Comparing the new design rainfalls to at-site rainfall frequency curves

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ABSTRACT

Over recent years, the Bureau of Meteorology has released new design rainfalls for probabilities from 12 Exceedances per Year to the 1 in 2000 Annual Exceedance Probability and durations from 1 minute to 168 hours (7 days). The new design rainfalls were developed over a period of 10 years by a team with expertise in data collection and analysis; hydrology; meteorology; engineering; statistics; spatial analysis; and thin plate smoothing analysis of scattered point data. They are based on a greatly expanded database which incorporates rainfall data collected by organisations across Australia as well as the Bureau of Meteorology, which have been analysed using contemporary statistical methods that are appropriate for Australian rainfall data.

As is to be expected, there are changes between the new design rainfalls and those published as part of the 1987 edition of Australian Rainfall and Runoff. These changes vary depending on region, duration and probability and are due to a range of factors including: the longer period of rainfall records now available; the availability of rainfall data for locations previously not included; and differences in the method used to derive the design rainfalls.

Although the new design rainfalls are better estimates than the 1987 estimates, large changes – both increases and decreases – from the 1987 estimates have caused concern for some users. Where there have been large increases in the design rainfalls this has implications for existing infrastructure in terms of an increased level of risk and for new infrastructure needing to be designed to withstand larger rainfalls and floods. Conversely, in locations where there have been large decreases in the design rainfalls inconsistencies can be introduced between the design requirements of existing infrastructure compared to those of new infrastructure.

When faced with large differences between the new design rainfalls and the 1987 design rainfalls, some users have attempted to 'sanity check' the new design rainfalls by comparing them to rainfall quantiles derived from at-site frequency analysis. Although at-site frequency analysis of the Annual Maximum Series of observed rainfall was an integral part of the method adopted for the both the 1987 IFDs and 2016 design rainfalls, it was only one of many steps used to produce the gridded, regional design rainfalls. Therefore, direct comparisons between the new design rainfalls and at-site rainfall frequency analysis need to be undertaken with caution.

INTRODUCTION

The design of infrastructure including gutters, roofs, culverts, stormwater drains, flood mitigation levees, retarding basins and dams requires the estimation of rainfall depths, and subsequently floods, for a wide range of annual exceedance probabilities (AEP). Although the design standards for structures vary from state to state, broadly they can be categorised as shown in Table 1.

Table 1. Typical Design Probabilities.

Infrastructure	Typical Range of AEPs
Water sensitive urban design (WSUD)	4 EY
Road reserves	50% to 10%
Gutters and pipes	20% to 10%
Stormwater drains	2% to 1%
Minor culverts	20% to 2%
Major culverts	2% to 1%
Flood mitigation	5% to 1%
Floodplain management	2% to 0.05%
Bridge design	0.05%
Dam spillways	1 in 10 000 to 1 in 10 000 000

When estimates of rainfalls for the range of probabilities are required, one of two methods are adopted, depending on the quantity and quality of the rainfall data that is available.

1. At-site rainfall frequency analysis

   If sufficient data are available at a site then an at-site frequency analysis can be undertaken. This involves analysing the data at a specific site to ascertain the rainfall corresponding to the design AEP. At-site rainfall frequency analysis is regularly performed by practitioners using readily available software.

2. Design rainfall estimation

   If data are not available or the available data are insufficient in terms of length of record or quality of data, the design rainfalls are estimated using statisitcal techniques. The Bureau of Meteorology (the Bureau) has recently released new design rainfall estimates for all locations across Australia (Bureau of Meteorology, 2016).

Although at-site frequency analysis is an integral part of design rainfall estimation, it is only one of many steps used in the derivation of the new design rainfalls. As a result, comparisons between rainfall quantiles derived using at-site frequency analysis and rainfall quantiles derived by design rainfall estimation need to be undertaken with caution.

Despite this, there is a tendency amongst some practitioners to compare the design rainfalls to at-site frequency analysis. This is particularly so where the 2016 design rainfall differ significantly from the previous design rainfalls (Bureau of Meteorology, 1987).

In the following sections, the two methods for deriving rainfall quantiles will be presented. For selected sites, rainfall quantiles estimated using both methods will be compared and the reason for the differences discussed.

AT-SITE RAINFALL FREQUENCY ANALYSIS

Approach

At-site rainfall frequency analysis involves the following steps:

1. extraction of either an Annual Maximum Series (AMS) or Partial Duration Series (PDS) from recorded data
2. ranking the data series from highest to lowest
3. determining plotting position (empirical estimates of AEP) of each data point

4. fitting a probability distribution to the data series
5. plotting the confidence limits associated with the probability distribution (commonly 95% and 5% confidence limits)
6. reading off the value of rainfall corresponding to a given AEP from the fitted distribution

Data requirements

In order for at-site rainfall frequency analysis to produce reliable quantile estimates, the data need to meet the following standards:

- the data need to be accurate
- the data need to meet the assumptions for accurate statistical analysis – of independence, stationarity and homogeneity
- there needs to be sufficent length of record to give reliable quantile estimates

Data accuracy

In order to accurately estimate rainfall quantiles, the data being used for the at-site frequency analysis needs to be as accurate as possible. In particular, as the largest recorded rainfalls are being used it is important to ensure that the data in the AMS or PDS are true maxima and not accumulated totals. Common errors in rainfall data are:

Daily Read Rainfall Data

- accumulated totals – over weekends; public holidays
- missing data – days, months, years
- unflagged accumulations
- time shifts – data recorded on the wrong day
- gross errors

Continuous Rainfall Data

- timeshifts of clock – DINES pluviographs
- errors in digitisation of charts or incorrect chart paper
- missed pulses – tipping bucket raingauges (TBRG)

Data assumptions

For accurate statistical analysis the rainfall data need to be:

- independent – the maxima in the series need to be independent and not part of the same event
- stationary – the series must not have changed over time due to long-term climate change or inter-decadal variability
- homogenous – the data must not have been subject to changes in data collection protocols (Dines; TBRG); change of gauge location or exposure; urbanisation

Data length of record

In order to estimate quantiles for the required range of probabilities shown in Table 1, adequate length of rainfall record is required. This is particularly the case in Australia, where the large natural variability in recorded rainfall means that longer periods of record are needed than in other parts of the world.

Various studies have been undertaken to determine the number of station-years required in a record to estimate rainfall quantiles for less frequent probabilities. Jakob et al. (1999) recommended that the total number of station-years be equal to approximately five times the return period of interest. Kjeldsen and Jones (2009) suggest the use of 500 station-years is appropriate regardless of the target return period.

This means that to estimate the 5% AEP rainfall quantle 100 years of record are required, however, as shown in Figure 1 only 520 daily read rainfall stations across Australia have over 100 years of record. Further, there are no stations which have the 500 years of record required to estimate the 1% AEP rainfall.

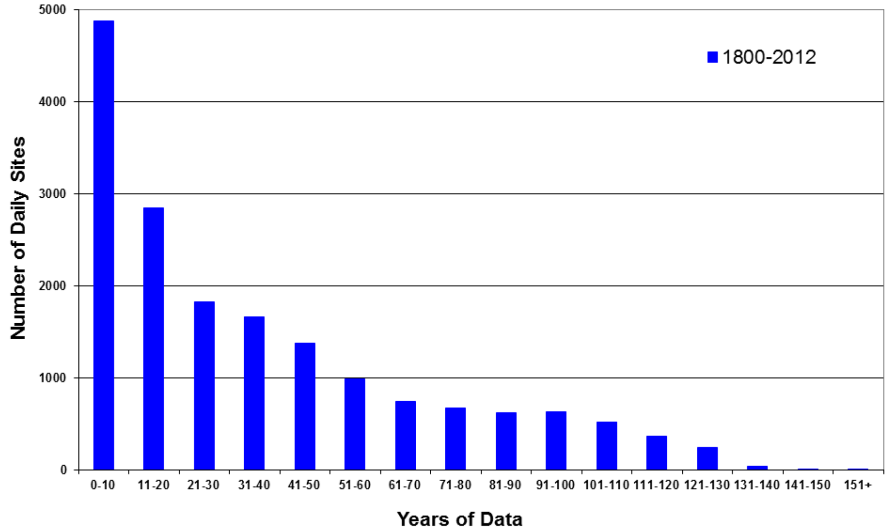

Figure 1. Length of Available Daily Read Rainfall Data.

The situation is considerably worse for continuous rainfall records as show in Figure 2 with only three continuous rainfall stations across Australia having over 100 years of record.

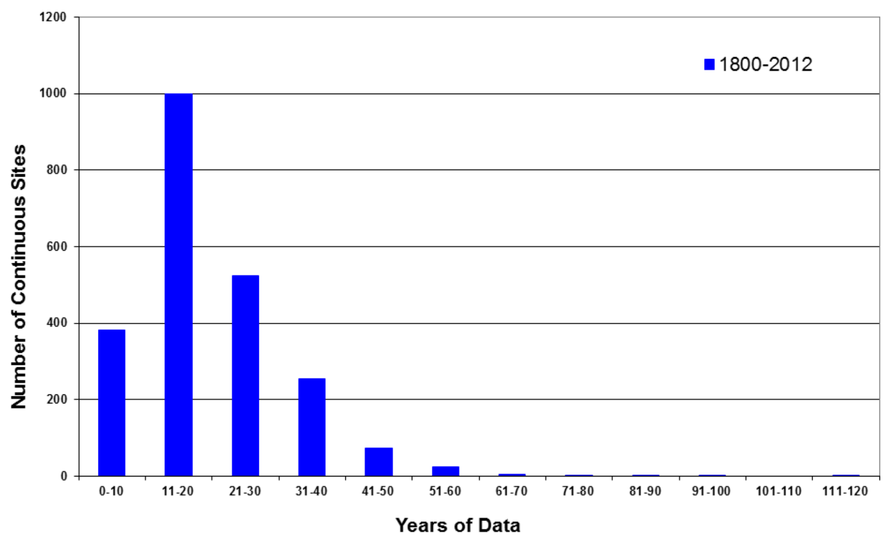

Figure 2. Length of Available Continuous Rainfall Data.

DESIGN RAINFALL ESTIMATION

Approach

Design rainfall estimation requires the following steps:

1. establishment of a database of rainfall data
2. quality controlling of the rainfall data

3. extraction of the AMS and PDS from the database
4. fitting a probability distribution to each data series
5. extraction of L-moments
6. extension of sub-daily rainfall statistics to daily read stations
7. regionalisation of statistics
8. gridding of data
9. extraction of the value of rainfall corresponding to a given AEP from the grids

The application of the general approach for design rainfall estimation is discussed further below for the 2016 design rainfall estimates.

Data requirements

The database established for the 2016 design rainfalls was sourced from organisations collecting rainfall data across Australia and consisted of 8074 daily read rainfall stations and 2280 continuous rainfall stations.

Data accuracy

In order to ensure that the rainfall data were as accurate as possible, a detailed and systematic approach for quality controlling all the daily read data and the PDS of the continuous rainfall data was applied. Automated quality controlling software was developed to assist in the identification and correction of a significant number of potential errors. The automated procedures were supplemented by the manual checking of the residual suspect data using the functionalities of the Bureau's Quality Monitoring System (QMS).

For the daily read rainfall data the automated quality controlling procedures:

- infilled missing data in each time series
- disaggregated flagged accumulated daily rainfall totals based on neighbouring records
- identified and corrected suspect data including:
  - unflagged accumulated totals; and
  - time shifts
- identified gross errors - data inconsistent with neighbouring records but not captured by either of the above two categories.

The automated quality control procedures for continuous rainfall data 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.

Each continuous rainfall value in the data subset that was flagged as being spurious by the automated quality controlling procedures was subjected to manual quality controlling. The manual quality controlling was undertaken to determine whether the flagged value was correct or not (Green et al, 2011).

Data assumptions

In order to ensure that the rainfall data met the requirements for accurate statisitcal analysis of independence, stationarity, and homogeneity the following analyses were undertaken:

- *independence* – meteorological analysis of daily read and continuous rainfall data was undertaken to define the minimum inter-event separation time (MIT) required between rainfall events to satisfy the requirement for events to be independent for valid frequency analysis. The resultant MIT were applied to the AMS and PDS (Xuereb and Green, 2012).
- *stationary* – two methods were used to establish if there were trends in the AMS. The first examined the records at individual stations to assess trends in the time series of the annual

maximum rainfalls and changes in the probability distributions fitted to the annual maxima to estimate design rainfall quantiles. The second method used an area averaged approach to check for regional trends in the number of exceedances of pre-determined thresholds for the series. It was concluded that although some individual stations showed strong trends in the annual maximum time series, particularly for short durations and more frequent events, the magnitude of these changes was within the expected accuracy of the fitted design rainfall relationships. It was therefore considered appropriate to assume stationarity and use the complete period of record at all stations in the estimation of the design rainfalls.

- *homogenous* – as part of quality controlling of the rainfall data, the metdata for each station was checked to identify changes in instrumentation; change of site; change in site clearance; and urbanisation

Data length of record

The length of record of the 8074 daily read rainfall stations and 2280 continuous rainfall stations in the rainfall database was from the commencement of recording for all stations to December 2012. However, in order to reduce the uncertainty in the design rainfall estimates, minimum station record lengths were adopted. The criteria used were:

- 30 or more years of record for daily read rainfall stations; and
- more than 8 years of record for continuous rainfall stations

As the above minimum station record lengths were still very short for the accurate estimation for most of the required design rainfall probabilities, regionalisation was used to reduce the uncertainty and overcome bias in estimating rainfall quantiles. Regionalisation recognises that for stations with short records, there is considerable uncertainty when estimating the parameters of probability distributions and short, overlapping 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.

The Region of Influence (ROI) approach was used for regionalising the station estimates. For the more frequent design rainfalls (5% AEP and more frequent) a circular ROI of 500 station years with distance defined in three dimensions was adopted. For the rarer design rainfalls (2% AEP and less frequent) the ROI was increased to a minimum of 2000 stations years (Johnson et al, 2012).

The regionalisation process enabled frequency distribution parameters and rainfall quantiles for any required exceedance probability to be estimated at any rainfall station site, however design rainfalls estimates were required across Australia, not just at station locations. Therefore, a spline interpolation method was applied to the regionalised rainfall data from across Australia to estimate gridded values for the whole country using the software package ANUSPLIN (Hutchinson 2007). This spline interpolation included a weighting for elevation from a 0.025 degree digital elevation model as part of the interpolation to account for the effects of topography on rainfall distribution, thus accounting for potential higher rainfall about elevated areas without rain gauges (The et al, 2012).

2016 DESIGN RAINFALL ESTIMATES

The design rainfall estimation approach described above was used to estimate new design rainfalls for Australia (Bureau of Meteorology, 2016). The 2016 design rainfalls are based on a more extensive database, with more than 30 years of additional rainfall records and inclusion of data from an extra 2300 rainfall stations across Australia. By combining contemporary statistical analysis and techniques with this expanded rainfall database, the 2016 design rainfalls provide more accurate design rainfall estimates for Australia than previously provided. As is to be expected, the differences between the data and methods adopted have resulted in differences between the 2016 design rainfall quantiles and the 1987 design rainfall quantiles (Bureau of Meteorology, 1987). These differences vary not only across Australia but across durations and quantiles as shown in Figure 3 for the case of a one hour duration and 1% AEP.

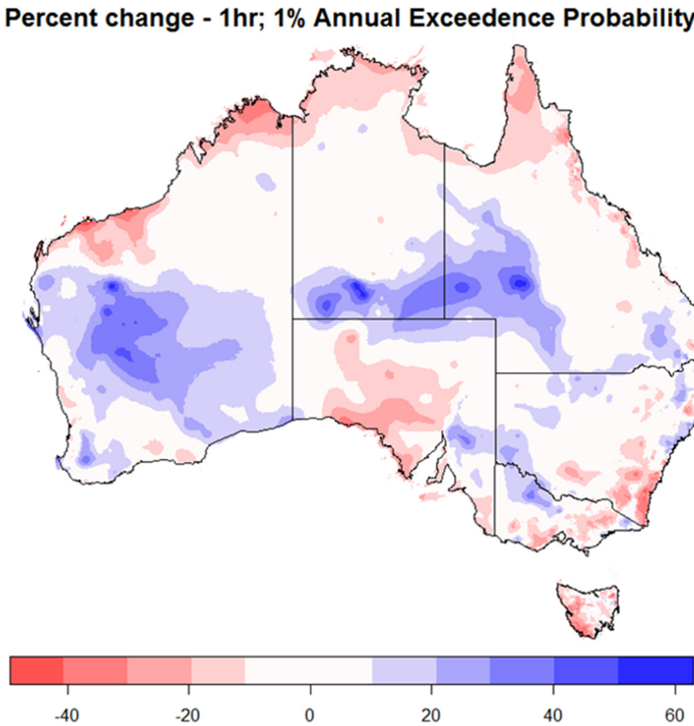

Figure 3. Differences (%) between 2016 design rainfalls and 1987 design rainfalls across Australia for the 1 hour duration, 1% AEP.

Looking at a more specific region, Figure 4 shows the changes for seven sites in Tasmania for the 24 hour duration and the 50% AEP and 1% AEP probabilities. As shown in Figure 4, the changes range from -16.4% to +21.0%

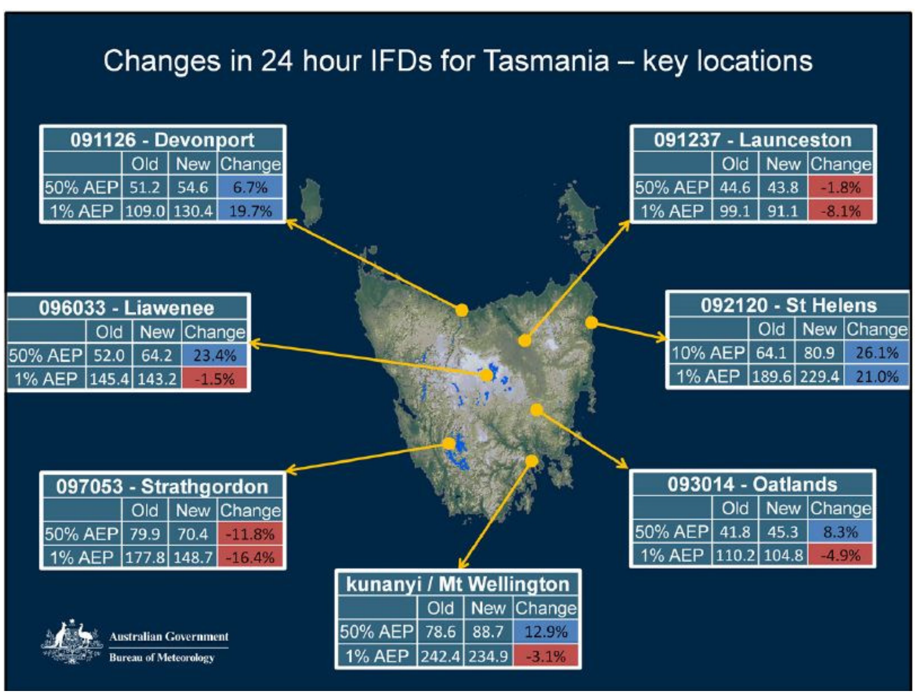

Figure 4. Differences (%) between 2016 design rainfalls and 1987 design rainfalls for key locations in Tasmania.

When faced with large differences between the new design rainfalls and the 1987 design rainfalls, some users have attempted to 'sanity check' the new design rainfalls by comparing them to quantiles derived from at-site rainfall frequency analysis. This is despite the fact that the differences between at-site rainfall frequency analysis and design rainfall estimation (as described above) mean that at-site quantiles cannot be compared directly to gridded, regionalised design rainfall quantiles.

In the following section, the quantiles derived by at-site rainfall frequency analysis and the quantiles derived by design rainfall estimation will be compared for two sites in Tasmania.

COMPARING AT-SITE FREQUENCY ANALYSIS AND DESIGN RAINFALL QUANTILES

As shown in Figure 4, differences are seen between the 2016 design rainfall quantiles and the 1987 design rainfall quantiles. For two sites, these design rainfall quantiles are compared to the at-site rainfall frequency analysis.

091126 Devonport

The rainfall station at Devonport (091126) was opened in 1962 and has over 50 years of rainfall records. Table 2 shows the quantiles from the 1987 design rainfalls and the quantiles from the 2016 design rainfalls while Figure 5 compares the design rainfall quantiles with the at-site rainfall frequency quantiles.

Table 2. Design Rainfall Quantiles – 091126 Devonport.

AEP	1987 Design Rainfall (mm)	2016 Design Rainfall (mm)
1EY	45.84	49.30
50%*	51.19	54.60
20%*	65.08	71.90
10%	73.92	84.50
5%	84.00	97.40
2%	97.92	116.00
1%	108.96	130.40

*Note: The 1987 2 year and 5 year design rainfalls have been converted to 50% AEP and 20% AEP to allow this comparison.

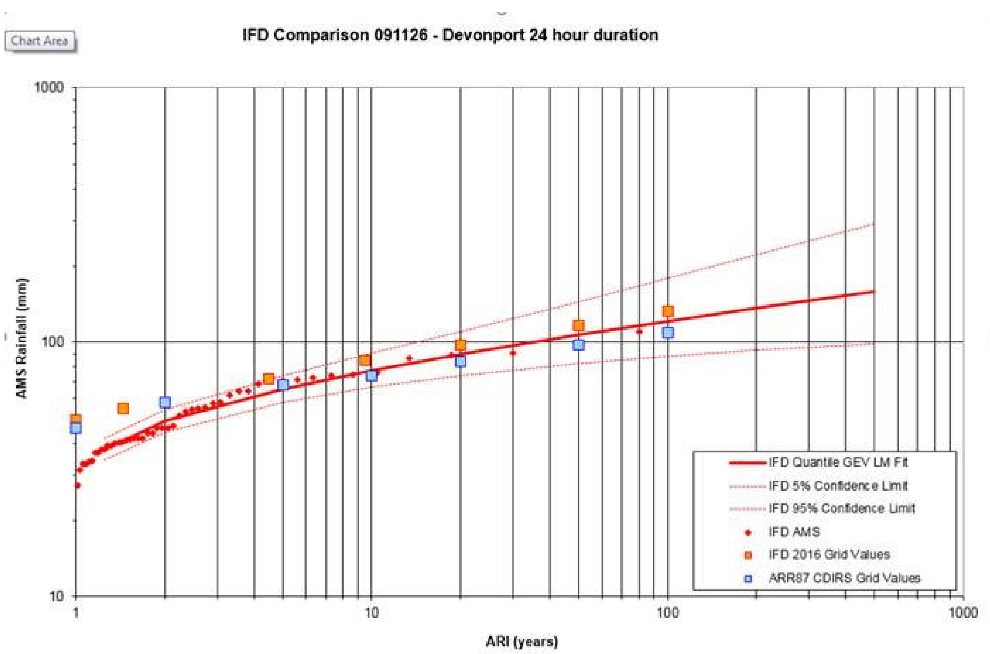

Figure 5. Comparison between design rainfall and at-site quantiles – 091126 Devonport

Comparing the two sets of design rainfall quantiles and the quantiles derived using at-site rainfall frequency analysis, the following observations can be made:

- although with more than 50 years of record, the data from rainfall station Devonport (091126) was included in the 2016 design rainfall database, it was not included in the 1987 design rainfall database as it did not meet the criterion of 30 or more years of record for daily read rainfall stations that was adopted for the 1987 database;
- as a consequence, the 1987 design rainfall quantiles would not have been estimated using data from the site
- even though rainfall station Devonport (091126) has approximately 50 years of data, this would only enable accurate quantiles to be estimated for the 10% AEP and more frequent quantiles
- the 2016 design rainfall quantiles incorporate not only data from the site but, through the regionalisation process incorporate data from surrounding rainfall stations to increase the number of station years to 500 (for the more frequent AEPs) and 2000 (for the rarer AEPs)

092120 St Helens

The rainfall station at St Helens (092120) was opened in 2001 and has approximately 15 years of rainfall records. Table 3 shows the quantiles from the 1987 design rainfalls and the quantiles from the 2016 design rainfalls while Figure 6 compares the design rainfall quantiles with the at-site rainfall frequency quantiles.

Table 3. Design Rainfall Quantiles – 092120 St Helens.

AEP	1987 Design Rainfall (mm)	2016 Design Rainfall (mm)
1EY	54.96	69.90
50%*	64.14	80.90
20%*	93.23	116.00
10%	113.04	142.00
5%	134.64	167.00
2%	164.88	202.00
1%	189.60	229.40

*Note: The 1987 2 year and 5 year design rainfalls have been converted to 50% AEP and 20% AEP

Comparing the two sets of design rainfall quantiles and the quantiles derived using at-site rainfall frequency analysis, the following observations can be made:

- with only approximately 15 years of record, the data from rainfall station St Helens (092120) was not included in either the 2016 design rainfall database or the 1987 design rainfall database. For the 1987 design rainfall database the station had not been opened and for the 2016 design rainfall database it did not meet the criterion of 30 or more years of record for daily read rainfall stations;
- as a consequence, the neither 1987 design rainfall quantiles or the 2016 design rainfall quantiles would have been estimated using data from the site
- the limited amount of data (approximately 15 years) available at rainfall station St Helens (092120) would only enable accurate quantiles to be estimated for probabilities more frequent than the 20% AEP
- the 2016 design rainfall estimation process, through the regionalisation process and subsequent gridding, enables design rainfall quantiles for the complete range of probabilities to be provided at a site where there is limited reorded rainfall data.

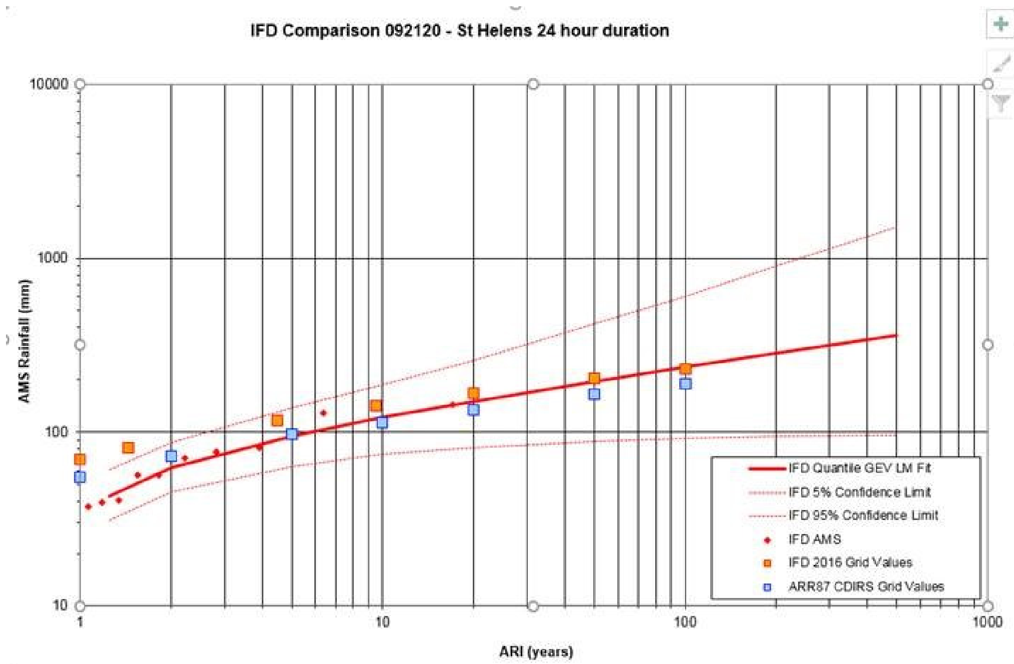

Figure 6. Comparison between design rainfall and at-site quantiles – 092120 St Helens

CONCLUSIONS

There are two main methods for estimating rainfall quantiles for the range of probabilities required for the design of infrastructure. Where there is sufficient data available at a site, then an at-site frequency analysis can be undertaken. If data are not available or the available data are insufficient in terms of length of record or quality of data, the design rainfalls are estimated using statisitcal techniques.

Each of the approaches requires that the data be accurate, independent, stationary, homogenous, and of sufficent length of record in order to produce reliable rainfall quantile estimates for the probability of interest. While the detailed analyses undertaken in the application of design rainfall estimation meet these requirements, they are less likely to be met during at-site rainfall frequency analysis.

The new design rainfall estimates for Australia recently released by the Bureau of Meteorology are based on a greatly expanded database which has been analysed using contemporary statistical techniques; as such they are better estimates than previous design rainfall estimates. Further, as the new design rainfall quantiles are regionalised, gridded estimates they are more accurate than rainfall quantiles derived using at-site rainfall frequency analysis.

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