The New Intensity-Frequency-Duration (IFD) Design Rainfall Estimates for Australia

Janice Green
IFD Revision Project Manager, Climate and Water Division, Bureau of Meteorology,
Canberra, Australia
E-mail: j.green@bom.gov.au

The Bureau of Meteorology has recently completed a revision of the IFDs with the new IFDs available via the Bureau's website. These new IFDs replace those previously provided in AR&R87. The new IFDs are based on a greatly expanded rainfall database in addition to adopting more statistically rigorous methods that are more appropriate to to the analysis of Australian rainfall data. The new IFD estimates better meet the changing needs of users by providing estimates for the shorter durations and more frequent Annual Exceedance Probabilities that are required for urban design. In addition, IFDs are provided for durations as long as 168 hours.

Introduction

Design rainfall estimates are an essential component of the design of infrastructure including gutters, roofs, culverts, stormwater drains, flood mitigation levees, retarding basins and dams. The previous Intensity-Frequency-Duration (IFD) estimates for Australia were developed by the Bureau of Meteorology (the Bureau) nearly 30 years ago using a database comprised primarily of information from the Bureau's network of daily read and continuous rainfall stations and adopting techniques for the statistical analysis of the data that were considered appropriate at the time. The IFDs were disseminated as hard copy maps in Volume 2 of Australian Rainfall and Runoff (AR&R87) (IEAust, 1987) and either a graphical or an analytical process was required to derive IFDs for a specific site. The focus of the IFDs was the design of structures on relatively large rural catchments and therefore durations of less than five minutes were not considered necessary. The approach adopted for the IFD estimates contained in AR&R87 is summarised in Table 1.

Table 1 Summary of AR&R87 IFD method

Variable	**Output**
Data	Primarily Bureau stations
Record length	up to 1983; 7500 daily read > 30 years; 600 pluviographs > 6 years
Durations	5 minutes to 72 hours (3 days)
Frequencies	1 year to 100 years
Frequency analysis	Annual maximum series; method of moments; Log-Pearson Type III
Daily to sub-daily	Principal Component Analysis
Gridding	Manual drawing of the isohyets;
Delivery method	Maps; IFD tables & charts calculated on-line

In the intervening years, the Bureau's network of rainfall stations has been expanded and nearly 30 more years of additional data have been collected resulting in an increase in the number of stations with sufficient length of record to be included in the analyses. In addition, the Bureau now has ready access, under terms of the Water Regulations 2008, to daily read and continuous rainfall data collected by other organisations which supplements the Bureau's network, particularly in urban areas and areas of steep rainfall gradients.

In parallel with the expansion of the rainfall database, there have been significant advances in statistical methods, gridding procedures, and information dissemination techniques which make a revision of the IFD estimates long overdue. Further, the requirements of end-users have changed with a significantly greater focus on urban design on small catchments than with the AR&RR87 IFDs, necessitating the provision of IFD estimates for durations as short as one minute. This has required an emphasis on providing sub-hourly IFDs and the need to develop methods that optimise the information available from the continuous rainfall stations. In addition, IFDs for longer durations, up to 168 hours are also provided.

In the following sections an overview of the work that has been undertaken by the Bureau into revising the IFD estimates will be presented. A summary of the approach is provided in Table 2.

Table 2 Summary of new IFDs method

Variable	**Output**
Data	Bureau stations plus stations from other data collecting agencies
Record length	up to 2011; 8074 daily read > 30 years; 2280 pluviographs > 8 years (754 Bureau; 1526 Regs)
Durations	1 minute to 168 hour (7 day)
Frequencies	1 Exceedance Per Year (EY) to 1% AEP
Frequency analysis	Annual maximum series; L-moment; GEV
Daily to sub-daily	Bayesian Generalised Least Squares Regression
Gridding	ANUSPLIN
Delivery method	New webpage on Bureau's website

Database

Sources of data

The previous IFD estimates were based primarily on the Bureau's network of daily read and continuous rainfall stations which consisted of approximately 7500 daily read rainfall stations with greater than 30 years of data and 600 continuous rainfall stations with greater than 6 years of data.

In the intervening years, the Bureau's network of rainfall stations has been expanded and nearly 30 years of additional data have been collected resulting in an increase in the number of stations with sufficient length of record to be included in the analyses. In 2013, the Bureau of Meteorology's Australian Data Archive for Meteorology (ADAM) contains:

- approximately 20 000 daily read rainfall stations (both open and closed) starting in 1800
- nearly 1500 continuous rainfall stations – using both Dines tilting syphon pluviograph (DINES) and Tipping Bucket Rain Gauge (TBRG) instrumentation.

In addition, the Bureau now has ready access, under terms of the Water Regulations 2008, to daily-read and continuous rainfall data collected by other agencies. These additional stations supplement the Bureau's network particularly in areas of steep rainfall gradients and urban areas. Data from the following additional rainfall stations have been received via the Water Regulations:

- approximately 350 daily read rainfall stations
- approximately 2175 continuous rainfall stations.

The effect of more than doubling the number of continuous rainfall stations upon which the IFD estimates are derived is a significant improvement in the accuracy and representativeness of the IFD estimates, especially for sub-daily durations and in urban areas.

The location of the rainfall stations used in revising the IFDs and the period of record are shown in Figure 1 for the daily read stations and Figure 2 for the continuous rainfall stations.

Figure 1 Location of daily read rain gauges and period of record

Figure 2 Location of Bureau and Water Regulations continuous rain gauges

Quality controlling of data

For the previous IFDs, limited manual checking of the values of the Annual Maximum Series (AMS) was undertaken. For the new IFDs a detailed and systematic approach for quality controlling (QCing) all daily read data and the Partial Duration Series (PDS) of the continuous data was applied.

The QCing undertaken of both the daily read and continuous rainfall data is summarised below; detailed descriptions of these procedures can be found in Green et al (2011; 2012).

Daily read rainfall data

For the daily read rainfall data the QCing of the data that was undertaken included:

- Infilling of missing data
- Disaggregation of flagged accumulated daily rainfall totals
- Detection of suspect data, identification and correction of:
  - Unflagged accumulated totals
  - Time shifts
- Identification of gross errors
- Manual correction gross errors identified as having a high probability of being incorrect

Continuous rainfall data

Automated procedures were also developed and applied for the QCing of the continuous rainfall data. These procedures used comparisons with other data sources including the Australian Water Availability Project (AWAP) gridded data, daily read rainfall stations, automatic weather stations, and synoptic stations to identify spurious and missing data. Manual QCing of the data was undertaken to correct spurious data.

In order to reduce the amount of continuous rainfall data that needed to be quality controlled to a manageable volume, only a subset of the largest rainfall events based on the Partial Duration Series (PDS) was QC'd. The PDS was created by extracting the highest rainfall records equal to three times the number of years of record at each site.

Meta data

The meta data associated with each of the Bureau's rainfall stations were also checked. For each station, the Bureau's meta database, SitesDB, includes details of the station's location in latitude and longitude, and elevation. A project was recently undertaken whereby, for stations that are currently open, the co-ordinates and elevation of the gauge were checked when the routine inspections were made. If the co-ordinates in SitesDB were found to be incorrect, the meta data were corrected.

For stations that are no longer operational, gross error checks on station locations and elevation were performed by comparing DEM derived elevations to those recorded in the station's metadata. Checks of latitude and location were also carried out by plotting the latitudes and longitudes in GIS. Revisions to station locations or elevations were carried out using Google Earth and information on the station provided in the Bureau's station metadata catalogue.

For the limited number of closed stations for which an elevation was not included in SitesDB, the station elevation was extracted from the Geoscience Australia 9 second DEM based on the latitude and longitude.

At-site Frequency Analysis

As outlined in Table 1, previous IFD estimates were derived using statistical techniques that were considered appropriate at the time. A Log-Pearson Type III distribution was fitted to the annual maximum series of rainfall data using the method of moments.

However, in recent years analyses have been undertaken as part of the development and application of the Co-operative Research Centre for Catchment Hydrology Focussed Regional Growth Estimation (CRC-FORGE) approach for the estimation of design rainfalls for Annual Exceedance Probabilities (AEPs) from 1% to 0.05% (Nandakumar et al, 1997). These analyses found that a Generalised Extreme Variable (GEV) distribution fitted using L-moments (Hosking and Wallis, 1997) was the most appropriate approach for Australian rainfall data.

In order to assess the most appropriate distribution to adopt across Australia for both the AMS and the PDS for the IFD revision project, a range of distributions were trialed using single site analysis. Five distributions – GEV, Generalised Logistic (GLO), Generalised Normal (GNO), Pearson Type III (PE3) and Generalised Pareto (GPA) – were fitted to both the AMS and PDS extracted from the available long-terms continuous rainfall stations for durations of 6, 12, 18, and 30 minutes and 1, 2, 3, 6, and 12 hours. The goodness of fit of each distribution was assessed using the approach recommended by Hosking and Wallis (1997) which uses a goodness of fit measure Z^{Dist} with a threshold $|Z^{Dist}| \leq 1.64$. The following distributions found to produce to produce the best fit on an at-site analysis:

- Annual Maximum Series – Generalised Extreme Value (GEV)
- Partial Duration Series – Generalised Pareto (GPA)

The comparison of distributions was subsequently repeated for regional estimates with the same results.

On the basis of the results of the above comparison, the GEV distribution was fitted to the previously extracted AMS and the GPA was fitted to the PDS for all stations which met the record length criteria of thirty years for daily read rainfall stations and nine years for continuous rainfall stations. While the adoption of a minimum of nine years for the continuous rainfall stations was relatively short, it was an increase by 50% of the length of record adopted for previous IFDs and improved the spatial distribution of continuous stations included in the analyses.

Regional Frequency Analysis

Regional frequency analysis was undertaken using L-moments which were extracted from each of the frequency distributions. While for durations of 1 day and longer this process was straightforward, for sub-daily durations the scarcity of long term continuous rainfall records meant that an alternative approach was needed to supplement the available data. For the IFD revision project, a Bayesian Generalised Least Squares Regression (BGLSR) approach was adopted, a summary of which is provided below; more details can be found in Johnson et al (2012a).

Daily durations (24 hours to 168 hours)

The linear combinations of the data (L-moments) (Hosking and Wallis, 1997) of mean, variation (L-CV) and skewness (L-skewness) were used to summarise the statistical properties of the extreme value series data at each station location. L-moments are commonly used in rainfall and flood frequency analysis (Hosking and Wallis, 1997) due to their efficiency in fitting the data and lack of bias in the sample estimates, particularly in the higher order moments, when compared to ordinary moments.

Sub-daily durations (1 hour to 12 hours)

At sites where continuous rainfall data were available with more than eight years of record, the mean, L-CV and L-skewness, were determined from the at-site extreme value series for each duration.

The continuous rainfall stations were also used to derive prediction equations between site characteristics and the sub-daily L-moments. This was done in order to be able to estimate sub-daily rainfall parameters based on site characteristics and daily rainfall statistics to improve the spatial coverage of sub-daily data.

As can be seen from Figures 1(a) and 1(b) the spatial coverage of sub-daily rainfall stations is considerably less than that of the daily read stations. Therefore, a method is needed to improve the spatial coverage of the sub-daily data. This is most commonly done using information from the daily read stations with statistics of sub-daily data being inferred from the daily data. For the previous IFDs, Principal Component Analysis (PCA) followed by regression was used to derive equations for predicting the ARIs at durations below 24 hours from the ARI for the 24, 48 and 72-hour durations. However, a major weakness of the previously adopted approaches is their inability to account for variation in record lengths from site to site and inter-station correlation.

The approach that was adopted for the new IFDs was Bayesian Generalised Least Squares Regression (BGLSR) as it accounts for possible cross-validation and unequal variance between stations by constructing an error covariance matrix and can explicitly account for sampling uncertainty and intersite dependence. A further advantage of the BGLSR is that the Bayesian formulation allows for the separation of sampling and statistical modeling errors. This is important because it was found that the sampling errors dominate the total error in the statistical model. The BGLSR produces estimates of the standard error in:

- the regression coefficient
- the predicted values at-site used in establishing the regression equations
- the predicted values at daily rainfall stations (i.e. ungauged sites not used in deriving the regression)

The error variances for the predictions are comprised of the regional model error and the sampling variance. Further details on the Bayesian GLSR approach can be found in Reis et al (2005) and Madsen et al (2002, 2005).

Following a detailed assessment of the influence various factors have on large rainfalls, the following values (predictors) were used to predict the mean, L-CV and L-skewness (predicants) using the BGLSR:

- Location (latitude and longitude)
- Elevation
- Slope
- Aspect
- Distance from the coast
- Mean annual rainfall
- Rainfall statistics for 24 hour, 48 hour and 72 hour durations - mean, L-CV and L-skewness.

The regression equations derived from the BGLSR were then applied to the daily read stations to predict the sub-daily L-moments at the daily station locations. This allowed for a greater density of sub-daily data to be used in gridding across Australia which is described below.

Regionalisation

Regionalisation recognises that for stations with short records, there is considerable uncertainty estimating the parameters of probability distributions as short records can bias estimates of rainfall statistics. To overcome this, it is assumed that information can be combined from multiple stations to give more accurate estimates of the parameters of the extreme value probability distributions.

For the revision of the IFDs, regionalisation has been used to estimate the L-CV and L-Skewness with more confidence. The regionalisation approach adopted is called the “index flood procedure” (Hosking and Wallis, 1997). This approach assumes that sites can be grouped into homogenous regions, such that all sites in the region have the same probability distribution, other than a scaling factor. The scaling factor is then normally termed the index flood or in this case, since the regionalisation is of rainfall data, the “index rainfall”. The index rainfall is the mean (i.e. first L-moment) of the extreme value series data at the station location.

For the IFD revision project, the station point estimates were regionalised using a Region of Influence Approach (ROI). The ROI approach assumes that all the stations in the region of the station of interest have a common probability distribution which only needs to be scaled by a site specific factor. The assumptions of the approach are, firstly, that the specified probability distribution (GEV in the case of the AMS) is appropriate; that the region is truly homogenous; and, finally, that sites are independent or that their dependence is quantified. After trialling various approaches homogenous ROIs were defined as circle which was expanded from the site of interest until it included sufficient rainfall stations to provide 500 station years of record. In creating the ROIs distance was defined in three dimensions (latitude, longitude and elevation) in order to take into consideration areas of steep gradient. More details on the regionalisation can be found in Johnson et al (2012b).

Gridding of GEV Parameters

The regionalisation process resulted in estimates of the GEV parameters at all station locations, which were combined with the mean of the extreme value series at that site to estimate rainfall quantiles for any required exceedance probability. However IFD estimates are required across Australia, not just at station locations and therefore the results of the analyses needed to be extended in some way to ungauged locations. For the previous IFDs, the gridding of the regionalised rainfall intensities was undertaken manually. Although a splining program was used, its purpose was only to translate the hand-drawn contours into grid format.

For the new IFDs, the software package ANUSPLIN (Hutchinson 2007) was chosen to grid the GEV parameters so that IFD estimates are available for any point in Australia. ANUSPLIN applies thin plate smoothing splines to interpolate and smooth multi-variate data. The degree of smoothing of the fitted functions was determined through generalised cross validation. The splines are fitted using three independent variables; latitude, longitude and elevation. The elevation scale was exaggerated by a factor of 100 to represent the importance that elevation has on precipitation patterns (Hutchinson 1995).

The GEV parameters have been being gridded in ANUSPLIN rather than the rainfall depths, as earlier testing had shown little difference in the resulting quantile estimates irrespective of whether point GEV parameters or point rainfall depths are gridded. Gridding the GEV parameters provides more flexibility in the choice of exceedance probabilities that can be extracted and enable the provision of a greater number of AEPs. More details on the gridding approach adopted can be found in The et al (2012).

Calculation of Growth Factors and Rainfall Depths

The outputs of the ANUSPLIN analysis were grids across Australia of index rainfall for each duration and the GEV shape (alpha) and scale (kappa) parameters. These were then processed to firstly estimate the growth factors for each grid location and then the rainfall depths for each exceedance probability.

Due to the different values selected for analysis in the AMS and the PDS, fitted distributions for the two series will lead to different estimates of the rainfall quantiles. For frequent events, the PDS is considered to be more reliable as it will include many rainfall events around the exceedance probability of interest. A conversion factor therefore needed to be applied to the AMS rainfall estimates for events more frequent than the 10% AEP to account for the lower estimates than those obtained if the PDS had been used. The adopted conversion factors were 1.11 for the 50% AEP and 1.02 for the 20% AEP. These conversion factors were based on the ratio of the 50% and 20% AEP estimates of the 24 hour rainfall depth from the AMS and PDS respectively, averaged across Australia.

Sub-hourly values

To derive IFDs for durations of less than one hour to one minute the 'simple scaling' model developed by Menabde et al (1999) was adopted. The model was calibrated using the extreme value series from the database of continuous rainfall stations with more than eight years of data. For each continuous rainfall station the scaling factor, η, was determined and the at-site η values gridded. The model was then applied to the 1 hour duration rainfall depth grids to estimate the rainfall depths for the 1 minute to 30 minute rainfall events according to the following equation:

$$I_d = \left(\frac{d}{D}\right)^{\eta} I_D$$

Where I_d is the sub-hourly rainfall intensity for duration d, I_D is the 60 minute rainfall intensity (i.e. duration D is 60 minutes).

Smoothing across durations

In order to reduce inconsistencies across durations and smooth over discontinuities in the gridded data (unevenly spaced differences in design rainfall estimates at neighbouring durations) arising from application of the method, a smoothing process was undertaken. This was done by applying a 6th order polynomial to each grid point to all the standard durations from 1 minute up to 10,080 minutes.

The polynomial was of the form:
$y(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + \ldots . a_n x^n$. where n is the order of the polynomial and a_0, $a_1, \ldots a_n$ are coefficients to be determined.

Inconsistencies with respect to duration (rainfall depths at lower durations exceeding those at higher durations) were also found and were addressed in the manner described below.

Inconsistencies were detected by subtracting each grid from a longer duration grid at the same average recurrence interval (ARI) and checking for negative values. Inconsistencies were addressed by adjusting by adjusting the longer duration rainfall upwards so that the ratio of shorter duration rainfall to the longer duration rainfall equals 0.99, or

$$\frac{\text{Rainfall depth at the shorter duration}}{\text{Rainfall depth at the longer duration}} = 0.99$$

The smoothing procedure was applied first to the original grids and the smoothed grids adjusted for inconsistencies. The grids were smoothed once again and a final adjustment for inconsistencies across durations was performed. The final grids were also checked for inconsistencies across AEPs.

Outputs

The outputs from the revision of the IFD estimates reflect the change in the needs of the end-users for IFD information and the technology available for dissemination of the information.

Durations

The extent of durations considered in the previous IFD relationships (outlined in Table 1), was 5 minutes to 72 hours. In response to changes in user requirements, the new IFD estimates have been provided for durations from 1 minute to 168 hours (7 days). In addition advice on how to extrapolate to durations of less than one minute and greater than 7 days will also be provided. The broader range of durations reflects the changed requirements of end-users with the increased focus on very short durations for urban designs such as gutters and the longer durations for retarding basins and dams.

AEPs

AR&R87 provided advice on how to apply the algebraic method the derive IFDs for AEPs of 0.5 and 0.2%. Book VI of the 1999 edition of AR&R (Nathan & Weinmann, 1999) provided details on how to interpolate between the 1% AEP and the Probable Maximum Precipitation (PMP) for the cases where rare regional estimates were or were not available. Rare regional estimates (CRCFORGE estimates) have now been derived by each state for AEPs from 1% to 0.05%, however, there are minor differences in the way in which they have been derived and how they are applied.

The new IFD information has been provided for AEPs to 1%. In addition, the new IFD information will be blended with the CRCFORGE estimates for each state to enable a smooth rainfall frequency curve to be derived to an AEP of 0.05% using an approach that is consistent across Australia.

Dissemination

The series of six master maps contained in Volume 2 of AR&R87 represented a significant advancement in the dissemination of IFD information at that time. However, with the capability to provide this information on-line, for example, via the Bureau's Computerised Design IFD Rainfall System (CDIRS), hard copy maps are used less frequently by practitioners. Although CDIRS made the estimation of IFDs considerably quicker and more consistent, some limitations included the inability to provide IFD estimates for non-standard durations and AEPs (including AEPs less than 1%) and the limitation of IFDs only being able to be estimated for a single point at a time.

The new IFD estimates for a point have been disseminated in an electronic format via a new webpage which can be accessed from the Bureau's website. The new interface provides users with IFDs for the standard durations but also allows users to select non-standard durations for which IFDs are required. In addition, the new webpage facilitates the downloading of the new IFD tables in csv format and the new IFD curves as pngs.

Enhancements

Over the next 12 months, work will continue on the development of enhancements to the new point IFDs. These enhancements will include areal IFDs, sub-annual IFD, seasonal IFDs, and uncertainty estimates. As they become available, these enhancements will be incorporated into the new IFD website. Work will also continue on including additional features into the new webpage including allowing IFDs for multiple locations to be derived at the same time and for IFDs to be provided for locations selected from an interactive map.

Implications of the new IFDs

The new IFDs have been derived using a greatly expanded database (both in terms of number of stations and length of record) and using contemporary methods for the statistical analysis of the data and gridding of the regional values. A summary of the approach adopted to derive the new IFDs is provided in Table 2 while the method used for the AR&R87 is summarized in Table 1.

There are significant differences between the new IFDs and the AR&R87 IFDs because of the changes in the amount of data and the methods used to derive the new IFDs.. These differences vary not only across Australia but also between durations and AEPs.

Maps for each region of Australia showing the differences between the new IFDs and the AR&R87 IFDs are provided on the new IFD webpage together with a narrative (including a series of Frequently Asked Questions – FAQs) explaining the basis for the differences.

Climate change advice

The new IFDs are for the current climatic regime. As part of the overall AR&R revision a climate change research strategy paper has been prepared to enhance understanding of how projected climate change may alter the behaviour of factors that influence the estimation of the design floods that are used in policy decisions involving infrastructure, town planning, floodplain management and flood warning and emergency management.

The AR&R Revision Climate Change Research Strategy identifies research priorities over both the short term (Stage 1 – one year) and the longer term (Stage 2 – four years). The Strategy identifies five research themes:

1. Rainfall intensity-frequency-duration relationships
2. Rainfall temporal patterns
3. Continuous rainfall sequences
4. Antecedent conditions (including baseflow)
5. Simultaneous extremes

At the time of writing, funding has been provided for Stage 1 of Themes 1 and 2. In the interim, advice will be provided on how to consider climate change impacts on projects that have life spans such that they are vulnerable to these impacts.

Conclusions

The Bureau of Meteorology has revised the IFD estimates to be used by practitioners for the design of infrastructure ranging from gutters to dams. The new point IFDs are available from a new IFD webpage on the Bureau's website. Over the subsequent 12 months enhancements to the point IFDs will be rolled out together with additional features to the new IFD webpage.

The revision used a greatly expanded rainfall database incorporating not only the nearly 30 more years of additional data collected at the Bureau's gauges but also data from the rain gauge networks operated by other agencies. All the data were subject to rigorous quality controlling procedures.

In addition, the revision adopted more statistically rigorous techniques such as the Generalised Extreme Variable distribution and L-moment for rainfall frequency analysis, Bayesian Generalised Least Squares Regression for deriving sub-daily rainfall statistics, GIS based methods for gridding and an "index rainfall procedure" for regionalisation.

The new IFD estimates are provided for durations from 1 minute to 7 days. The AEPs for which the new IFDs have been provided are from 50% to 1%. The new IFD information will be blended with the existing CRCFORGE estimates for each state for AEPs from 1% to 0.05% to enable a smooth rainfall frequency curve to be derived to an AEP of 0.05%. The dissemination of the new IFD estimates is in electronic format via a web interface which enables users to derive IFDs at a user entered point.

References

Green, J.H., Xuereb, X. and Siriwardena, L. (2011). "Establishment of a Quality Controlled Rainfall Database for the Revision of the Intensity-Frequency Duration (IFD) Estimates for Australia". Presented at 34th IAHR Congress, Brisbane, Qld, June 2011.

Green, J.H., Johnson, J., McKay, D., Podger, P., Sugiyanto, M., and Siriwardena, L. (2012). Quality Controlling Daily Read Rainfall Data for the Intensity-Frequency Duration (IFD) Revision Rainfall Project. Presented at Hydrology and Water Resources Symposium, Sydney, NSW, November 2012.

Hosking, J.R.M. and Wallis, J.R., (1997). Regional Frequency Analysis: An Approach Based on L-Moments. Cambridge University Press, Cambridge, UK. 224 pp.

Hutchinson, M.F. (1995), Interpolating mean rainfall using thin plate smoothing splines, Int J Geographical Information Systems, 9(4), 385-403

Hutchinson, M. F. (2007), ANUSPLIN version 4.37 User Guide, The Australian National University, Centre for Resources and Environmental Studies, Canberra

Institution of Engineers, Australia (1987) (AR&R87). Australian Rainfall & Runoff - A Guide to Flood Estimation Volumes 1 and 2. Institution of Engineers, Australia, Barton, ACT.

Johnson, F., Xuereb, K., Jeremiah, E., and Green, J. (2012a). Regionalisation of Rainfall Statistics for the IFD Revision Project. Presented at Hydrology and Water Resources Symposium, Sydney, NSW, November 2012.

Johnson, F., Haddad, K., Rahman, A., and Green, J. (2012b). Application of Bayesian GLSR to Estimate Sub Daily Rainfall Parameters for the IFD Revision Project. Presented at Hydrology and Water Resources Symposium, Sydney, NSW, November 2012.

Madsen, H., Mikkelsen, P.S., Rosbjerg, D. and Harremoes, P. (2002), Regional estimation of rainfall intensity duration curves using generalised least squares regression of partial duration series statistics. Water Resources Research, 38 (11), 1239

Madsen, H., Arnbjerg-Neilsen, K. and Mikkelsen, P.S. (2009), Update of regional intensity-duration-frequency curves in Denmark: Tendency towards increased storm intensities. Atmospheric Research, 92, 343-349

Nandakumar, N., Weinmann, P. E., Mein, R. G., Nathan, R. J. (1997), Estimation of Extreme Rainfalls for Victoria using the CRCFORGE Method, CRC for Catchment Hydrology.

Nathan, RJ and Weinmann, E, (1999) Estimation of Large to Extreme Floods, Book VI in Australian Rainfall and Runoff - A Guide to Flood Estimation , The Institution of Engineers, Australia, Barton, ACT, 1999.

Reis Jr., D.S., Stedinger, J.R. and Martins, E.S. (2005), Bayesian GLS regression with application to LP3 regional skew estimation. Water Resour Res. 41, W10419, (1) 1029.

The, C., Johnson, F., Hutchinson, M., and Green, J. (2012). Gridding of Design Rainfall Parameters for the IFD Revision Project for Australia. Presented at Hydrology and Water Resources Symposium, Sydney, NSW, November 2012.