalls for durations of 1 to 7 days and AEPs of 10%, 5%, 2%, and 1% under scenario RCP 4.5, following the methodology derived from GCM data (as described in section 2.3). Additionally, Table 4 presents the expected percentage changes for the same design rainfalls under scenario RCP 8.5. These values represent an average across all data points within the studied basin, defined for a specific grid size of 5 km × 5 km, as detailed in section 2.3.

Fig. 5 focuses on the GCM-derived 1% AEP design rainfall, showing the expected changes per sub-basin relative to the baseline design rainfalls for each RCP and timeframe. As the Queensland State Policy advocates for the adoption of the 1% AEP flood frequency in waterway flood management planning (Witheridge, 2013), our discussion primarily centers on this specific AEP.

Upon comprehensive analysis, the trend based on GCM-derived design rainfall indicates a decrease over time under both RCPs, particularly affecting northeastern sub-basins upstream of the Somerset Dam (sub-basins 9 and 10 – refer to Figs. 1, 5, and 6). These regions are expected to witness reductions in the range of 30–40% in their design rainfalls. This notable finding implies a reduction in Somerset Dam inflows, directly impacting reservoir storage and Wivenhoe Dam inflows.

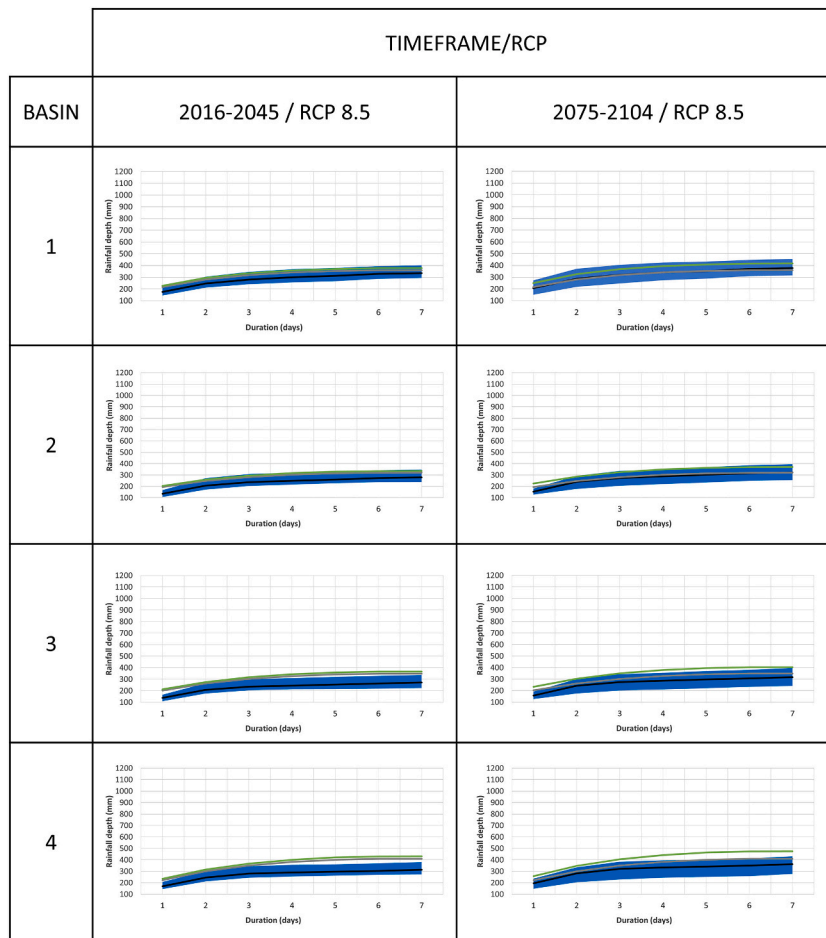


Fig. 4. (continued).

Conversely, the southern sub-basins and the northern part of the study area (e.g., sub-basins 1, 6, and 7, highlighted in green in Figs. 5 and 6) display minimal changes, which are statistically insignificant. As a result, these regions are unlikely to undergo significant alterations compared to the current baseline design rainfalls. This aligns with the findings of Boretti (2023), who, after analyzing 160 years of data in Brisbane, in proximity to sub-basins 6 and 7, discovered no significant trends in rainfall, indicating a relatively stable rainfall pattern for the city. At the same time, the overall decrease in design rainfalls, as indicated by GCM data for the sub-basins located in the center and northeast of the study area, aligns with the conclusions of other researchers who observed an overall reduction in average rainfall in this region under climate change scenarios (e.g., Webb and Hennessy, 2015, and Ramezani et al., 2023).

### 3.3. GCM-derived design rainfalls per future timeframe

**Timeframe 2016–2045:** Under RCP 4.5 and 1% AEP, on average, the overall rainfall depth is expected to decrease at 18% for the whole study area. Ten of the 12 sub-basins (sub-basins 1, 2, 3, 4, 5, 6, 9, 10, 11 and 12) presented a decrease in rainfall depth compared to the baseline period for all rainfall durations. Sub-basin 7 results yielded an increase in the rainfall depth for all the durations of rainfall, and sub-basin 8 presented an increase just in the 2-day and 3-day rainfall. Under RCP 8.5 and 1% AEP, results showed similar trend as RCP 4.5, though with less intensity. At this scenario, 11 of the 12 sub-basins (sub-basins 1, 2, 3, 4, 5, 6, 8, 9, 10, 11 and 12) presented a decrease in rainfall depth compared to the baseline period, and the overall rainfall depth is expected to decrease at 19% for the entire study area.

**Timeframe 2036–2065:** Under RCP 4.5 and 1% AEP, three of the 12 sub-basins (sub-basins 1, 6 and 8) did not present a decrease in rainfall depth compared to the baseline period, considering all the durations of rainfall. Sub-basin 1 is projecting an increase in the 7-day rainfall; sub-basin 6 is pointing to an increase in the 1-day, 2-day, 3-day, 4-day and 7-day rainfalls; and sub-basin 8 is pointing to an increase in the 2-day rainfall. On average, considering all sub-basins and durations, a decrease of 13% in the rainfall depth is likely to happen. Considering the RCP 8.5 scenario and 1% AEP, nine of the 12 sub-basins (sub-basins 1, 2, 3, 4, 5, 9, 10, 11 and 12) are expected to have their rainfall depths reduced in the future. Sub-basin 6 is likely to intensify its 2-day and 3-day rainfalls; sub-basin 7 is showing

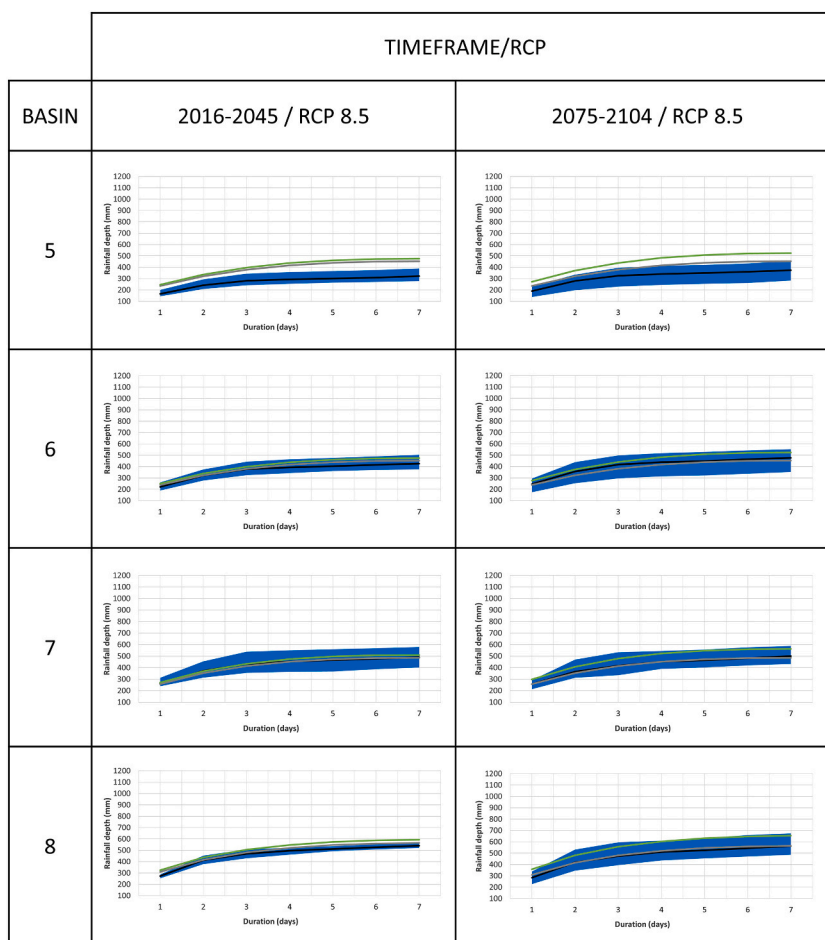


Fig. 4. (continued).

an intensification of its 1-day, 2-day, 3-day, 4-day, 6-day and 7-day rainfalls, and sub-basin 8 is susceptible to intensify just its 2-day rainfall. In the RCP 8.5 scenario, and considering all sub-basins and durations, the rainfall depths are expected to decrease by 16% as compared to the baseline.

**Timeframe 2056–2085:** Under RCP 4.5 scenario and 1% AEP, the results showed that, for 11 of the 12 sub-basins (sub-basins 1, 2, 3, 4, 5, 6, 8, 9, 10, 11 and 12), rainfall depths are expected to decrease for all the studied durations. Only sub-basin 7 is showing an increase in the rainfall depth for the 2-day, 3-day and 7-day rainfalls. On average, a rainfall depth decrease of approximately 18% is expected for the entire study area and all durations. Compared to the RCP 4.5 scenario, the RCP 8.5 scenario is pointing to a smaller decrease in the future rainfall depth. In this scenario, and for 1% AEP, nine (sub-basins 1, 2, 3, 4, 5, 9, 10, 11 and 12) of the 12 sub-basins are showing a decrease in the rainfall depth. Sub-basin 6 is projecting an increase in the 2-day and 3-day rainfalls; sub-basin 7 is pointing to an increase in the rainfall depth for all rainfall durations; and sub-basin 8 is projecting an increase in the 2-day, 3-day and 7-day rainfalls. The expected rainfall depth decrease in this scenario is about 16%, which is slightly higher than the decrease found in the RCP 4.5 scenario.

**Timeframe 2075–2104:** Under RCP 4.5 scenario and 1% AEP, rainfall depth projections for all the 12 sub-basins and all durations, are pointing to an average decrease of 18%. Under RCP 8.5 scenario, for seven of the 12 sub-basins (sub-basin 3, 4, 5, 9, 10, 11, 12) are pointing to a decrease in the rainfall depth for all rainfall durations. Sub-basin 1 is projecting an increase in the 2-day, 3-day, 6-day and 7-day rainfalls, sub-basin 2 is pointing to an increase in the 7-day rainfall, sub-basin 6 is pointing to an increase in all the rainfall depth durations, sub-basin 7 is projecting an increase in the 2-day, 3-day, 4-day and 7-day rainfalls, and sub-basin 8 is pointing to an increase just in the 2-day rainfall. The average decrease of rainfall depth, considering all the durations, is expected to be 11% for the entire study area.

### 3.4. AR&R-derived design rainfalls

Table 5 shows the anticipated percentage changes in design rainfalls for durations spanning 1 to 7 days and AEPs of 10%, 5%, 2%, and 1%, following the methodology outlined in the AR&R guidelines (detailed in section 2.4). Concurrently, Table 6 presents the

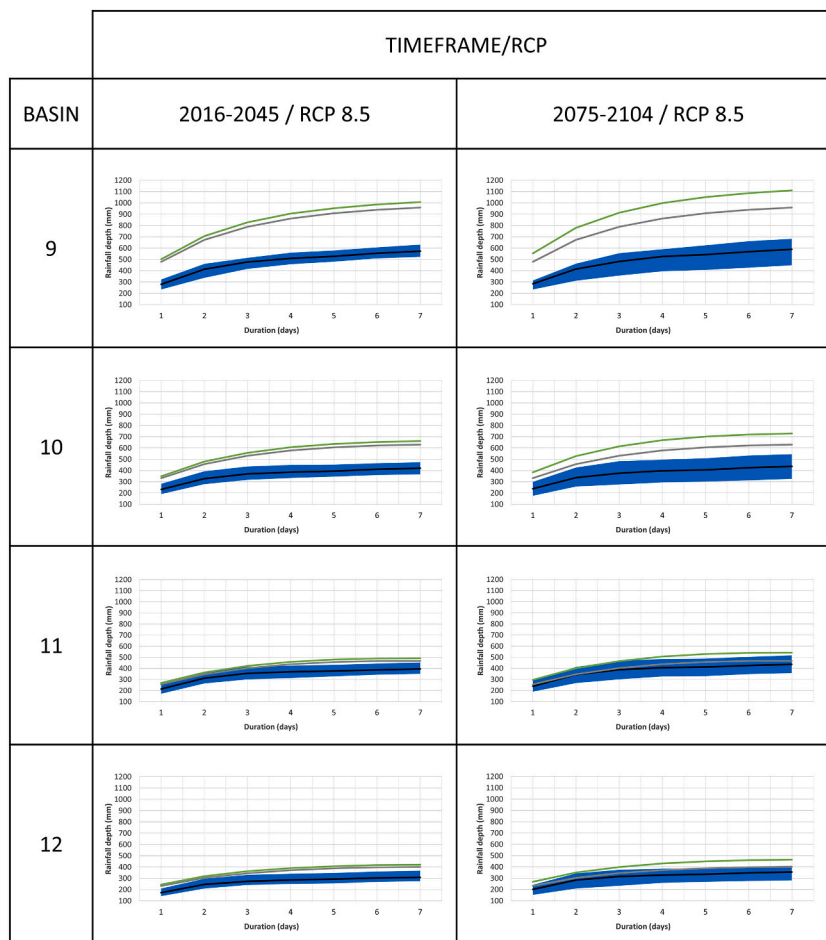


Fig. 4. (continued).

expected percentage changes in the same design rainfalls but under scenario RCP 8.5. These values, representing an area-weighted average for the entire Wivenhoe Dam basin, were initially computed for a grid size of  $0.025^\circ$  (approximately  $2.7 \text{ km} \times 2.7 \text{ km}$ ) as described in section 2.4.

Fig. 4 depicts DDF curves for the 1% AEP design rainfalls, covering baseline, GCM-derived, and AR&R-derived scenarios, delineated by sub-basin, RCP, and for the short-term (2016–2045) and long-term (2075–2104) timeframes analyzed in this study. Results for intermediate timeframes exhibit intermediary outcomes between these two extremes. In summary, the AR&R method, which updates design rainfalls based on temperature change, yields higher rainfall values compared to those obtained from GCM precipitation data. Furthermore, the AR&R method surpasses baseline design rainfall values, indicating a significant impact of temperature changes on design rainfall estimations. Therefore, it can be concluded that the use of design rainfalls derived from the AR&R method may lead to overdesign of infrastructure, potentially resulting in severe consequences. These consequences include higher upfront costs, operational inefficiency, material waste, ecological disruption, higher energy costs, increased ongoing expenses, community displacement, among other potential impacts.

#### 4. Conclusions

The following main conclusions were achieved with this study:

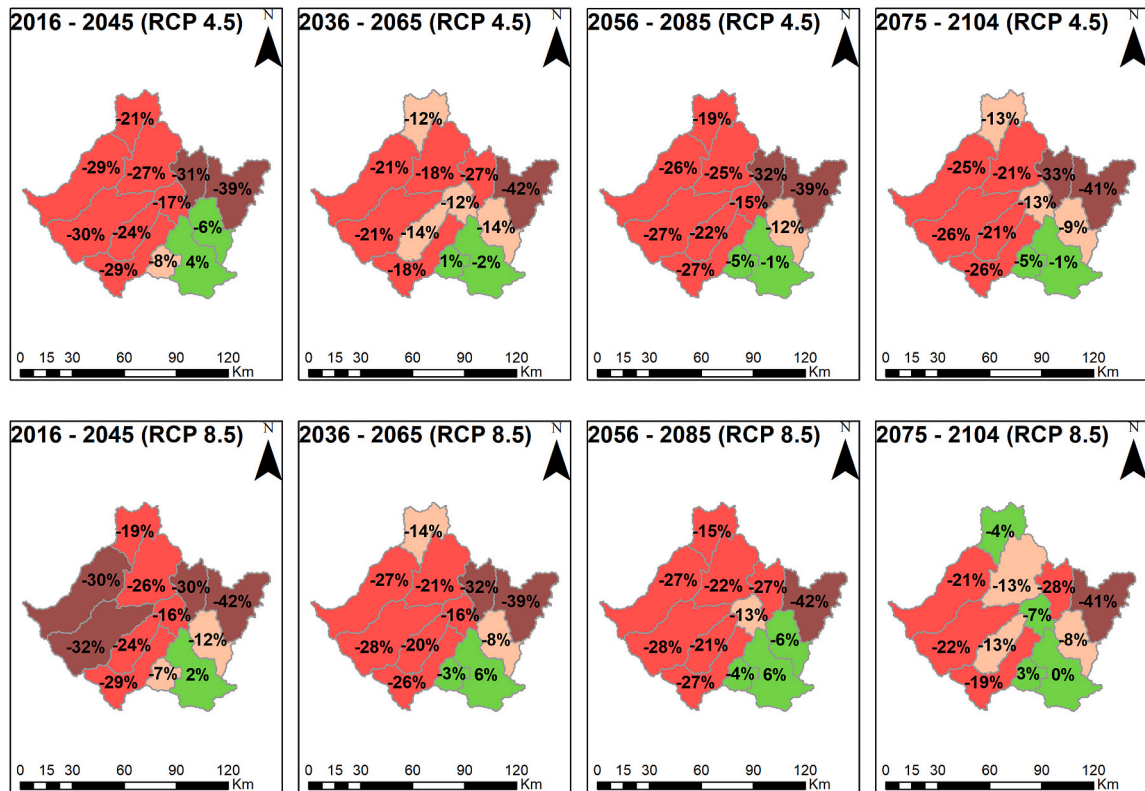
- Regardless of the chosen timeframe or RCP scenario, future climate DDF curves indicate a decrease in the 1-day, 2-day, 3-day, 4-day, 5-day, 6-day and 7-day rainfall depths (1% AEP) in the Wivenhoe Dam basin.
- The short-term timeframe (2016–2045) is the one that presents the highest decreases in 1-day, 2-day, 3-day, 4-day, 5-day, 6-day and 7-day rainfall depths (1% AEP) of all studied timeframes.
- The area-weighted average rainfall depth for the entire Wivenhoe Dam basin does not decrease as a linear function of the timeframes. For instance, the short-term timeframe (2016–2045) and the second middle-term timeframe (2056–2085) are showing less intense rainfalls, when compared to the first middle-term timeframe (2036–2065) and the long-term timeframe (2075–2104).

**Table 3**  
Percentage changes in GCM-derived design rainfalls in comparison with baseline design rainfalls - RCP 4.5.

|          | Timeframe | 2016–2045 |         |         |         | 2036–2065 |         |         |         | 2056–2085 |         |         |         | 2075–2104 |         |         |         |
|----------|-----------|-----------|---------|---------|---------|-----------|---------|---------|---------|-----------|---------|---------|---------|-----------|---------|---------|---------|
|          | AEP       | 10%       | 5%      | 2%      | 1%      | 10%       | 5%      | 2%      | 1%      | 10%       | 5%      | 2%      | 1%      | 10%       | 5%      | 2%      | 1%      |
| Duration | 1 day     | −18.64%   | −19.09% | −20.22% | −21.40% | −14.46%   | −14.65% | −15.56% | −16.66% | −17.94%   | −18.47% | −19.68% | −20.90% | −16.87%   | −17.31% | −18.44% | −19.63% |
|          | 2 days    | −9.95%    | −11.02% | −13.26% | −15.22% | −5.08%    | −5.79%  | −7.77%  | −9.61%  | −9.85%    | −11.00% | −13.31% | −15.28% | −9.07%    | −10.12% | −12.34% | −14.28% |
|          | 3 days    | −9.44%    | −11.02% | −13.73% | −16.04% | −5.35%    | −6.61%  | −9.07%  | −11.28% | −9.84%    | −11.51% | −14.26% | −16.58% | −9.73%    | −11.34% | −14.04% | −16.32% |
|          | 4 days    | −10.98%   | −13.25% | −16.57% | −19.19% | −6.69%    | −8.62%  | −11.68% | −14.20% | −11.07%   | −13.34% | −16.64% | −19.25% | −11.07%   | −13.28% | −16.52% | −19.08% |
|          | 5 days    | −11.50%   | −14.00% | −17.47% | −20.30% | −7.42%    | −9.57%  | −12.77% | −15.50% | −11.26%   | −13.72% | −17.14% | −19.93% | −11.45%   | −13.85% | −17.20% | −19.96% |
|          | 6 days    | −9.93%    | −12.58% | −16.19% | −19.07% | −5.97%    | −8.24%  | −11.56% | −14.32% | −9.24%    | −11.77% | −15.27% | −18.10% | −9.72%    | −12.23% | −15.70% | −18.50% |
|          | 7 days    | −7.85%    | −10.51% | −14.19% | −17.15% | −3.71%    | −5.96%  | −9.33%  | −12.16% | −7.20%    | −9.72%  | −13.28% | −16.17% | −7.60%    | −10.06% | −13.56% | −16.40% |

**Table 4**  
Percentage changes in GCM-derived design rainfalls in comparison with baseline design rainfalls - RCP 8.5.

|          | Timeframe | 2016–2045 |         |         |         | 2036–2065 |         |         |         | 2056–2085 |         |         |         | 2075–2104 |         |         |         |
|----------|-----------|-----------|---------|---------|---------|-----------|---------|---------|---------|-----------|---------|---------|---------|-----------|---------|---------|---------|
|          | AEP       | 10%       | 5%      | 2%      | 1%      | 10%       | 5%      | 2%      | 1%      | 10%       | 5%      | 2%      | 1%      | 10%       | 5%      | 2%      | 1%      |
| Duration | 1 day     | −19.46%   | −19.83% | −20.88% | −22.02% | −16.61%   | −16.85% | −17.81% | −18.92% | −16.93%   | −17.00% | −17.80% | −18.82% | −11.46%   | −11.94% | −13.15% | −14.42% |
|          | 2 days    | −10.43%   | −11.32% | −13.38% | −15.24% | −8.31%    | −9.14%  | −11.19% | −13.05% | −8.43%    | −9.06%  | −10.93% | −12.70% | −1.74%    | −2.77%  | −5.07%  | −7.11%  |
|          | 3 days    | −10.25%   | −11.65% | −14.18% | −16.39% | −8.49%    | −9.85%  | −12.37% | −14.59% | −8.63%    | −9.82%  | −12.19% | −14.34% | −1.94%    | −3.54%  | −6.35%  | −8.76%  |
|          | 4 days    | −11.69%   | −13.73% | −16.84% | −19.35% | −9.76%    | −11.76% | −14.87% | −17.38% | −10.03%   | −11.89% | −14.86% | −17.32% | −2.82%    | −5.06%  | −8.45%  | −11.17% |
|          | 5 days    | −12.31%   | −14.61% | −17.89% | −20.61% | −10.33%   | −12.55% | −15.78% | −18.50% | −10.74%   | −12.83% | −15.95% | −18.62% | −3.83%    | −6.32%  | −9.85%  | −12.79% |
|          | 6 days    | −10.93%   | −13.38% | −16.79% | −19.56% | −8.80%    | −11.14% | −14.49% | −17.26% | −9.44%    | −11.66% | −14.90% | −17.60% | −2.27%    | −4.83%  | −8.44%  | −11.41% |
|          | 7 days    | −9.11%    | −11.57% | −15.05% | −17.88% | −6.53%    | −8.85%  | −12.24% | −15.06% | −7.39%    | −9.60%  | −12.90% | −15.67% | −0.03%    | −2.58%  | −6.26%  | −9.28%  |



**Fig. 5.** Average percent change expected to occur in the studied area for the 1-day rainfall (1% AEP), considering the four timeframes 2016–2045, 2036–2065, 2056–2085, 2075–2104 and the two RCP scenarios (4.5 and 8.5). Light green colors represent sub-basins where the average rainfall will change from 7% to –7% (small change). Orange colors represent sub-basins where the average rainfall will change from –7% to –15% (moderate change). Red colors represent sub-basins where the average rainfall will change between –15% and –30% (large change). Brown colors represent sub-basins where the average rainfall will change by more than –30% (extremely large change). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

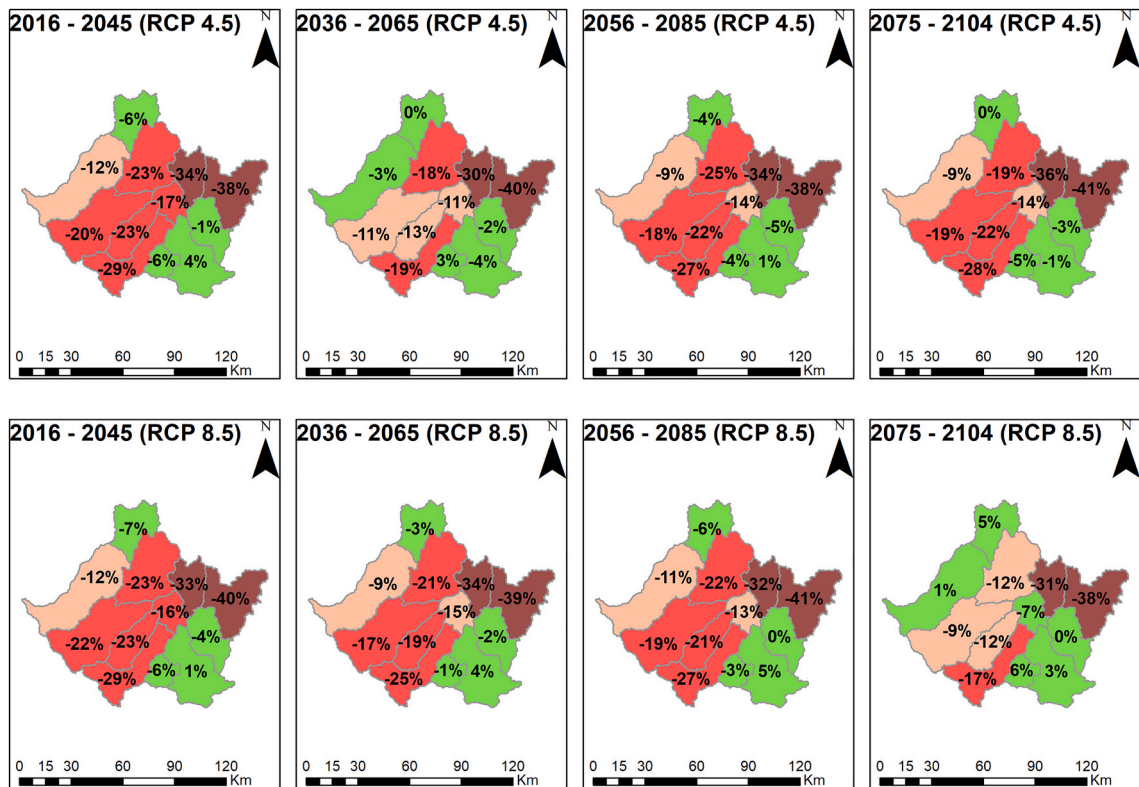
- Compared to the RCP 8.5 scenario, the RCP 4.5 scenario is indicating a higher reduction in the 1-day, 2-day, 3-day, 4-day, 5-day, 6-day and 7-day rainfall depths (1% AEP) compared to the baseline period.
- Particularly in sub-basin 7 (in the south of the studied area, where the Wivenhoe Dam is located, and near the city of Brisbane), the 1-day, 2-day, 3-day, 4-day, 5-day, 6-day and 7-day rainfall depths (1% AEP) are not susceptible to considerable changes. On the other hand, the upstream sub-basins are indicating significant decreases in depth for those same rainfall durations.
- Considering the effects of rainfall change on runoff, the average inflow into the Somerset Dam sub-basins (sub-basins 8, 9 and 10) is expected to have a strong decrease, especially in sub-basin 9, in future timeframes; this may lead to significant reductions in reservoir storage, and inflow to Wivenhoe Dam.
- The AR&R method yields rainfall depths that would probably lead to overdesign hydraulic infrastructure as compared to GCM-derived method proposed in this study. As such, practitioners should consider using GCMs rainfall projections for a more accurate and robust analysis of future design rainfalls.

## 5. Final considerations

Given the inherent variability of the climate system and the uncertainty associated with climate predictions, it is advisable to assess climate change impacts on design rainfalls by employing various timeframes and scenarios, and utilizing a combination of multiple GCMs, as proposed in this study. This approach is recommended as it enhances the likelihood of generating robust and reliable results.

The versatility of this framework extends its applicability beyond the Brisbane River Basin, making it valuable for other global regions where reliable GCM data is accessible. Additionally, it provides a means to evaluate the current simplified methods recommended by government bodies for updating design rainfalls to accommodate climate change, typically relying on temperature change. These simplistic approaches, lacking scientific rigor, may result in infrastructure being under or over-designed, thereby carrying severe social, economic, and environmental consequences.

It is important to emphasize that the prevailing choice among hydrologists has been to embrace the multi-model, multi-scenario approach to examine the impacts of climate change on hydrological variables. Design rainfall, being a pivotal input in engineering design, should not be treated differently in this regard. While simpler methods based on scaling factors may seem reasonable,



**Fig. 6.** Average percent change expected to occur in the studied sub-basin for the 7-day rainfall (1% AEP), considering the four timeframes 2016–2045, 2036–2065, 2056–2085, 2075–2104 and the two RCP scenarios (4.5 and 8.5). Light green colors represent sub-basins where the average rainfall will change from 7% to –7% (small change). Orange colors represent sub-basins where the average rainfall will change from –7% to –15% (moderate change). Red colors represent sub-basins where the average rainfall will change between –15% and –30% (large change). Brown colors represent sub-basins where the average rainfall will change by more than –30% (extremely large change). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

advancements in computational resources and the ease of automation now make it feasible to apply techniques involving large datasets, such as the one presented here, with nearly the same level of effort as the simplified approaches. Therefore, we strongly advocate for the adoption of this method, as it can offer more robust insights into future scenarios.

Specifically for the Wivenhoe Dam basin, as detailed in this study, the developed insights into future design rainfalls and their spatial distribution within the Basin will facilitate more accurate predictions of runoff and inflows into the two reservoirs. Consequently, the findings promise to contribute significantly to enhanced reservoir management, operations, and flood control measures in South-East Queensland.

## 6. Limitations and recommendations for future research

The current study was undertaken considering GCMs and climate scenarios from the fifth phase of the coupled model intercomparison project (CMIP5). The rationale for opting for CMIP5 over the more recent CMIP6 is supported by the following justifications: i) CMIP5 scenarios have been widely used in climate research and policy discussions, making them a well-established reference for comparing and interpreting climate model results; ii) Because of its earlier release, CMIP5 data has been pre-processed and provided as “application-ready” data by the Australian [CSIRO and Bureau of Meteorology \(2015\)](#). These datasets, derived from CMIP5 models that underwent evaluations for accurately representing local historical climates, have been downscaled with a subset of top-performing models selected for immediate impact assessment applications; iii) While CMIP6 research is limited to specific regions globally (e. g., [Crévolin et al., 2023](#), in Canada), there are indications that multi-model data for CMIP6 scenarios SSP5–85 and SSP2–45 closely align with design rainfalls generated for CMIP5 scenarios RCP8.5 and RCP4.5, respectively; iv) Notably, in Australia, CMIP6 models have shown only incremental improvement compared to CMIP5 models (e.g. [Große et al., 2020](#); [Deng et al., 2021](#)), suggesting the practical indifference in choosing between the two scenarios within this geographical context.

Nevertheless, it is acknowledged that CMIP6 represents advancements, featuring more sophisticated models and refined scenarios and simulations. As more CMIP6 data becomes available and additional research is conducted, updating studies with CMIP6 data is crucial for a comprehensive comparison. However, within the Australian context, the indication from existing CMIP6 studies of minimal model improvement and the close alignment of scenarios SSP5–85 and SSP2–45 with RCP8.5 and RCP4.5, respectively, allows

**Table 5**  
Percentage changes in AR&R design rainfalls in comparison with baseline - RCP 4.5.

|          | Timeframe | 2016–2045 |       |       |       | 2036–2065 |       |       |       | 2056–2085 |        |        |        | 2075–2104 |        |        |        |
|----------|-----------|-----------|-------|-------|-------|-----------|-------|-------|-------|-----------|--------|--------|--------|-----------|--------|--------|--------|
|          | AEP       | 10%       | 5%    | 2%    | 1%    | 10%       | 5%    | 2%    | 1%    | 10%       | 5%     | 2%     | 1%     | 10%       | 5%     | 2%     | 1%     |
| Duration | 1 day     | 5.00%     | 5.00% | 5.00% | 5.00% | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% |
|          | 2 days    | 5.00%     | 5.00% | 5.00% | 5.00% | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% |
|          | 3 days    | 5.00%     | 5.00% | 5.00% | 5.00% | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% |
|          | 4 days    | 5.00%     | 5.00% | 5.00% | 5.00% | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% |
|          | 5 days    | 5.00%     | 5.00% | 5.00% | 5.00% | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% |
|          | 6 days    | 5.00%     | 5.00% | 5.00% | 5.00% | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% |
|          | 7 days    | 5.00%     | 5.00% | 5.00% | 5.00% | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% |

**Table 6**  
Percentage changes in AR&R design rainfalls in comparison with baseline - RCP 8.5.

| Timeframe |        | 2016–2045 |       |       |       | 2036–2065 |        |        |        | 2056–2085 |        |        |        | 2075–2104 |        |        |        |
|-----------|--------|-----------|-------|-------|-------|-----------|--------|--------|--------|-----------|--------|--------|--------|-----------|--------|--------|--------|
|           |        | AEP       | 10%   | 5%    | 2%    | 1%        | 10%    | 5%     | 2%     | 1%        | 10%    | 5%     | 2%     | 1%        | 10%    | 5%     | 2%     |
| Duration  | 1 day  | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% | 15.76%    | 15.76% | 15.76% | 15.76% |
|           | 2 days | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% | 15.76%    | 15.76% | 15.76% | 15.76% |
|           | 3 days | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% | 15.76%    | 15.76% | 15.76% | 15.76% |
|           | 4 days | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% | 15.76%    | 15.76% | 15.76% | 15.76% |
|           | 5 days | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% | 15.76%    | 15.76% | 15.76% | 15.76% |
|           | 6 days | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% | 15.76%    | 15.76% | 15.76% | 15.76% |
|           | 7 days | 5.00%     | 5.00% | 5.00% | 5.00% | 11.60%    | 11.60% | 11.60% | 11.60% | 11.60%    | 11.60% | 11.60% | 11.60% | 15.76%    | 15.76% | 15.76% | 15.76% |

us to affirm the validity of the findings presented in this study.

### CRedit authorship contribution statement

**Marcos Abilio Medeiros de Saboia:** Writing – original draft, Data curation, Investigation, Methodology, Writing – review & editing. **Fernanda Helfer:** Writing – review & editing, Conceptualization, Supervision.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

The baseline rainfall data was extracted from the BOM website, while the GCM rainfall projections were provided by the CSIRO.

### Acknowledgments

We acknowledge the World Climate Research Programme's Working Group on Coupled Modeling, which is responsible for CMIP, and we thank the climate modeling groups (listed in Table 1 of this paper) for producing and making available their model output. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

Author Marcos Abilio Medeiros de Saboia gratefully acknowledges the financial support provided by the Government of Ceará State, Brazil.

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## Further-reading

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