Review and update of design rainfall-intensity-frequency-duration for eleven local government areas in South East Queensland

Quick Guide for Users

Final

17 April 2025

Acknowledgements

The Multi-LGA IFD Review and Update Project has been funded under Work Package 3 of the Flood Risk Management Program. The Flood Risk Management Program is a jointly funded Australian and Queensland Government (50:50) 2021-22 Rainfall and Flooding - Exceptional circumstances Category C and D funding package approved under the *Disaster Recovery Funding Arrangements (DRFA)*.

The authors would like to thank the independent peer reviewers, who provided valuable feedback during this project and assisted greatly with the refinement of the analysis at key points: Don Carroll, Dörte Jakob and Rory Nathan. The authors also thank the stakeholders and organisations that provided rainfall data that was used in the analysis: Bureau of Meteorology, Queensland Government, Seqwater and the Bundaberg Regional, North Burnett Regional, Fraser Coast Regional, South Burnett Regional, Cherbourg Aboriginal Shire, Gympie Regional, Noosa Shire, Sunshine Coast Regional and Toowoomba Regional, Somerset Regional and Scenic Rim Regional councils.

Document status

Client	Queensland Reconstruction Authority
Project	Review and update of design rainfall-intensity-frequency-duration for eleven local government areas in South East Queensland
Report title	Quick Guide for Users
Version	Final
Authors	Ash Rasheed, Leah Traill, Declan O'Shea and Phillip Jordan
Project manager	Phillip Jordan
File name	S:\3_Projects\QRA00002\6_Deliverables\Report\QRA00002_DesignRainfallIFDUpdate_QuickUserGuide_Final.docx
Project number	QRA00002

Document history

Version	Date issued	Reviewed by	Approved by	Sent to	Comment
Version 1	19/08/2024	Michel Raymond	Michel Raymond	QRA and project stakeholders	Addressing review comments
Version 2	09/09/2024	Michel Raymond	Michel Raymond	As above	Release of *ARR* version 4.2 (incorporating update of former draft of DCCEEW 2023 Climate Change Considerations chapter), minor revision applications of IFD data sets
Version 3	15/11/2024	Phillip Jordan	Phillip Jordan	As above	Minor change to introduction
Version 4	25/02/2025	Michel Raymond	Michel Raymond	As above	Content added on extrapolation for extreme rainfall range to PMP
Final	17/04/2025	Michel Raymond	Michel Raymond	As above	Remove QRA logo and update copyright and limitation statement

1. IFD data summary

Design rainfall intensities, or design rainfall depths, are used as the basis for rainfall-based design flood estimation.

Several councils in South East Queensland (SEQ) were approved for funding to develop local IFD datasets across their Local Government Areas (LGA) under Work Package 3 of the Flood Risk Management Program. QRA identified an opportunity for efficiency and combined these projects into the Multi-LGA IFD Review and Update Project. This review and update stems from the experiences of flood management professionals in SEQ over recent years, since the updated design rainfall IFD estimates that were released by the Bureau of Meteorology (BoM) in 2016 (Green *et al.*, 2015a, 2015b; Bureau of Meteorology, 2016). The BoM (2016) IFD update was undertaken in conjunction with the 2019 update of *Australian Rainfall and Runoff* (*ARR*2019) (Ball *et al.*, 2019).

Updated design Intensity Frequency Duration (IFD) depths were produced for all combinations of 24 durations from 5 minutes to 168 hours for 13 annual exceedance probabilities from 63% to 0.05% (1 in 2,000 AEP) for an area covering 11 local government areas in south-eastern Queensland and the surrounding region. This update represents a significant increase in available rainfall data, for the number of rainfall gauges applied to the analysis and with an additional 11 years (2013-2023) of gauge records available, compared the BoM 2016 IFDs.

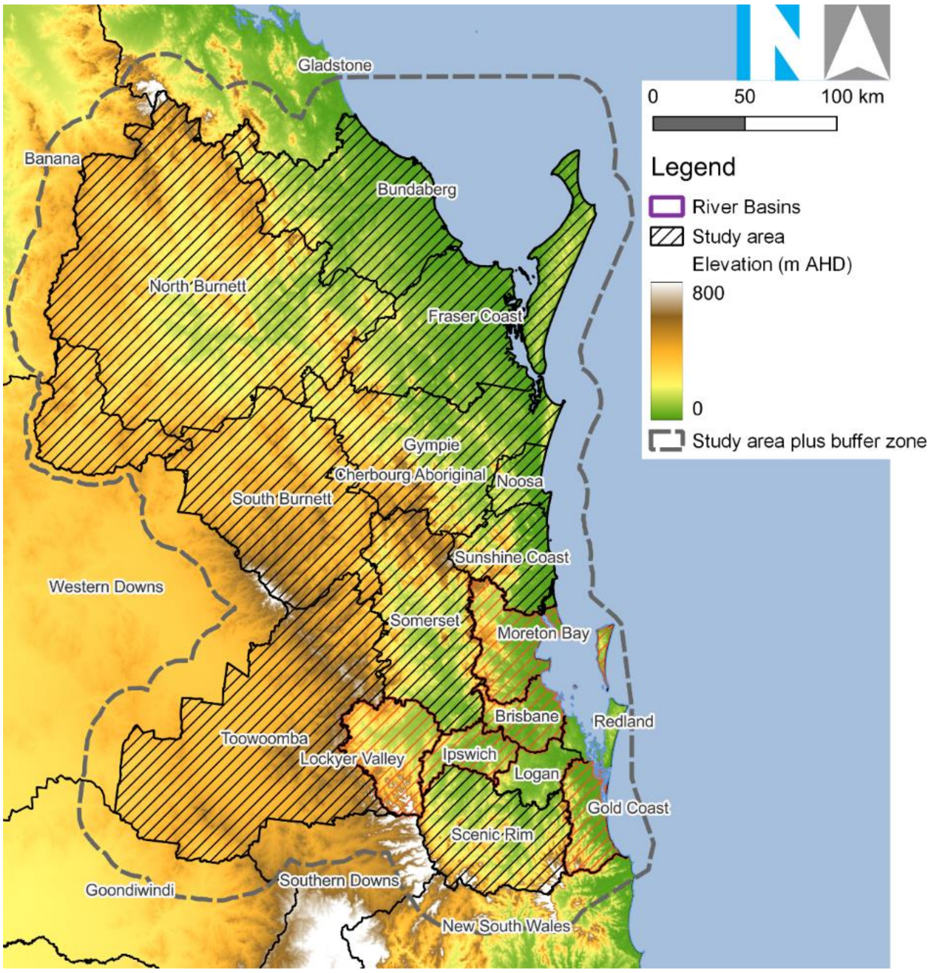

Figure 1 Local government areas for current project and recent previous studies and the extent of the buffer region, where rainfall site data was collected for analysis

2. Two sets of IFD data

IFD estimates were produced for every grid cell across the study area, using two different approaches:

1. Applying regionalised L-moments to calculate GEV distributions at each 0.025° grid cell in the study area, calculating design depths for standard durations and AEP combinations at each grid cell and checking for and removing any minor remaining inconsistencies. These IFD data grids are considered the best-estimates of design rainfall quantiles based upon available data. The grids are representative of a climate centred on 2010 mean global temperatures, or 0.6°C above the BoM (2016) IFD baseline for global mean temperature change.
2. At each grid cell, for each combination of standard duration and AEP, taking the maximum of:
   - Design rainfall depth from approach 1 (derived from this study) and
   - BoM (2016) IFD estimate that has been adjusted forward to the same 2010 global mean temperature, by allowing for 0.6°C increase in global mean temperature and applying the factors for sensitivity in IFD estimates with duration from Table 1.6.1 of *ARR* version 4.2.

These two IFD data sets, which are both aligned to 2010 global mean temperature, serve different purposes:

- The first set is based on all available QA'd data to 2023 using latest statistical techniques including advanced smoothing algorithms as per this report to derive a set of IFD tables that are minimally biased. This set is referred to as the HARC (2024) data set.
- The second set is based on an envelope approach that adopts, for all durations, the maximum of either the HARC (2024) data set and the uplifted BoM (2016) IFD data set. This set is referred to as the eHUB (2024) data set. This set is included as it was noted that predominantly for the shorter durations (<3 hours) the uplifted BoM (2016) data set was generally higher than the HARC (2024) data set. This enveloped data set allows LGA's to retain the same level of flooding/drainage infrastructure serviceability into the future.

3. Applying IFD data sets with climate change

The IFD data sets presented here is representative of 2010 global average temperatures (defined by the 20 year average). This period is characterised by global temperatures 0.6°C warmer than the 1961-1990 period that BoM 2016 IFDs are represented by (i.e. 0.9°C above a 1850-1900 baseline referenced by IPCC data). This difference should be considered when adjusting the IFDs from this study for future climates. Therefore, when using either the HARC (2024) or eHUB (2024) data, Table 1.6.2 of *ARR* (version 4.2) should be replaced by Table 1.

Table 1 IPCC Sixth Assessment Report global mean surface temperature projections for four socio-economic pathways relative to the baseline temperature for the updated IFD estimates for the SEQ region (HARC, 2024). The 90% uncertainty interval is provided in parenthesis*

Projection scenario	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Current and near-term (2021-2040)	0.6 (0.3-0.9)	0.6 (0.3-0.9)	0.6 (0.3-0.9)	0.7 (0.4-1.0)
Medium term (2041-2060)	0.8 (0.4-1.3)	1.1 (0.7-1.6)	1.2 (0.8-1.7)	1.5 (1.0-2.1)
Long-term (2081-2100)	0.9 (0.4-1.5)	1.8 (1.2-2.6)	2.7 (1.9-3.7)	3.5 (2.4-4.8)

Notes: * Projections obtained from the Summary for Policymakers of the Working Group I Contribution to the IPCC Sixth Assessment Report (AR6)

4. Directory structure and file formats

The directory structure is as follows:

- IFD_data: contains the gridded IFD data (both IFD data sets)
  - _IFD_data_HARC2024: gridded IFD data produced from rainfall data in the study region. These are produced in three formats:
    - Contour line: Shape files (*.shp) of contour lines of IFD depth, in mm. Files are labelled by AEP or ARI and duration (in hr or min).
    - IFD grids: Compressed GeoTIFF format grids (*.tiff) of IFD depth, in mm. Files are labelled by AEP or ARI and duration (in hr or min). Grids are at 0.025° x 0.025° resolution to GDA94 datum and therefore align with the BoM (2016) IFD grids
    - IFD grids ASCII: Uncompressed ASCII text format grids (*.asc) of IFD depth, in mm. Files are labelled in a similar manner to grids provided on the BoM portal: duration is always in minutes and the AEP label is the percentage AEP multiplied by 1000. For example:
      63212aep = 63.212% AEP = 1EY
      01000aep = 1% AEP = 1 in 100 AEP
      00050aep = 0.05% AEP = 1 in 2,000 AEP
      Grids are at 0.025° x 0.025° resolution to GDA94 datum and therefore align with the BoM (2016) IFD grids
  - _IFD_data_Max_BoM_HARC2024: gridded IFD data produced from the maximum of BoM (2016) IFD data adjusted by +0.6°C and rainfall data analysis in the study region (HARC, 2024).
    These are produced in the same three formats as listed above.
  - IndividualSiteComparisons: for every rainfall site analysed in the study region: plots of comparisons between the fitted IFD, fits to annual maxima series at the individual gauge site, BoM (2016) IFD and LIMB study (WMAwater, 2021) (if available)
  - PercentDifferenceComparisons: gridded comparisons between the updated regional IFD, BoM (2016) and LIMB
  - Plots_GEVParameters: plots of fitted GEV parameters for each duration across the study region
  - Plots_IFD: plots (pictures, rather than grids) of IFD depth values for each combination of duration and AEP
  - Plots_LMoments: plots of smoothed L-moments across the study region for each duration
- Rainfall_Data: contains processed annual maxima rainfall series data after QA processes
- Report: project report and previous draft versions, including milestone reports
- Supporting_Info: miscellaneous supporting information and analyses

5. Rainfall data and method summary

Details of the rainfall data used and method of analysis are provided in the full project report (HARC, 2024).

The core scope, as set out in QRA's project brief, covered eight LGAs. Extensions to the project scope were approved by QRA to extend the project study area to include 11 LGAs: Bundaberg, North Burnett, Fraser Coast, South Burnett, Cherbourg, Gympie, Noosa, Sunshine Coast, Somerset, Scenic Rim and Toowoomba. Previous studies (WMAwater, 2021 and CoGC) had updated IFD estimates for five LGAs: Lockyer Valley, Ipswich, Moreton Bay, Brisbane and Gold Coast. Therefore, across these previous two projects and the current project, IFD estimates were updated for a total of 18 LGAs, covering most of the South East corner of the State, as shown in Figure 1.

Rainfall data was provided by QRA, local governments, Seqwater and BoM; or obtained from the BoM or the Queensland Water Management Information Portal (QWMIP). Rainfall data was obtained from all daily and sub-daily recording rainfall sites that were contained within the buffer region shown by the dashed line in Figure 1.

After implementing the QA process, valid annual maxima data was obtained from 810 sub-daily and 567 daily gauges, a total of 1,236 gauges. Figure 2 shows the number of gauges across the study region and the number of valid water year maxima identified at each gauge. Densities of gauges are highest in the south-east of the study region, between Noosa and the Gold Coast, and extending west into Ipswich and the eastern parts of Lockyer Valley, Somerset and Scenic Rim.

Table 2 lists the total number of QA'd water year maxima across the study region. The size of the sub-daily rainfall set used for the current study in this region was more than three times greater, both in terms of the number of rainfall gauges and the number of water year maxima, than the data set of sub-daily rainfall gauges that was used by the BoM (2016) IFD analysis.

Table 2 Total number of water year maxima by gauge type and rainfall burst duration

Duration range	Sub-daily gauges	Daily gauges	Total
5 min - 3 h	14,071	0	14,071
4.5 h - 18 h	13,926	0	13,926
24 h, 48 h, 72 h	16,955	29,439	46,394
30 h - 36 h	13,912	0	13,912
96 h - 168 h	16,832	29,481	46,313

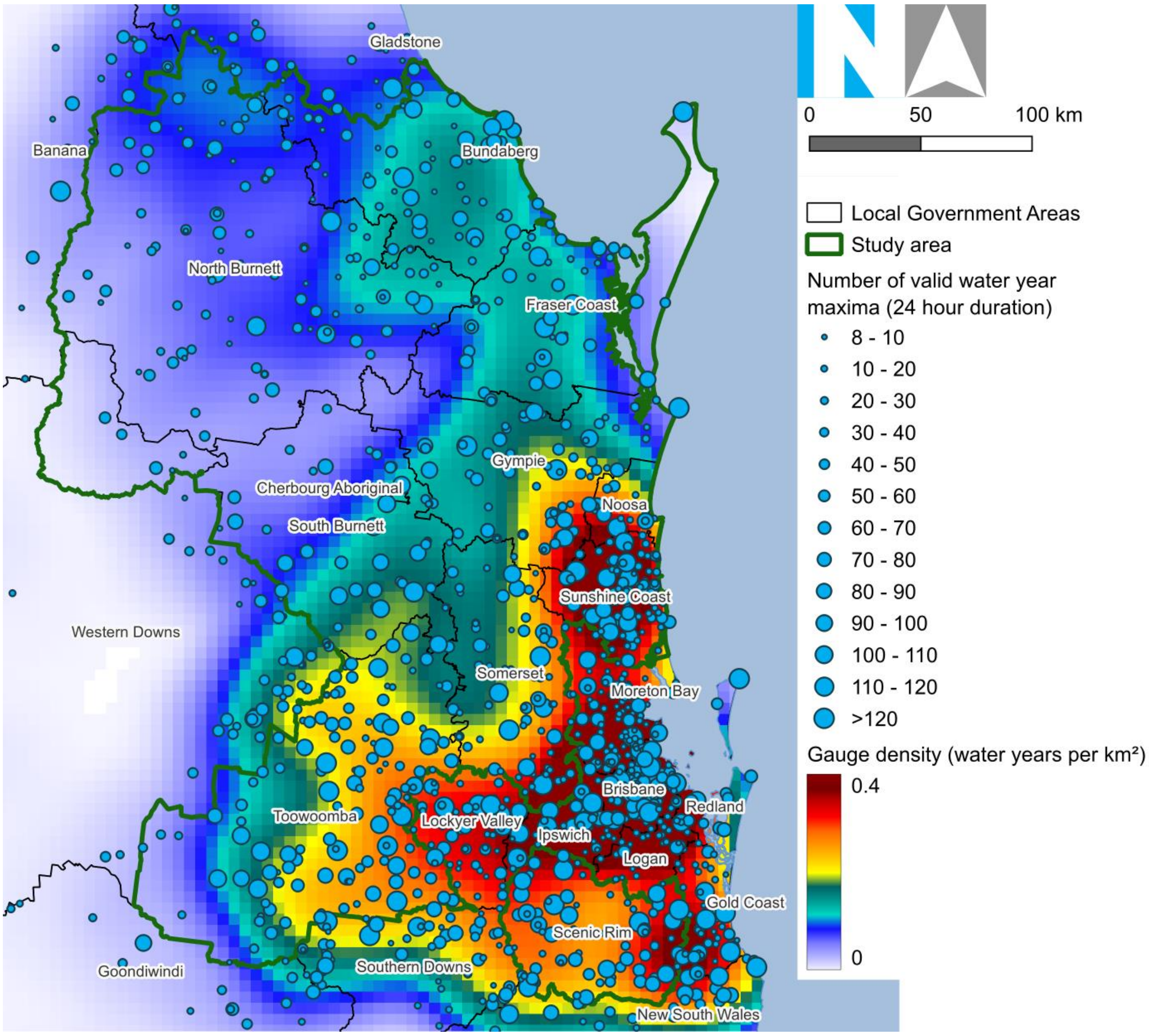

Figure 2 Density of coverage of daily and sub-daily gauges across the study region, showing number of valid water year maxima at each site for the 24 h duration and density of gauges (number of water year maxima per km²)

A water year of 1 October to 30 September was adopted for the analysis, as the lowest number of annual maxima are recorded in the months of July to September of each year. Factors to adjust the daily rainfall (restricted from 9am to 9am) to 24 hour rainfall that is not fixed to a set time window (unrestricted rainfall) were assessed from the data after QA screening of valid data.

Updated design Intensity Frequency Duration (IFD) depths were produced for all combinations of 24 durations (from 5 minutes to 168 hours) and 13 annual exceedance probabilities (63.2% to 1 in 2,000 AEP and 2 and 5 year average recurrence intervals) for an area covering 11 local government areas in south-eastern Queensland and the surrounding region. This update represents a significant increase in available rainfall data, with an additional 11 years (2013-2023) of gauge records available compared the BoM 2016 IFDs.

For an individual rainfall station with a relatively short record, there is considerable uncertainty in estimating L-moments due to sampling variability. To control the potential impact of shorter record lengths, a regionalisation approach was adopted where higher order L-moment ratios L-CV and L-skewness were estimated using a Region of Influence (ROI) approach (Burn, 1990). Similar methods were also applied by the BoM (2016) and LIMB study (WMAwater, 2021), although with slightly different approaches adopted for spatial interpolation and pooling of data. These differences are explained in the main report (HARC, 2024).

The methodology for producing the IFD curves using regionalisation of L-moments has also been tailored to suit the high density of rainfall gauges in SEQ. In particular, the method makes use of a hybrid approach for the regionalisation of L-CV and L-skewness, which uses regional wide averages for short durations (≤ 2 hours) and a region of influence approach for long durations (≥ 48 hours) to account for systematic difference in daily and sub-daily gauge data. The method applied for the current study was as follows:

- For each rainfall event duration, the L1 value was spatially interpolated from all rainfall sites with at-least 8 years (for sub-daily gauges) or 30 years (for daily gauges) of water year maxima values. Spatial interpolation was undertaken via kriging, with mean annual rainfall as the explanatory co-variate. Mean annual rainfall was selected as the covariate, as it provided the highest Coefficient of Determination (R^2) for all durations considered compared to other covariates that were considered (elevation, slope, standard deviation of elevation and distance to coast).
- For each rainfall event durations of less than 2 hours, the L-CV and L-Skewness values were adopted from the regional average of L-CV and L-Skewness across the entire study region, calculated from all sub-daily sites with at least 18 years of water year maxima.
- A minimum threshold of 0.17 was set for L-skewness, which ensured that the fitted GEV distribution’s shape parameter was negative and hence the GEV quantile function had an infinite upper bound. The threshold generally was applied to durations of 1 hour and shorter. In conjunction with this, the L-CV values for durations where L-skewness was thresholded to 0.17 were set to the value of the shortest duration with L-skewness above 0.17.
- For each rainfall event duration of 48 hours and longer, the L-CV and L-Skewness values were calculated by pooling together the nearest rainfall gauge sites that had at least 18 years of water year maxima (for sub-daily gauges, and at least 30 water year maxima for daily gauges), until 500 water years of data had been accumulated. The pooled value of L-CV and L-Skewness were then calculated using the weighted average by the number of years of annual maxima at each rainfall site.
- Smoothing was undertaken, at every grid cell, to ensure that there was a monotonic increase in L-CV and L-Skewness with duration. These adjustments were relatively small but were required to ensure that the design rainfall depth increases monotonically with increasing duration at every grid cell.
- The parameters of the GEV distribution were calculated from the smoothed L-moment values at every grid cell, for every duration across the study area.
- Design rainfall depths were calculated from the GEV parameters at every grid cell (0.005° and 0.025° resolution), for every duration and for each AEP between 63.2% and 0.05% across the study area.

6. Estimation of extreme rainfall depths to the PMP

Section 3.5 in Book 8 of *ARR* (version 4.2) provides guidance on estimating design rainfall depths for extreme events, between 1 in 2,000 AEP and the Probable Maximum Precipitation (PMP). As this section of *ARR* points out, "As there are no independently estimated design rainfalls for this range of AEPs, any specific interpolation procedure cannot be supported by direct evidence but it must be able to produce plausible and consistent estimates."

Book 8 of *ARR* then provides a recommended procedure for interpolating between catchment average IFD depths at 1 in 1,000 and 1 in 2,000 AEP and the PMP depth, which in most circumstances will produce plausible and consistent estimates. The recommended procedure in *ARR* interpolates a quadratic curve in log-depth versus log-AEP space. The *ARR* procedure assumes that the slope of the IFD curves (in log-log space) between 1 in 1,000 and 1 in 2,000 AEP sets the starting slope of the quadratic and that the fitted quadratic must fit through the PMP depth at the AEP of the PMP. The *ARR* procedure works appropriately, to produce "plausible and consistent estimates" when the ratio of the slope between the 1 in 1,000 and 1 in 2,000 AEP (S_{gc}, see equation 8.3.5 of *ARR*) is less than double the slope of the gap between the 1 in 2,000 AEP and the PMP (S_{gap}, see equation 8.3.6 of *ARR*) (i.e. $S_{gc}/S_{gap} < 2$).

The Book 8 ARR interpolation procedure will not produce plausible and consistent design estimates where the 1 in 1,000 and 1 in 2,000 AEP estimates are sufficiently large, compared to the PMP depth, that the slope ratio is 2 or greater.

For example, Hill et al (2000) identified that the log-log interpolation did not yield plausible results when interpolating BoM (2016) IFDs to GSAM-derived PMPs for 13 small catchments in South Australia. Similarly, there may be locations in the SEQ region where adopting the eHUB (2024) or HARC (2024) IFD data produces catchment average design rainfall depths, in conjunction with *ARR* recommendations for estimate of PMP and AEP of the PMP, that have $S_{gc}/S_{gap} \geq 2$ and consequently the Book 8 *ARR* interpolation method does not produce plausible and consistent interpolated design depths. In those circumstances, an alternative interpolation method is required, which preserves the intent of Section 3.5 of *ARR* Book 8. The alternative interpolation method, when using the *ARR* (Book 8, section 3.4.1) recommendations for the AEP of PMP depth should therefore:

- Match the design IFD depths for the catchment at the credible limit of extrapolation (typically 1 in 2,000 AEP), for every burst duration
- Match the PMP depth for the catchment at the AEP of the PMP, for every burst duration
- Be monotonically increasing with AEP, for a given burst duration
- Have a positive slope of depth versus rarity at the PMP, which is consistent with PMP depths being operational estimates of extreme depths, rather than fixed upper limits
- As far as practicable, match the slope of the design depths approaching the credible limit of extrapolation (typically between the 1 in 1,000 and 1 in 2,000 AEP) and
- Produce monotonic increases in the design depths with burst duration.

Several alternative interpolation methods have been proposed, which should be capable of meeting the above criteria:

1) Application of an alternative quadratic curve:
    a) Quadratic relationship fitted between standard normal variate of AEP and log-rainfall depth, i.e. Equation 8.3.2 of *ARR* but with z_d and g_y replaced by differences in standard normal variate values, rather than the ratio of log-ARIs (Hill *et al.*, 2000)
    b) Quadratic relationship fitted between Gumbel transformed AEP and rainfall depth (without log-transformation)
2) Application of equation 8.3.2 of ARR but with S_{gc} replaced by S_{gcMax}, where S_{gcMax} = 1.9 $_{\mathrm{Sgap}}$ (as implemented in URBS, Carroll, pers. comm.). This will ensure a monotonically increasing design depths with AEP (for a given duration), and a positive slope of depth versus rarity at the PMP but may in some circumstances lead to a change in the slope of the curve at 1 in 2000 AEP.
3) Fitting a GEV distribution to the design depths at AEPs of 1 in 1,000, 1 in 2,000 and the PMP (Sharpe, 2024).

Practitioners should check that the adopted interpolation procedure conforms to the criteria listed above. In choosing between methods practitioners should also bear in mind that there is considerable uncertainty in extrapolating to rainfall depths beyond 1 in 2000 AEP. It is not practical to recommend a preferred method that is uniformly applicable as the most appropriate method may vary depending on location and catchment size. The reasonableness of the derived extreme rainfall depths and shape of the IFD curve up to PMP requires the practitioner to apply professional judgment for the specific application and consequences of that application.

In some circumstances, such as risk assessment and design of infrastructure that should continue to perform safely during very large and extreme flood events (such as large dams), site-specific catchment design rainfall depths for very large to extreme events should be assessed in more detail for the catchment of that infrastructure (*ARR* Book 8, Section 3.4.3). Analyses should be performed of rainfall data across a wider region, such as a transposition region for PMP depths, to provide evidence to support design estimates for large and extreme rainfall bursts and the AEP of the PMP. Where a targeted analysis has been, or is, undertaken of large and extreme rainfall depths for a particular catchment, this should be adopted as the preferred approach to define extreme rainfall probability in preference to the *ARR* Book 8 (Section 3.4.2) recommendations for AEP of PMP and interpolation procedure. Previous studies may require adjustment to be consistent with the *ARR* version 4.2 climate change recommendations. The eHUB (2024) and HARC (2024) IFD data remains relevant to defining frequent design rainfalls, and in some cases it may be necessary to merge these new frequent design rainfalls with pre-existing catchment-specific extreme rainfall estimates to make a composite rainfall frequency curve. This may require a merge point to be defined at an AEP more frequent than the 1 in 2000 upper limit of the eHUB (2024) or HARC (2024) IFD data.

7. Abbreviations and glossary

Abbreviation / term	Full term
AEP	Annual exceedance probability
ARR	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
GEV	Generalised Extreme Value distribution
HARC	Hydrology and Risk Consulting
IFD	Intensity-Frequency-Duration
Kriging	A method of spatial interpolation, governed by prior estimates of covariances in the data. Under suitable assumptions of the covariance, kriging gives the best linear unbiased prediction at unsampled grid cells.
LGA	Local government area or Local government authority
LIMB	Lockyer, Ipswich, Moreton Bay and Brisbane local government areas
L-moment	Statistics used to summarise the shape of probability distributions, calculated using linear combinations of order statistics. L-moments are more robust than conventional moments and therefore they have been widely applied in analysis of rainfall, floods and other extremes of environmental phenomena over the last few decades.
L1	First L-moment: Mean of annual maxima series
L2, L3, L4	Second L-moment, Third L-moment, Fourth L-moment
L-CV	Ratio of L2/L1
L-Skewness	Ratio of L3/L2
L-Kurtosis	Ratio of L4/L2
MAR	Mean annual rainfall
QA	Quality assurance
QRA	Queensland Reconstruction Authority
SEQ	South east Queensland

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