ICFM 10
Adapting to Global Change:
Innovative Approaches to Flood Management and Resilience
May 20-22, 2026 | Western University, London, Ontario, Canada

Determining climate change impacts across Australia

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ABSTRACT

In 2024 an update to Australia's national guidance on climate change and flooding was released to include the latest temperature projections from IPCC 6 and the latest research on how warming will affect flood producing rainfall and runoff generation. This update supersedes interim advice from 2015 that was included in 2016 version of Australian rainfall and runoff. In 2015 climate change was seen as a future problem with climate change results generally being treated as a sensitivity assessment and not being actively factored in planning levels and decision making. The new update dramatically increases impact of climate change and shows that the warming since 1990 has already significantly increased flood levels.

This has created an immediate need to factor climate change into current and future planning decisions. The implications of new guidance was not explored prior to its release. This paper outlines extensive testing that was carried out on the Eastern Australian states. The recommended guidelines were tested on 500 New South Wales, Queensland, and Victorian catchments representing rural and urban catchments. For each available catchment the rating curve was used to determine the impact level as well as flow. This allowed the impact of climate change on flood planning level to be assessed. A Climate Change Calculator has been developed which allows practitioners to easily understand how climate risk will change over time over the design life of a structure or with emissions pathway. The calculator allows users to upload design event flood level grids and interpolate design event grids factored by climate change reducing the need for model runs and allowing floodplain managers to effectively determine changes in flood risk. The development of this tool and demonstration of its application using a case study in Singleton NSW is presented.

KEYWORDS: flood, climate change, Australia, impacts, design floods, ARR, flood planning level

1 INTRODUCTION

Australian Rainfall and Runoff (ARR), the national design flood guideline in Australia (Ball et al, 2019) introduced Interim Climate Change rainfall adjustment factors based in temperature scaling of 5% per degree of warming for three representative concentration pathways (RCP). Results were available for RCP4.5, RCP6 and RCP8.5 but the RCP6 results were qualified due to the limited number of model results. Different Australian climate zones were used with different climate change temperature increases. Using the ARR 2019 rainfall adjustments, the estimated increases for year 2090 ranged from 7.2% - 10.8% for RCP4.5 and for 15.4% - 22.8% for RCP8.5. These results were based on the 5th IPCC (2013). While it was acknowledged climate change would also affect rainfall temporal patterns, antecedent conditions and baseflow regimes, no adjustment was proposed for these design inputs.

With the release of IPCC synthesis report (2023) the climate guidance within ARR (2024) was updated based on a climate science review (Wasko et al. 2023). The scaling of rainfall was based on a higher increase in temperature due to climate change and higher scaling factors (8% for 24 hours and 15% for 1-hour storms). The resultant rainfall increases are dramatically higher compared to the guideline they are replacing and are constant across the country. Loss adjustments, which vary by region, were also provided.

This paper explores how the update to Australia’s national climate change guidance for design flood estimation changes the frequency of flood producing rainfall. Using 343 test catchments and a series of tools developed to specifically aid the understanding of the impact of climate change on flooding this paper shows how the impacts of climate change can be assessed. These tools also allow floodplain managers to rapidly assess the impact of climate change, interpolate flood levels and determine vulnerable areas. More importantly, they allow floodplain managers to adjust policy and direct resources prior to undertaking detailed modelled.

2 DATA

2.1 Test catchments

A total of 343 catchments along the east coast of Australia were considered suitable for the study (WMAwater, 2019; Babister and Babister 2022, WMAwater 2021). A subset of 155 with high quality rating curve information and a long term at site record (WMAwater (2019)) were used for detailed assessment. Figure 1 shows the location of catchments included in the study, the catchment area to the gauge (yellow areas) and the distribution of catchment areas (right). The catchments ranged in size from 2 to 16000 km², with the majority falling between 50 and 500 km². Synthetic urban catchments were developed at 10 major cities with catchment areas 1, 5 and 10km^2 and varying levels of imperviousness. These additional urban catchments allow the impact of climate change in each major urban centre to be assessed. The locations of the urban catchments are show as red dots

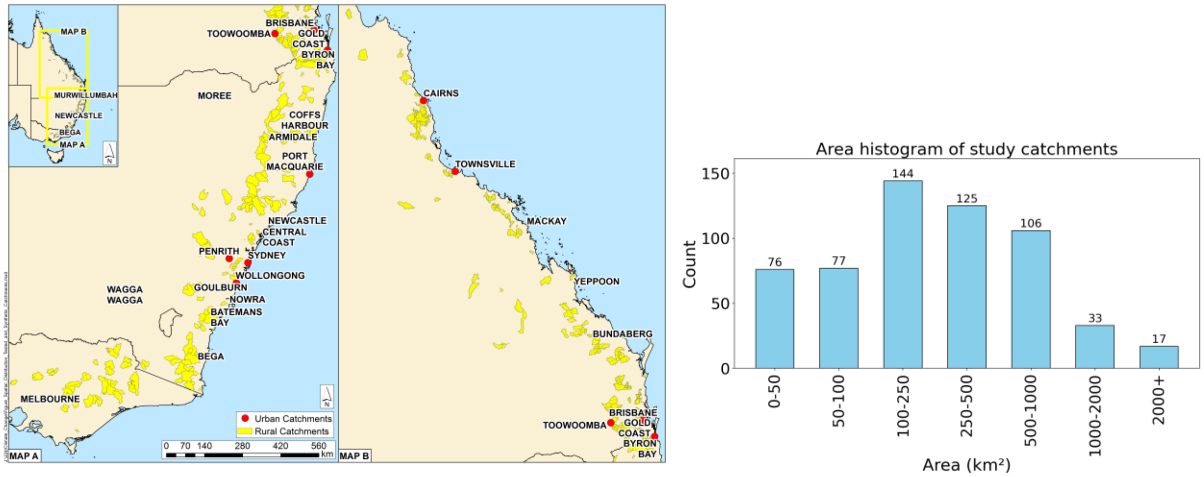


Figure 1: The location of study catchments (left) and histogram of study area (right)

2.2 Case Study- Singleton

Singleton was chosen as a case study due its population at risk due to a changing climate. Singleton is a town located on the Hunter River in New South Wales Australia. The population of the town is 17,500. Design flood level information (BMT WBM, 2023) in the form of an ascii grid for a range of Annual Exceedance Probability (AEP) shows that in a 1% AEP 2970 buildings are flooded.

3 METHODOLOGY

3.1 Impacts of climate change guidelines on flood planning levels

A hydrologic model was developed of each catchment (Section 2.1) using Watershed Bounded Network Model (WBNM). This is a widely used rainfall runoff model in Australia. The design inputs

(IFD, spatial and temporal patterns, losses) were applied as per ARR guidelines. The hydrologic models were run for the historic baseline conditions (1960-1990 baseline IFD, 2016 IFD (Bureau of Meteorology, 2016)) for durations from 1 Hour to 72 Hours and all ensemble temporal patterns. The standard design flood estimation process was used to produce historic baseline conditions flows. The same process was conducted for the climate change scenarios with the rainfall increases and loss adjustments made as per the ARR Climate change chapter. The critical duration was assumed not to change with climate change. For each scenario the peak flow for the climate change scenario was compared to the peak flow for the historic climate and the ratio of peak flow in climate scenario to historic peak flow calculated. For 155 catchments in New South Wales reliable rating curves were available that went past the 1% AEP level. For each scenario the peak flow was converted to a level using a rating curve. The change in level for the climate change scenario compared to the historic climate was then calculated.

3.2 Climate change calculator

Detailed hydrologic and hydraulic modelling of the catchment in order to estimate the shift in flood probability due to climate change provides a more robust estimate of the likely change.. Hydrologic and hydraulic modelling involves scaling of the rainfall, sampling other design inputs, identifying critical duration (through ensemble modelling). This amount of investment required for detailed modelling would preclude any routine estimation and would limit development of a tool that can quickly estimate the shift in flood probability due to climate change for any location in the country.

This limitation could be overcome by assuming that:

- a good approximation of critical duration can be estimated using the catchment area and 24 hr 1% AEP IFD (Babister et al, 2024a); and,
- using two design rainfall events with similar rainfall excess pattern and depth would result in the same peak flow.

That means a design rainfall with climate change scaling applied (to IFD, pre-burst, and losses), would produce the same flow as a historical climate design event with the same excess rainfall (Retallick et al, 2024b).

Using these assumptions the Climate Change Calculator was developed to estimate shifts in flood probability at any location in Australia using the available standard design rainfall inputs, and available at: ccc.wmawater.com.au. The Calculator is described in Babister et al (2024b), Babister et al (2024a), and Retallick et al (2024b). The tool can provide insights on how risk exposure over the life of the project changes. Knowing that exposure might change over time can potentially lead to more informed decision making. Current practice seems to relegate climate change assessment to sensitivity assessment that is often not factored into decision making (Retallick et al, 2024b). With climate change a present problem, this needs to change. The focus has often been too much on modelling and mapping a full range of design events under climate change and not enough on considering the current and future risk into decision making.

The climate change calculator includes a hydraulic interpolation function. Using ground elevation d from a hydraulic model, an upper water level grid and a lower water level grid with known AEPs, the user can choose a particular design event AEP between the upper and lower grid and estimate the flood extent using the hydraulic interpolator. During the interpolation, the lower design event grid is stretched, using the model terrain grid to match the extent of the upper grid. An interpolation is then applied to create the climate change design event grid within the stretched extent. The interpolated water levels lower than ground elevation grid levels are removed.

The method has been verified against calibrated hydraulic model design event results for a number of catchments using a leave one out analysis. For example, the 1% AEP design flood extent was interpolated (using the 5% AEP and 1 in 200 AEP) and compared to the existing flood extent. This analysis was conducted for all available AEPs (except for the rarest and most frequent AEP). Comparing the interpolated extents to the existing design flood extents provided an indication of interpolation accuracy. The method was found to be suitable for purpose.

3.3 Comparison of the climate change calculator with traditional rainfall runoff modelling

In order to ensure the robustness of the assumptions of the climate change calculator, outputs were compared to the AEP shifts calculated by traditional rainfall runoff modelling. Traditional rainfall runoff modelling was undertaken for the rural test catchments described in Section 3.1 using WBNM. Design inputs, such as temporal patterns, areal reduction factors, and losses were downloaded from the ARR data hub. Design rainfalls were sourced from the Bureau of Meteorology. The climate change rainfall and loss factors from ARR V4.2 (Ball et al, 2019) were also applied. The AEP of the historical 1% AEP in the future was calculated for each climate change scenario. The historical 1 in X AEP event equivalent to the future 1% AEP event was also calculated.

4 RESULTS AND DISCUSSION

4.1 Impacts of climate change guidelines on flood planning levels

An assessment of the ratio of the flow for the historic climate and selected future climate change scenario found that design flows increased across all rural catchments with climate change. The ratio of climate change peak flows to historical flows did not vary significantly with catchment size, peak flow or catchment location (Figure 2). A small increase in flow ratio occurred in smaller catchments compared to large catchments, likely due to the higher climate change factors for smaller catchments. The average flow ratio for SSP3 2050 was 1.21. An increase in the 1% AEP flood level due to climate change can be used as a surrogate for the likely changes in flood planning levels used by local governments due to climate change. Figure 3 shows the 1% AEP increases in flood level compared to the historic climate. The increase in level is largely linear with some catchments showing a slight upwards curvature. Therefore, it can be concluded that a reasonable estimate of smaller increases in climate change and in flood level can be obtained by simply ratioing the 4.1 degree SSP5-2090 case.

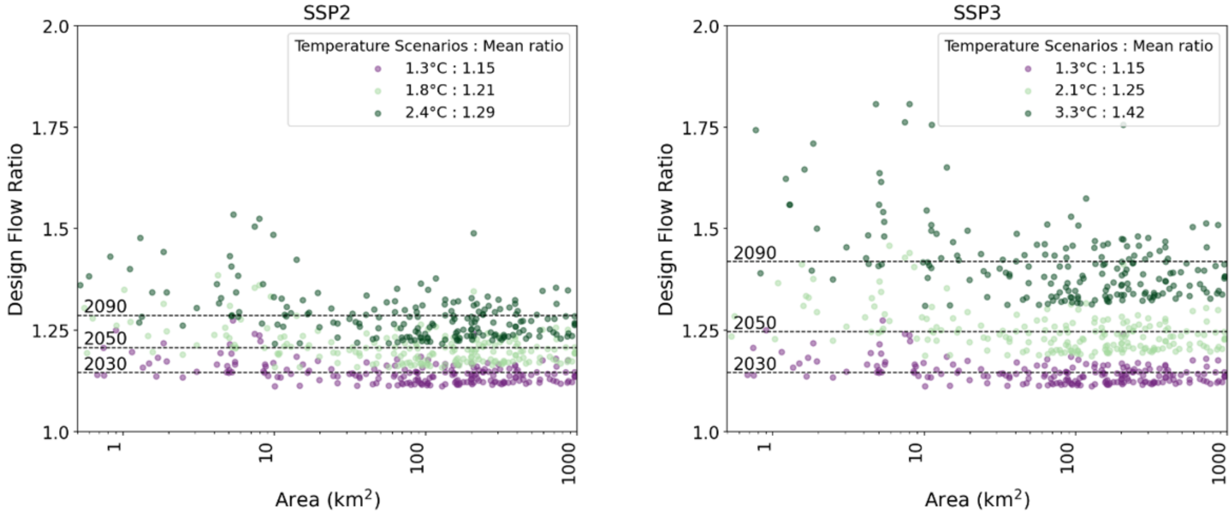


Figure 2: Outflow ratio for future climate scenarios sorted by SSP and catchment area. Mean ratio lines are added for the 2030, 2050 and 2090 time horizons.

4.2 Comparison of climate change calculator to traditional rainfall runoff modelling

Validation of the climate change calculator to traditional rainfall runoff method was undertaken for all test catchments. Figure 4 (left) shows the comparison of AEP estimates for the 1% AEP under various future climate scenarios for both methods for a catchment with an area of 325.6km^2. The calculator produces similar answers to the rainfall runoff method. Figure 4 (right) shows what historical 1 in X AEP event that a Future 1% AEP is equivalent to for the same catchment. The climate change calculator slightly underestimates the AEP of events for higher temperature increases.

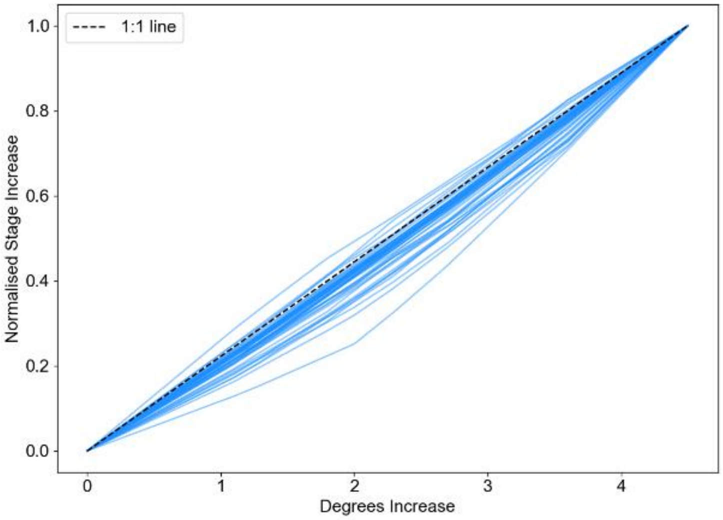


Figure 3: Normalised Increase in 1% AEP flood levels at NSW gauges with high quality rating curves

4.3 Case Study –Singleton

The application of the tool is demonstrated for the Hunter River catchment at Singleton. Figure 5 shows the input data and the processed catchment area . After locating the point, the catchment boundary is processed using the snap option (Figure 5). After submitting the query, a summary of the input, catchment map and several outputs are generated as follows.

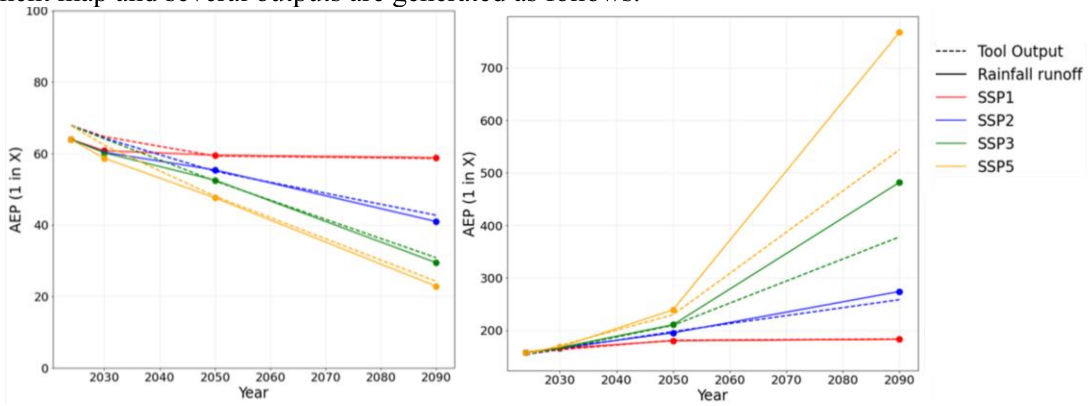
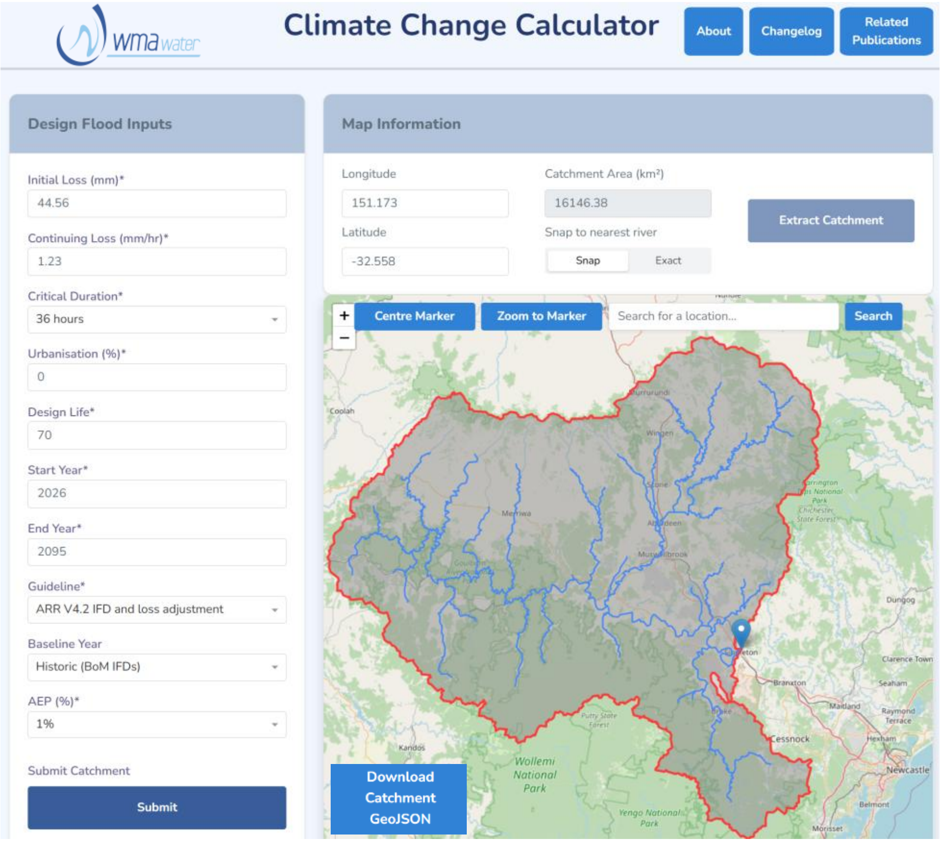


Figure 4: Comparison of annual exceedance probability (AEP) shifts between the climate change calculator (tool output) and traditional rainfall runoff method (left) and 1 in X AEP historical event that a future 1% AEP is equivalent to for various SSP scenarios (right)

Figure 6 shows outputs of the calculator relating to how the probability of a historical 1 in 100 AEP (BOM 2016 IFD) will be change with climate change in the future and vice versa. For example, for the Singleton, the catchment average 1 in 100 AEP rainfall will be equivalent to 1 in 65 AEP in 2025 (the current condition) under SSP1 scenario. Similarly, a 1 in 100 AEP in 2025 SSP1 scenario is equivalent to 1 in 140 AEP under historic climate. The "Mean over design exposure" is estimated by taking the geometric mean of the probability mass function over the design life (specified by the user). Other outputs include a graph of design rainfall under the different climate change scenarios and timeframes.



Design Flood Inputs

Initial Loss (mm)*: 44.56

Continuing Loss (mm/hr)*: 1.23

Critical Duration*: 36 hours

Urbanisation (%)*: 0

Design Life*: 70

Start Year*: 2026

End Year*: 2095

Guideline*: ARR V4.2 IFD and loss adjustment

Baseline Year: Historic (BoM IFDs)

AEP (%)*: 1%

Submit Catchment: Submit

Map Information

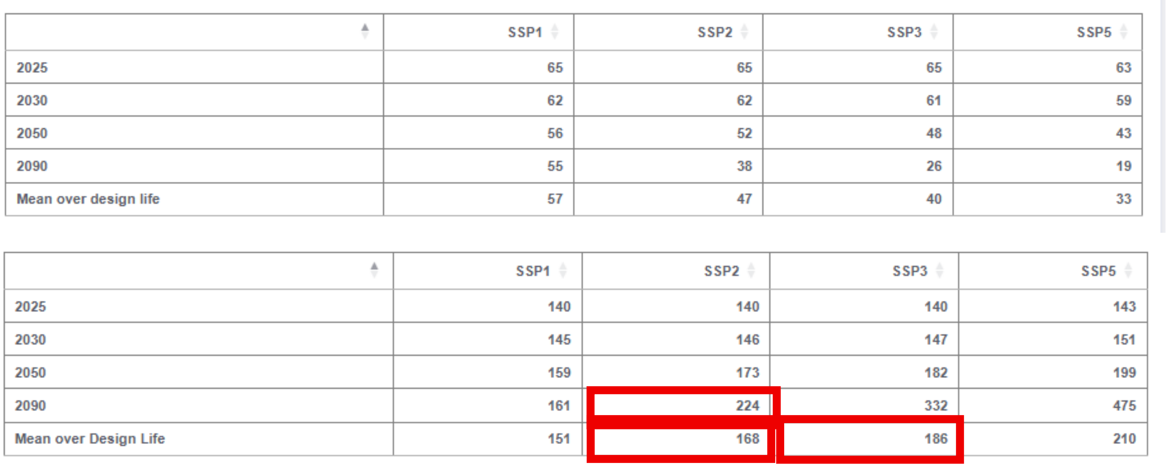
Longitude: 151.173

Latitude: -32.558

Catchment Area (km²): 16146.38

Snap to nearest river: Snap | Exact

Figure 5: Extraction details of catchment and advanced parameters preparing for submitting the query



	SSP1	SSP2	SSP3	SSP5
2025	65	65	65	63
2030	62	62	61	59
2050	56	52	48	43
2090	55	38	26	19
Mean over design life	57	47	40	33

	SSP1	SSP2	SSP3	SSP5
2025	140	140	140	143
2030	145	146	147	151
2050	159	173	182	199
2090	161	224	332	475
Mean over Design Life	151	168	186	210

Figure 6: Changes in historical 1% AEP probability due to climate change and proxy events for future 1% AEP

Figure 7 shows the probability of a 1% AEP design event occurring exactly X many times (where X is zero, one, two, …) over the exposure period under historical and climate change conditions. Each section indicates the probability of a certain number of occurrences. In the case of Singleton there is a decrease in the likelihood of no 1% AEP flooding with climate change over a 70-year period. The probability of having no 1% AEP floods (zero occurrence) drops from around 50% under the historic climate to about 28.98% in SSP1. The chance of multiple exceedances increases in future scenarios. The probability of one or more 1% AEP flood occurrence is 100% - 28.98% = 71.02 % under SSP1 shown by the lines on the secondary y axis.

The climate change calculator indicates that for Singleton under SSP2 scenario the 1 in 100 AEP design rainfall exceedance probability in year 2030 and 2050 is equivalent to 1 in 146 AEP and 1 in 173 AEP design rainfall based on historical series. Under SSP3 2050 the 1 in 100 AEP is equivalent to in 1 in 182 AEP. The flood study for the catchment includes the flood level grids for 1 in 100 and 1 in 200 AEP. Therefore, the climate change calculator was used to map SSP2 2030, 2050 and SSP3 2050 1 in 100 AEP flood level maps using the hydraulic interpolation. Figure 8 shows the change in flood extent for the SSP3 2050 as well as the 1 in 100 AEP flood extents used as an input in the hydraulic interpolation tool. The number of impacted buildings increases by 58% to 4708 in SSP2 2030, to 5212 in SSP 2 2050 and 5267 in SSP 3 2050.

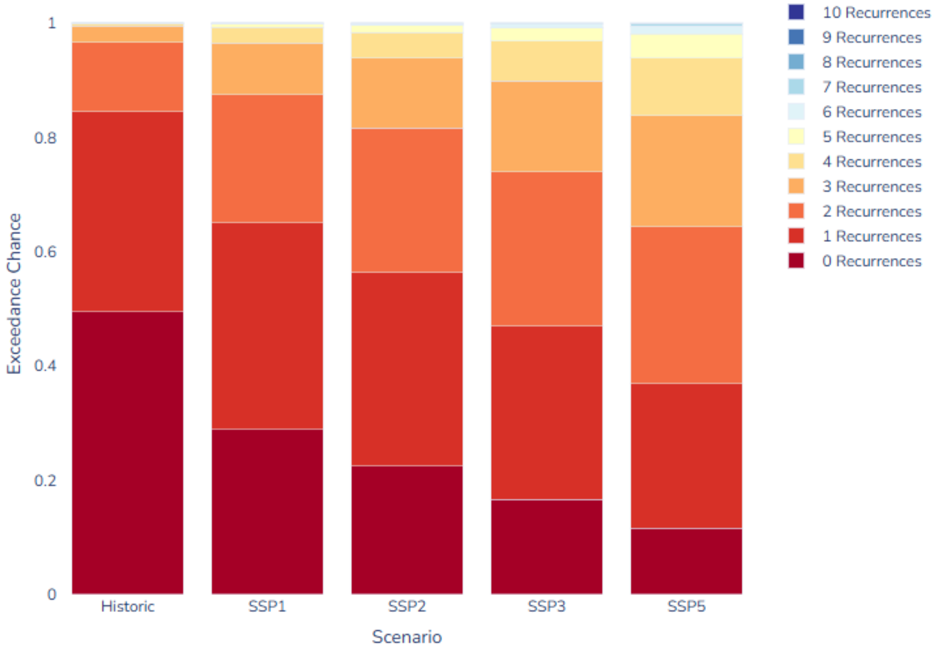


Figure 7: Expected exceedances over life time under various climate change scenarios compared to historical conditions

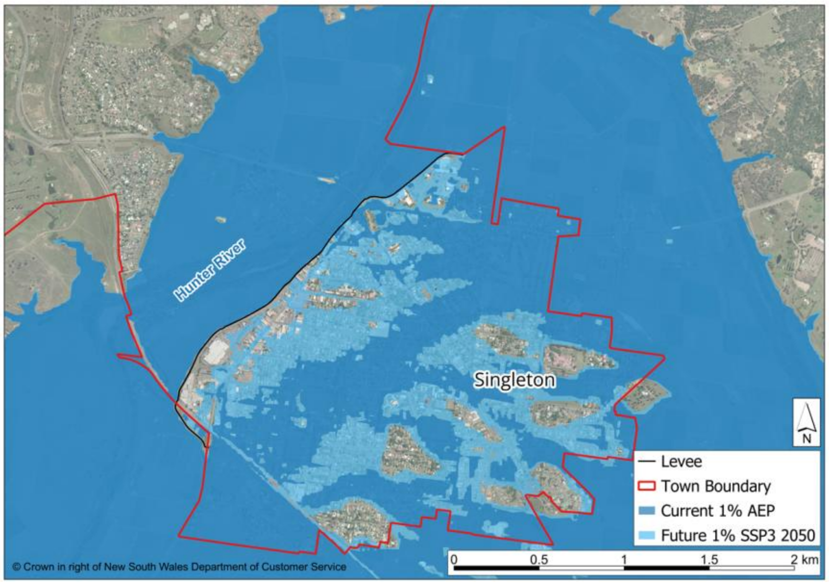


Figure 8: Singleton flood extents - current 1% AEP and interpolated 1% AEP SSP 3 2050

5 CONCLUSION

Australian Climate change guidelines provide factors for rainfall increases and losses under various climate scenarios. While the industry is keen to adopt the guidelines, no formal guidance has been provided by government agencies on which scenarios to adopt. The climate change calculator was developed to avoid unnecessary simulations and model runs. The new guidelines were tested on 500 catchments. The climate changes adjustments for current day warming (1 Degree) were found to increase the peak flow in the test catchments by approximately 10% compared to the baseline IFD. While there was a large variability in the magnitude of water level responded to temperature increase, the increase per degree of warming is generally linear. The climate change calculator allows practitioners, engineers, floodplain managers, planners and the general public to easily understand the change in climate risk. The tool has been compared against traditional rainfall runoff methods to ensure the estimates are robust. The hydraulic interpolation function available in the climate change calculator will reduce the need for costly two-dimensional model runs and allow floodplain managers to easily determine the change in flood risk in their catchment. The calculator can be used to estimate the number of buildings at risk of flooding under each future climate scenario. The interpolated grids identify the areas with the highest vulnerability to increases in flood levels due to climate change and can inform resource allocation.

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