# Modelling the impacts of water use, urban development and climate projections on surface water resources in the Barossa Prescribed Water Resources Area

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# Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provide the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Landscape Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

**John Schutz**
**CHIEF EXECUTIVE**
**DEPARTMENT FOR ENVIRONMENT AND WATER**

# Acknowledgements

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# Summary

Hydrological surface water modelling of the Barossa Prescribed Water Resource Area (PWRA) was undertaken in 2013-14, to support the review of the 2009 Barossa Water Allocation Plan. The key objectives were to define and quantify the surface water resource capacity in the PWRA and to evaluate the potential impacts of different management scenarios on flow regime. Ecological investigations were undertaken during the same period to define surface water management zones based on hydro-ecological characteristics; to develop hydro-ecological response models using the outputs from the surface water modelling and to identify risks to the water-dependent ecosystems under different water management scenarios. At this time, it was envisaged that as the amendment of the water allocation plan progressed, further hydro-ecological investigations would be required in the form of additional management scenario modelling and risk assessments.

This technical report describes the methodology and outcomes of an additional hydrological study undertaken for the Barossa PWRA in 2018. The purpose was to update the original hydrological model for the Barossa PWRA to:

i. Aid in assessing the impacts of the current water use, urban development and future climate projections on the Barossa PWRA flow regime, and
ii. Provide model outputs for further analysis related to environmental water requirements (EWRs) and risks to those EWRs under different conditions, including current conditions, full allocation; impacts of potential urban runoff capture and reuse and impacts of potential changes to climate.

The work was completed in 2018 for internal use to support decision making processes regarding water allocation planning within the PWRA. The modelling work contained herein uses the best data available at the time, aspects of it may have been superseded by updated data and knowledge.

**Model update and Scenario modelling**

Climate data and streamflow data were extended up to 2016, being the most recent data available at the time of modelling (2018). The hydrological model for the Barossa PWRA was recalibrated using the current (for the time) observed daily rainfall, evaporation, streamflow records and farm dam properties (e.g. capacity and surface area) within the Greenock Creek and Salt Water Creek project zones. In addition, a separate surface water model was developed for the Greenock Creek and Salt Water Creek project zones, including details of farm dams included in applications for water licenses yet to be issued ("likely to be" licensed dams) at the time of the assessment. Catchment parameters from the re-calibrated model of the Barossa PWRA were applied to the model for Greenock Creek and Salt Water Creek zones. The two models were then used simultaneously to generate simulated catchment runoff under various scenarios, to investigate the likely impacts of these scenarios on streamflow across the catchment.

Including "likely to be" licensed dams within Greenock Creek and Salt Water Creek project zones at the time of the assessment, there were a total of 1780 farm dams in the Barossa PWRA, 14% of which were licensed. The total estimated farm dam storage capacity in the Barossa PWRA was estimated to be 8692 ML, 68% of which was licensed. Several farm dams falling within the Barossa PWRA were excluded because they are not hydrologically connected to the Greenock Creek project zone.

Runoff generated from project zones, excluding farm dams and watercourse extractions, is termed 'Resource Capacity' and is generally used as a base volume from which water can be allocated sustainably to runoff capturing farm dams. The total surface water resource capacity of the Barossa PWRA was estimated to be 18.6 GL (41 mm when expressed in flow depth). This varied across the project zones within the Barossa PWRA, ranging from 70 to 80 mm in the high rainfall project zones of Upper Jacob Creek and Upper Tanunda Creek to around 11 mm in the lower rainfall project zones of Duck Ponds Creek and Mid Flaxman Valley.

Scenario modelling was used to investigate the likely impacts of different management scenarios on streamflow across the study area. Outputs from scenario modelling aid in assessing impacts on other hydrological responses, such as flow requirements of water-dependent ecosystems (WDEs) within the catchment.

**Summary of results**

Results of the modelling and further analysis of data for seventeen project zones indicate that the level of development (farm dams and watercourse extractions) had reduced the average annual streamflow in the Barossa PWRA by around 17%. This reduction was much higher during drier years, in excess of a 50% reduction. This reduction also varied across the project zones, and was dependent on a number of factors including farm dam density and rainfall and runoff variability.

Higher flow reductions were estimated across all the project zones when simulating the use of full allocations volumes, compared with current use scenario flow reductions. This reflects the fact that current use in most of the project zones was substantially lower than the allocated volumes. The estimated reductions in flows were highest in the Lower Flaxman Valley, Lower Jacobs Creek and Barossa Valley Gorge project zones, and were lowest in the Duck Ponds Creek, Upper Jacob Creek and Lyndoch Creek project zones. This again reflected the extent of development, and also the proportion of licensed to non-licensed use within each zone, with zones that had a higher proportion of licensed to non-licensed use showing greatest impacts.

To assess the impact of urban development on flow regime, daily flows were simulated at the end of each zone with and without the inclusion of urban areas. For this scenario, the reduction in generated runoff was significant for the project zones with larger urban areas, such as the Transition Zone, Barossa Valley Floor and Upper Angaston project zones, with the highest reduction of 25mm assessed in the Transition Zone project zone. Based on this, it was estimated that urban runoff accounted for nearly 14% of average annual flows at the outlet of the Barossa PWRA.

The long-term impact of climate change on flow regime at zone scale was also considered. Climate projections for rainfall and PET from three selected Global Circulation Models (GCMs), and for two emissions scenarios, were incorporated as model inputs into these hydrological models. One hundred realisations of each combination of GCMs and emissions (produced as part of the Goyder Institute SA climate ready data project) were used as inputs to the hydrological models, enabling an estimate to be made of variability in flow regime due to impacts of potential changes to climate over time until 2100.

For the intermediate emission scenario the median annual rainfall for each decade fluctuated between -5% and -10% below the mean historical baseline ("Historical") up to around 2050. The variability in annual rainfall increased slightly from 2050 onward. This reduction increased slightly for the high emission case, particularly after 2050, and the median annual rainfall fluctuated between -10% and -30% below the mean historical baseline. The median annual PET for each decade increased between 3% and 6% above the mean historical baseline under the intermediate emission scenario. The increase was more pronounced under the high emission scenario being between 5% and 11% above the mean historical baseline.

The climate projections were used as inputs to the hydrological models to produce the daily streamflow at the end of each project zone in the Barossa PWRA up to 2100. The final model set up used for the calibration process was configured with the future climate projection data, and the model run period modified to accommodate the future climate period. This meant the models represented the level of water use and current urban development at the time of assessment. It was assumed that there were no further changes in these parameters for the future projection period, and that the calibrated rainfall-runoff relationship represented by the GR4J parameters was suitable for the future climate condition.

Analysis of model outputs indicated that the combination of the projected reduced rainfall and increased PET resulted in reduced streamflow. As an example, for the decade of 2080 the median annual streamflow reduced by 60% for the intermediate emissions case, and 80% for the high emissions case. This pattern of impact was observed across all project zones, with the degree of impact varying based on the level of farm dam development in the project zones.

The results of this investigation will inform the amendment of the Water Allocation Plan (WAP) for the Barossa PWRA, by providing the scientific basis and data for establishment of surface water resource capacity, environmental water requirements and provisions, and ultimately in establishment of environmentally sustainable extraction limits for the PWRA.

# 1 Introduction

## 1.1 Context

The Barossa Water Allocation Plan (WAP) was reviewed in 2014, which at the time resulted in the (then) Adelaide and Mount Lofty Ranges Natural Resources Management (AMLR NRM) Board and (then) Minister for Sustainability, Environment and Conservation endorsing an amendment to the WAP. In order to support this amendment, the (then) AMLR NRM Board (through Natural Resources AMLR) engaged the (then) DEWNR to undertake technical investigations.

Hydrological surface water modelling was undertaken in 2013/14 to support the WAP review, and to define resource capacity and evaluate different management scenarios. As part of this work, ecological investigations were undertaken to characterise zones of similar ecology and several hydro-ecological response models were applied to identify ecological risks to the water-dependent ecosystems (WDEs) of the Barossa PWRA under different water resource management scenarios.

Groundwater investigations were undertaken in 2014/15 and 2015/16 to define resource capacity and evaluate different management scenarios, as well as estimate the potential impacts of climate change using the Goyder Institute's SA Climate Ready Data for South Australia (Goyder Institute for Water Research Occasional Paper No. 15/1).

It was envisaged that, as the amendment of the water allocation plan progressed, additional hydro-ecological work would be required in the form of additional management scenario modelling and risk assessments.

The progressive approach to water planning, including incorporating climate projections into the proposed model scenarios, also provided an opportunity to:

- update the hydrological model with the latest climate data, streamflow data and farm dam data; and
- verify model calibration against a wetter than average period, notably the year 2016.

## 1.2 Scope of the study

This technical report describes the methodology and outcomes of a hydrological study undertaken for the Barossa PWRA. The main purpose of this study was to update the existing Source hydrological model for the Barossa PWRA to (i) assess impacts of current water use, urban development and future climate projections on the Barossa PWRAs flow regime, and (ii) provide model outputs required for further analysis related to environmental water requirements within the Barossa PWRA. The original hydrological model is described in detail in Jones-Gill and Savadamuthu (2014).

The scope of this study includes the following:

- Extension of the modelling period to include up to date climate and streamflow data, in particular the high flow events of 2016;
- Update of the dam information (location, volume, surface area) for the Greenock Creek and Salt Water Creek zones, to better represent surface water development in that area;
- Assessment of the impact of a number of scenarios on the flow regime, including:
    - Farm dam development
    - Urban development
    - Climate projections
- Provision of modelled outputs for further hydro-ecological analysis

# 2 Data update and analysis

This section describes modifications and updates made to the farm dam, rainfall and streamflow input data-sets to the hydrological model of the Barossa PWRA. In the previous study, the Barossa PWRA was divided into 19 project zones (Figure 2.1), of which analysis and results for 17 project zones were presented. Of the two project zones that were not included in that study, one is a small section of the South Para Catchment near Williamstown and the other is Stockwell Creek, both of which do not drain into the North Para River and hence were not included in the modelling. This study also provides analysis and results for the same 17 project zones. Explanation on the methodology used in the process of catchment delineation is provided in Green et al., 2014.

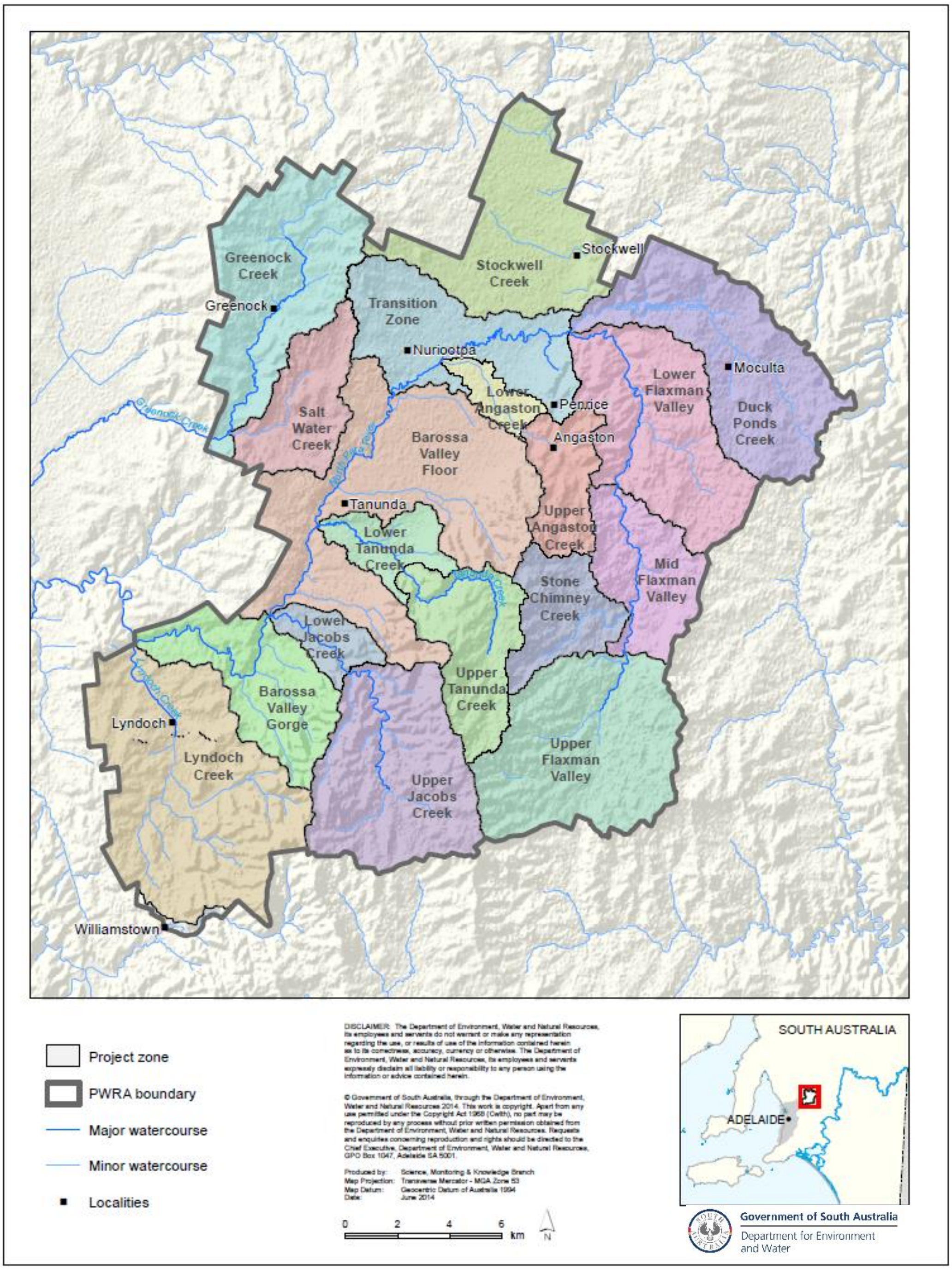



**Figure 2.1. Barossa PWRA surface water management zones**

## 2.1 Farm dam data

Inputs to the previous model were based on information derived from a 2010 aerial survey, which was digitised and stored in a GIS layer "AHGF_Waterbodies_2013". This spatial layer provides the location and surface area of dams across the Barossa PWRA. These dam surface areas were used to estimate the capacity of each dam using established dam volume to dam surface area relationships, see Jones-Gill and Savadamuthu (2014) for details.

In the preceding study, farm dams within the Greenock Creek and Salt Water Creek project zones were considered to be used for non-licensed purposes. Further assessment of the purpose of these farm dams was undertaken at the time of the assessment, and 80 of the farm dams were considered as being potentially used for licensed activities, as they were included on applications for water licenses which were yet to be issued at the time of assessment ('likely to be" licensed dams). In addition, farm dam properties (surface areas and volumes) were updated through these assessments and incorporated in the separate model built for these two project zones.

Including the "likely to be" licensed dams (at the time of assessment) within Greenock Creek and Salt Water Creek project zones, there were a total of 1780 farm dams in the Barossa PWRA, 14% of which were licensed. The total estimated storage capacity of those dams was 8692 ML, 68% of which was licensed.

Approximately 84% of farm dams were assessed to have a capacity less than 5 ML, representing 18% of the total storage capacity (Figure 2.2). A total of 53% of the dams fell into the lowest capacity category of less than 1 ML. Larger farm dams, with 10 ML capacity or greater, made up only 10% of the total number of farm dams, but contributed to 72% of the total storage capacity. The largest farm dams (>100 ML) constituted 25% of total storage capacity while being only 1% of the total number of farm dams.

Figure 2.2 shows that farm dams of capacity under 5 ML represented 84% of all farm dams in number, but only 4% of these farm dams were licensed. Most (73%) of the licensed farm dams were assessed to have a capacity greater than 5 ML, and the 25 licensed farm dams in the highest capacity categories (2% of the total number of farm dams) made up approximately 35% of the total farm dam capacity in the Barossa PWRA.

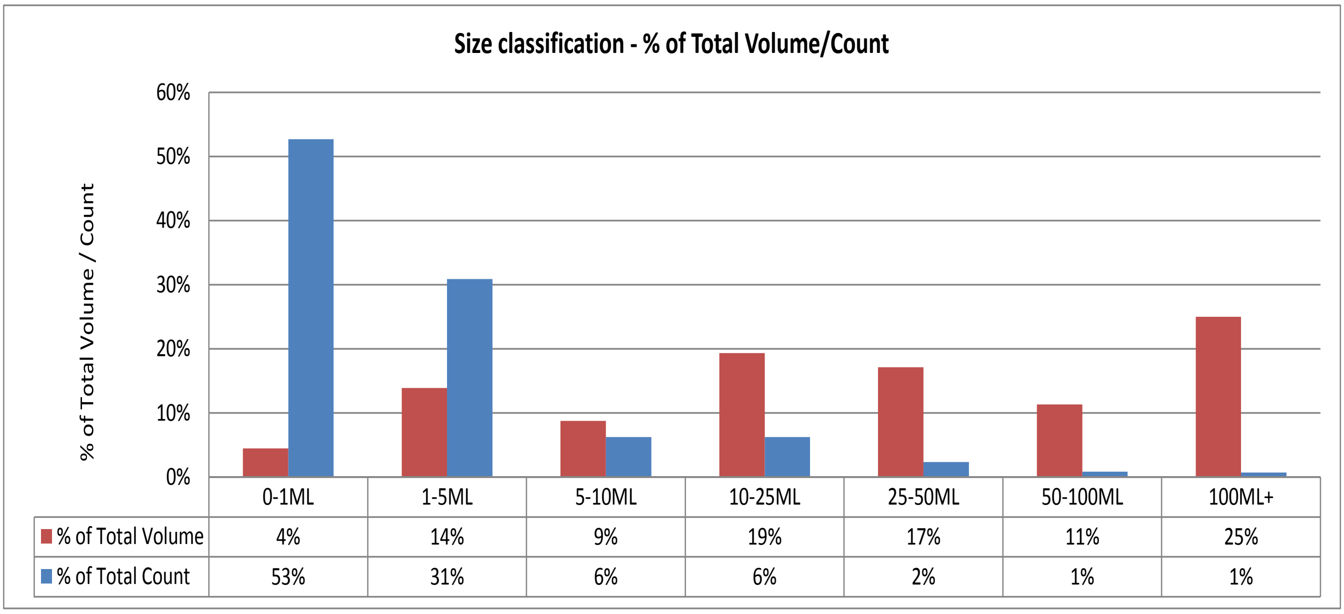



**Figure 2.2. 2018 combined volume of farm dams in each size classification for the Barossa PWRA**

Further analysis takes into account the split between licensed and non-licensed farm dams across the different size classifications. The updated number of licensed and non-licensed farm dams and their storage capacity is provided in Table 2.1.

**Table 2.1. 2018 Licensed and non-licensed farm dam size classification for the Barossa PWRA**

| Dam size class (ML) | No. dams Licensed | (%) | No. dams Non-licensed | (%) | % total dams | Storage capacity (ML) Licensed | (%) | Storage capacity (ML) Non-licensed | (%) |
|---|---|---|---|---|---|---|---|---|---|
| < 1 | 10 | (1%) | 928 | (52%) | 53% | 6 | (0%) | 385 | (4%) |
| 1–5 | 58 | (3%) | 492 | (28%) | 31% | 163 | (2%) | 1047 | (12%) |
| 5–10 | 57 | (3%) | 54 | (3%) | 6% | 394 | (5%) | 369 | (4%) |
| 10–25 | 68 | (4%) | 43 | (2%) | 6% | 1066 | (12%) | 616 | (7%) |
| 25–50 | 37 | (2%) | 5 | (0%) | 2% | 1325 | (15%) | 162 | (2%) |
| 50–100 | 12 | (1%) | 3 | (0%) | 1% | 810 | (9%) | 176 | (2%) |
| > 100 | 13 | (1%) | 0 | (0%) | 1% | 2171 | (25%) | 0 | (0%) |
| Total | **255** | (14%) | **1525** | (86%) | 100% | **5935** | (68%) | **2756** | (32%) |

Farm dam density provides a measure of the intensity of farm dam development across the landscape, and is calculated as Farm dam density (ML/km$^2$) = total farm dam capacity (ML) / catchment area (km$^2$). Updated farm dam density for the entire Barossa PWRA at the time of assessment was 16 ML/km$^2$, which is a similar value to other catchments in the Mount Lofty Ranges. However it is typical that farm dam density vary across catchments. Table 2.2 and Figure 2.3 shows farm dam densities on a project zone scale across the Barossa PWRA.

**Table 2.2 2018 Farm dam data for project zones in the Barossa PWRA**

| Project zone | Total no. dams | No. licensed dams | No. non-licensed dams | Total storage capacity (ML) | Licensed dam capacity (ML) | Non-licensed dam capacity (ML) | Farm dam density (ML/ km$^2$) |
|---|---|---|---|---|---|---|---|
| Upper Flaxman Valley | 283 | 37 | 246 | 1555 | 1152 | 403 | 35 |
| Stone Chimney Creek | 110 | 18 | 92 | 459 | 332 | 128 | 31 |
| Mid Flaxman Valley | 46 | 1 | 45 | 149 | 3 | 146 | 8 |
| Lower Flaxman Valley | 102 | 2 | 100 | 159 | 29 | 130 | 4 |
| Duck Ponds Creek | 141 | 3 | 138 | 120 | 12 | 108 | 3 |
| Stockwell Creek | 99 | 17 | 82 | 433 | 195 | 238 | 14 |
| Transition Zone | 81 | 21 | 60 | 416 | 230 | 186 | 14 |
| Upper Angaston Creek | 40 | 3 | 37 | 94 | 43 | 51 | 7 |
| Lower Angaston Creek | 8 | 1 | 7 | 28 | 3 | 26 | 6 |
| Barossa Valley Floor | 185 | 24 | 161 | 745 | 489 | 256 | 12 |
| Greenock Creek | 147 | 44 | 103 | 821 | 702 | 119 | 22 |
| Salt Water Creek | 91 | 34 | 57 | 462 | 363 | 99 | 24 |
| Upper Tanunda Creek | 72 | 7 | 65 | 700 | 590 | 111 | 32 |
| Lower Tanunda Creek | 45 | 14 | 31 | 229 | 172 | 57 | 24 |
| Upper Jacob Creek | 117 | 15 | 102 | 1062 | 893 | 169 | 26 |
| Lower Jacob Creek | 18 | 1 | 17 | 259 | 204 | 55 | 37 |
| Lyndoch Creek | 148 | 11 | 137 | 678 | 310 | 368 | 11 |
| Barossa Valley Gorge | 47 | 2 | 45 | 321 | 214 | 108 | 13 |
| **Total (Barossa PWRA)** | **1780** | **255** | **1525** | **8692** | **5935** | **2756** | **17** |

The updated model makes the assumption that water use follows the same distribution pattern incorporated in the previous study. For example, water use from “likely to be” licensed dams within the Greenock Creek and Salt Water Creek project zones was set at 34% of the farm dam capacity (similar to use from licensed dams in other project zones), as metered water use data was not available at the time of assessment.

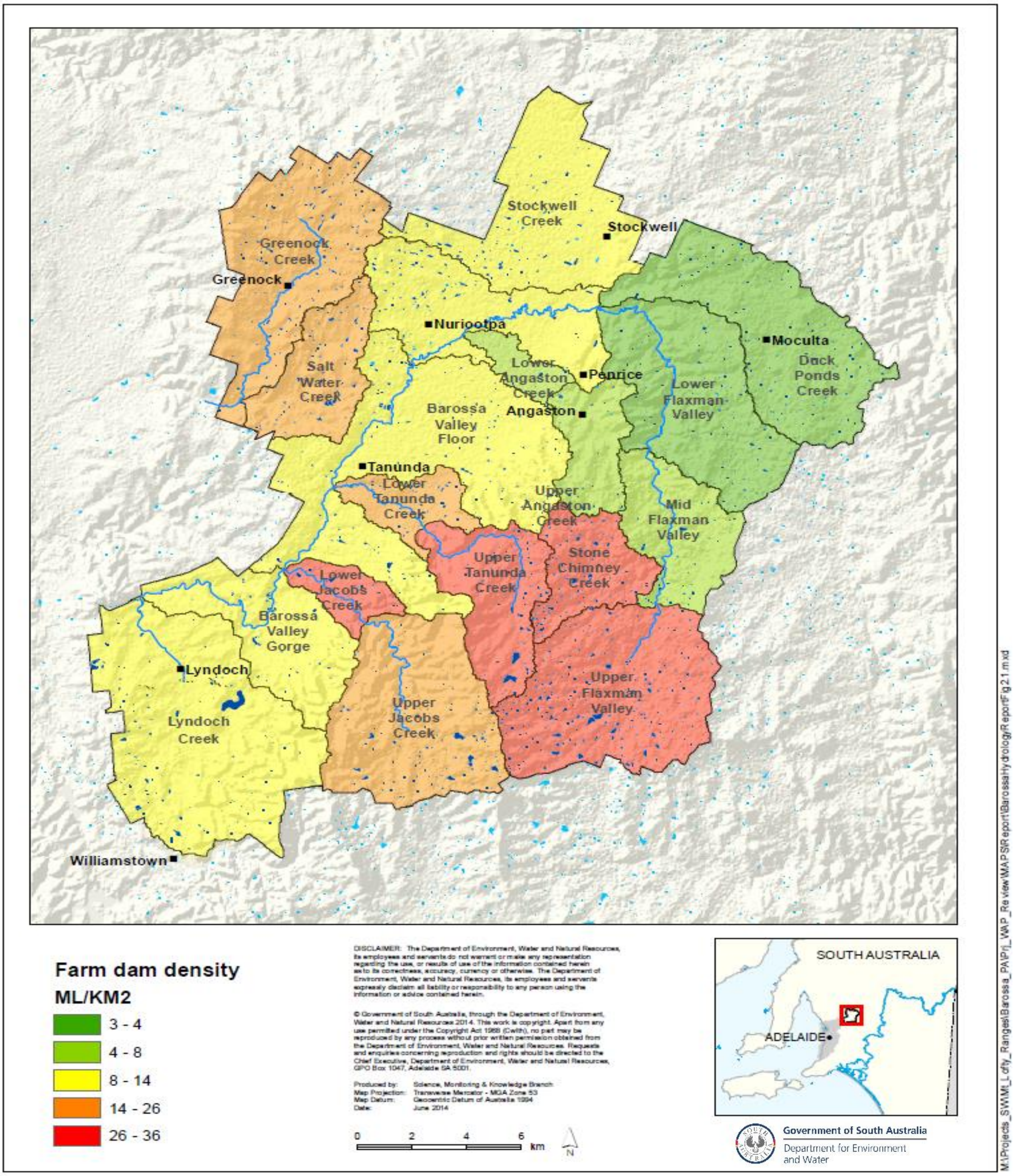



**Figure 2.3. Farm dam densities**

## 2.2 Rainfall data

The Barossa PWRA has good spatial and temporal coverage of rainfall gauging stations (Jones-Gill A and Savadamuthu K, 2014), with daily rainfall records available from as early as 1870 (Figure 2.4). Analysis of daily rainfall data was previously undertaken at monthly and decadal time scales up to 2012 for 13 rainfall sites. In addition, community rainfall data recorded at Heggies Vineyard (location of higher rainfall) was analysed, and included to the dataset. The rainfall datasets were updated up to December 2016 for all sites, and trend analysis performed.

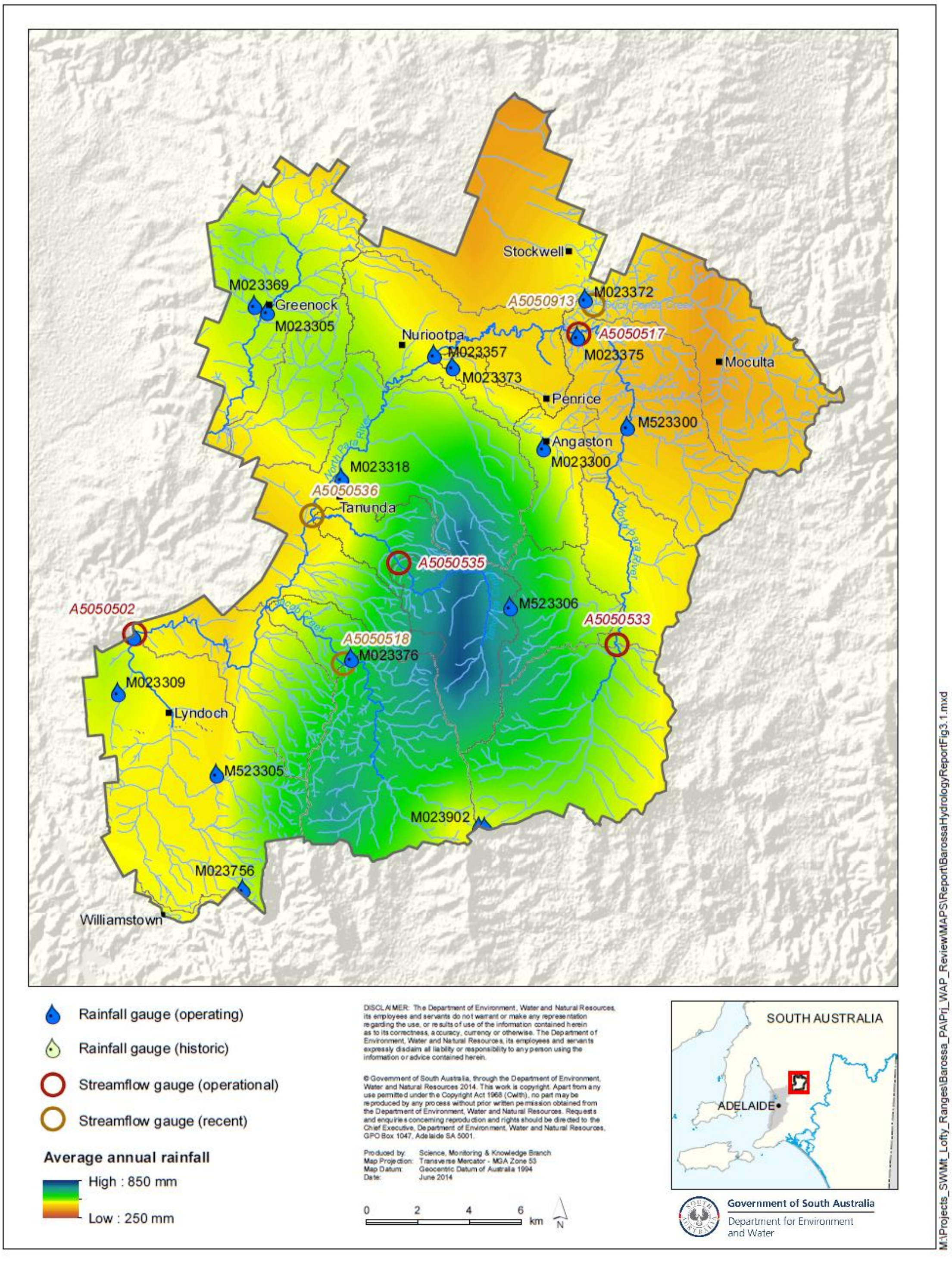



**Figure 2.4. Rainfall and streamflow gauges in the Barossa PWRA**

Residual mass analysis is a useful method for examining trends in long-term data. On a year-by-year basis, the residual of the annual rainfall less the long-term average rainfall was calculated. Positive residuals represent wetter than average years, with negative residuals representing drier than average years. A residual mass curve is a plot of the cumulative residual over time. Therefore, an upward trending residual mass curve indicates a wet period and vice versa. Figure 2.5 shows the residual mass curve for the rainfall sites with long-term SILO data available across the Barossa PWRA and Figure 2.6 shows the trend over the last decade.

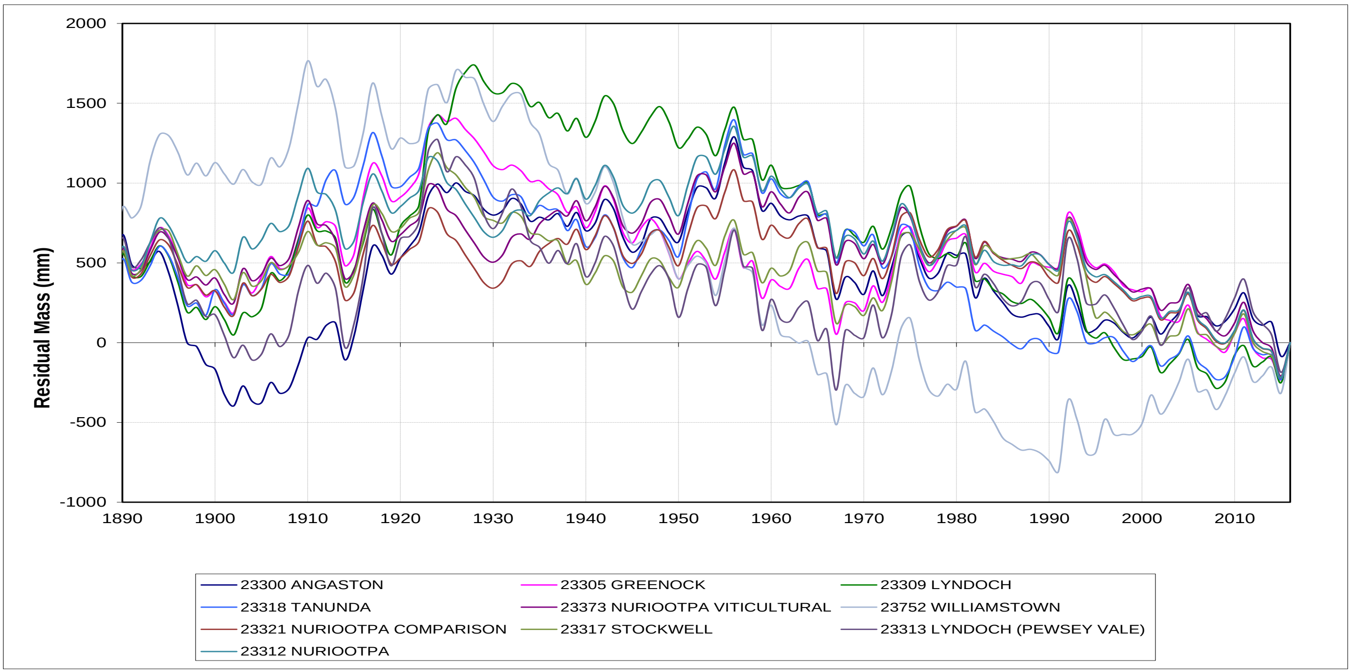



**Figure 2.5. Residual mass curves for rainfall sites across the Barossa PWRA (SILO sites only)**

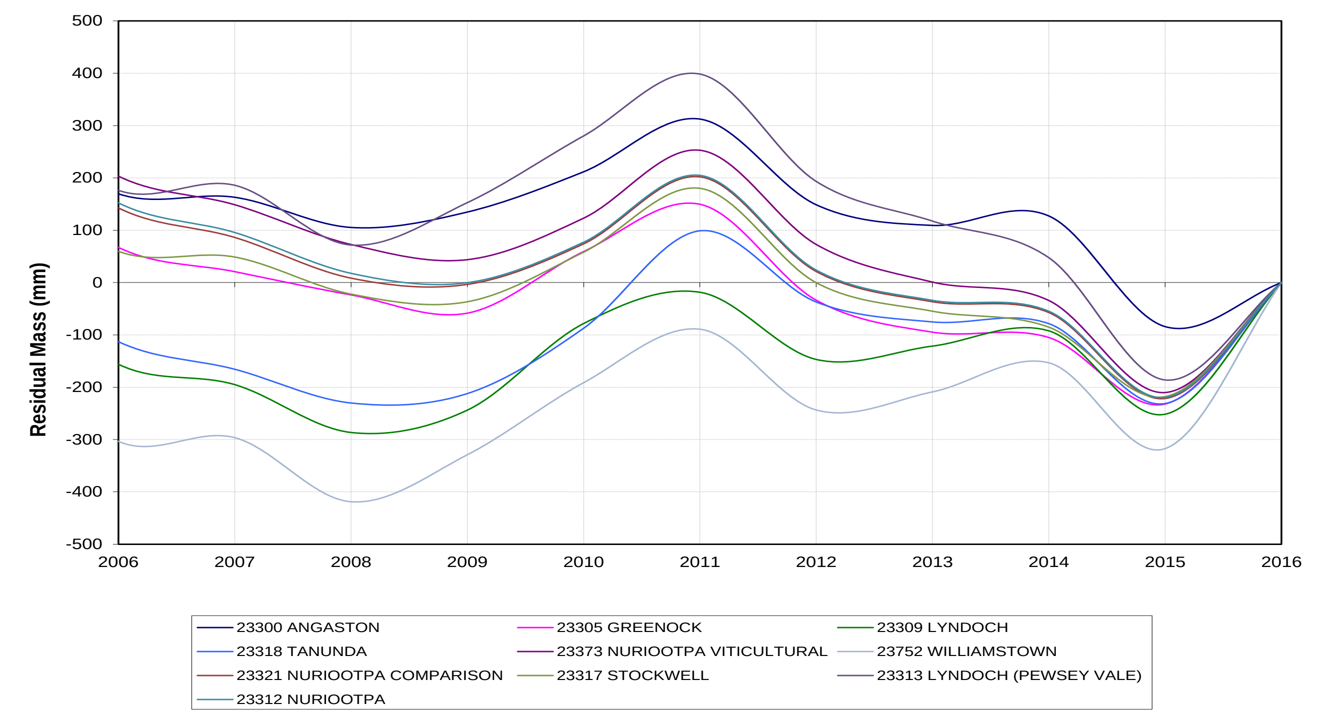



**Figure 2.6. Residual mass curves for rainfall sites across the Barossa PWRA (SILO sites only) – last decade**

The majority of rainfall stations exhibit similar trends for the period 1889 to 2016:

- an upward trend indicating a wetter than average period occurs from approximately 1900 to the early 1920s
- a relatively stable period, indicating average rainfall conditions from the early 1920s to 1960
- a decreasing trend indicating drier than average rainfall conditions from 1960 to 2015.
- then a slight upward trend is shown in 2016 due to wetter than average conditions in this year.

Stations numbers 23312 (Nuriootpa) and 23752 (Williamstown) appear to be exceptions. Nuriootpa has a comparatively stable residual mass curve throughout the period, indicating a less variable trend. This is consistent with the location of this site being on the Barossa Valley Floor.

Figure 2.7 to Figure 2.12 show the annual and decadal rainfall for Angaston (23300), Tanunda (23318) and Williamstown (23752), respectively.

The rainfall observed at Angaston in 2016 is significantly higher than the preceding few years, but still remains close to the long-term average (534mm). The rainfall observed at Tanunda and Williamstown in 2016 was significantly higher than the preceding few years and also the long-term averages of 552 mm and 649 mm respectively. Consequently, the period from 2010 to 2016 exceeds this long-term average.

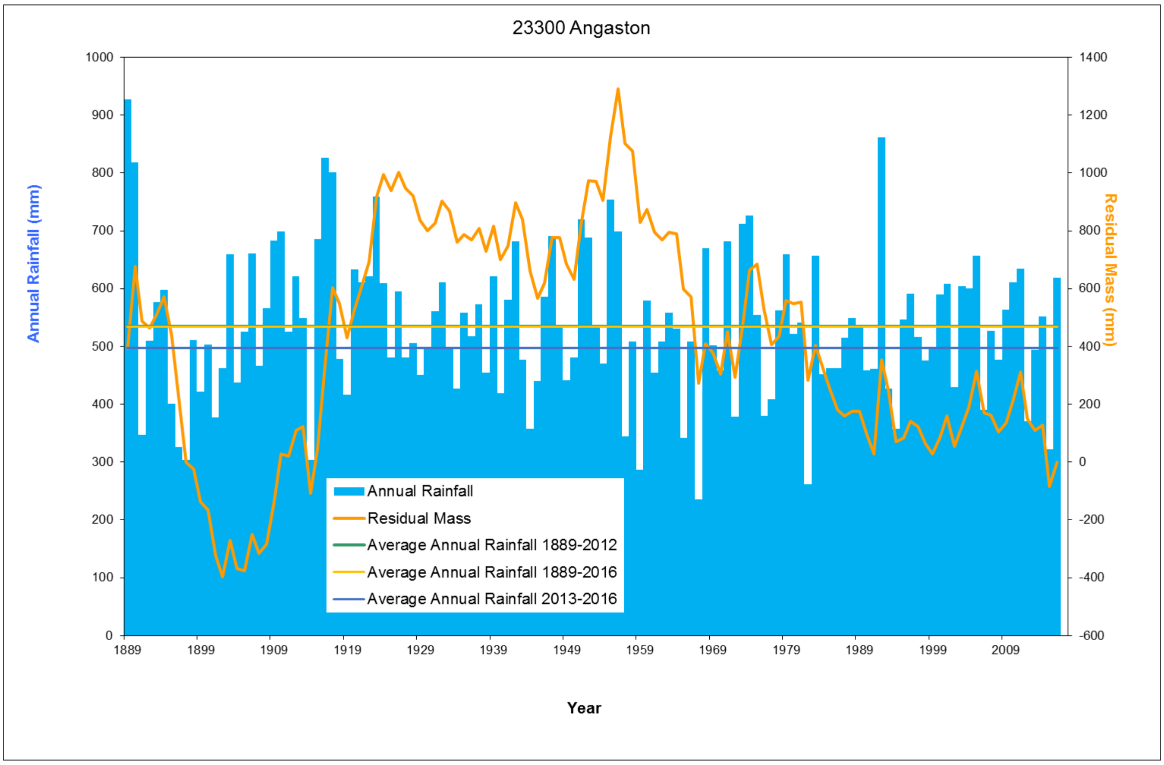



**Figure 2.7. Annual rainfall at Angaston (23300)**

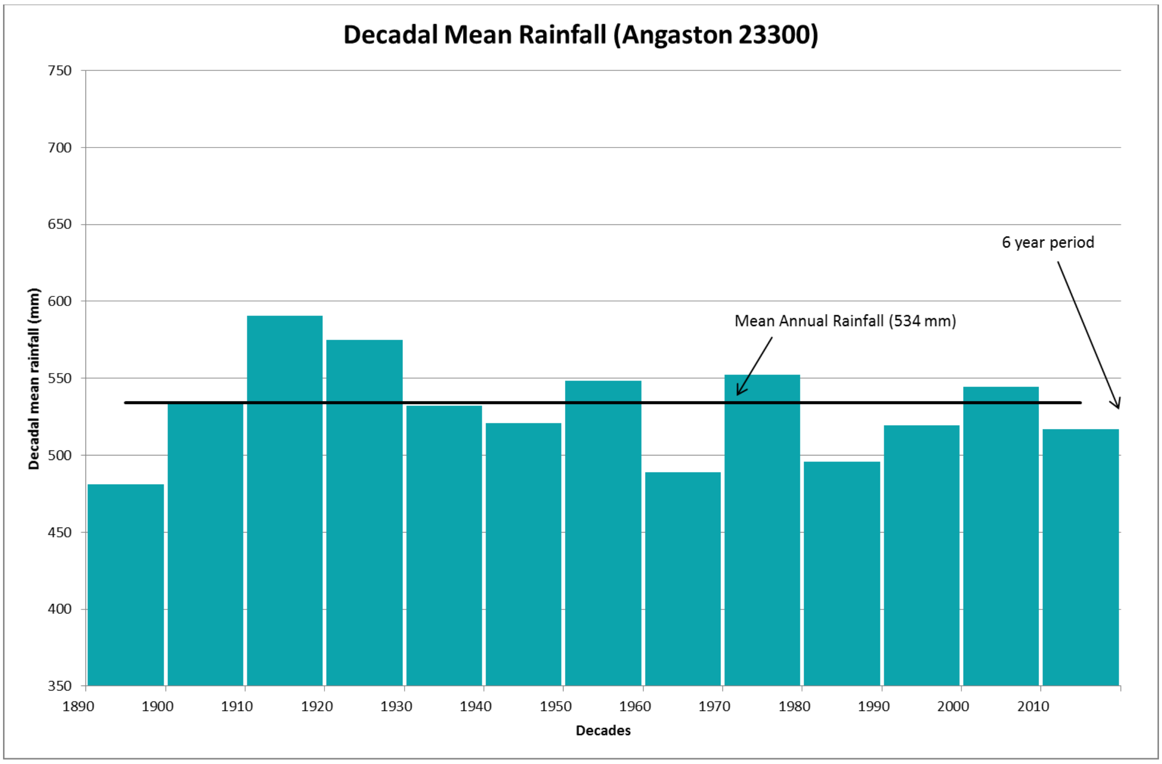



**Figure 2.8. Decadal rainfall at Angaston (23300)**

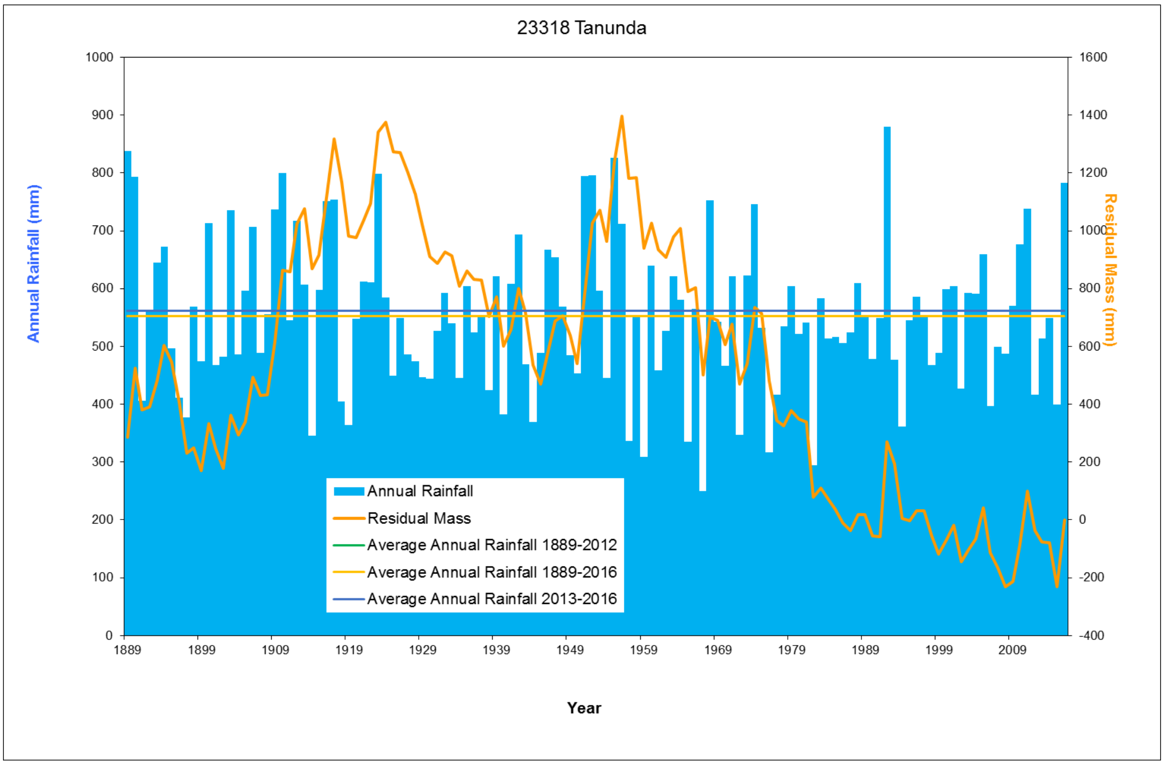



**Figure 2.9. Annual rainfall at Tanunda (23318)**

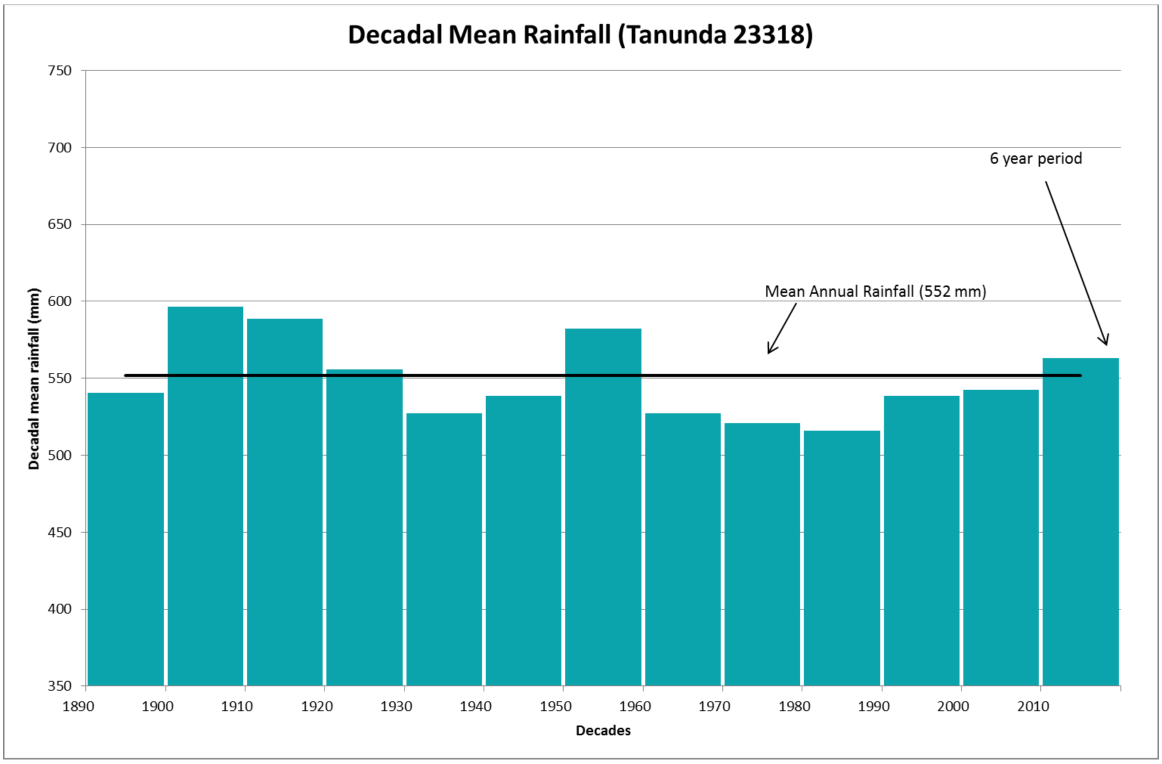



**Figure 2.10. Decadal rainfall at Tanunda (23318)**

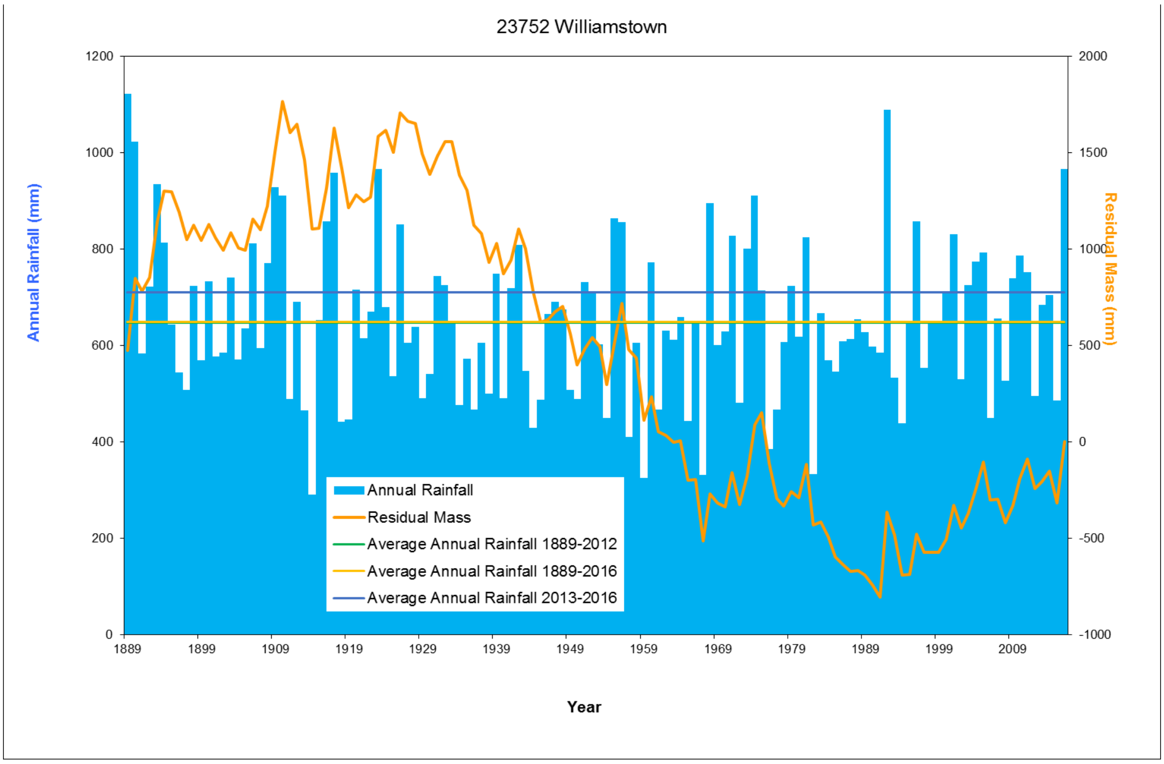



**Figure 2.11. Annual rainfall at Williamstown (23752)**

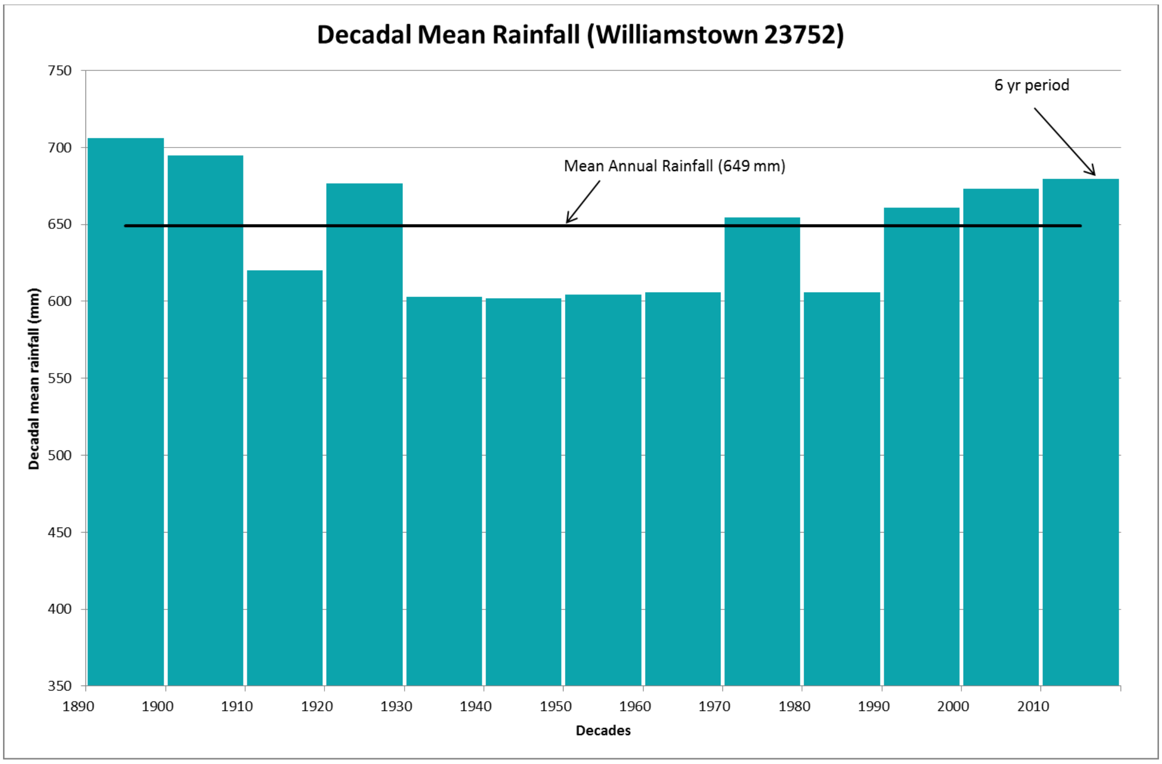



**Figure 2.12. Decadal rainfall at Williamstown (23752)**

Frequency interval analysis was done using updated data to show the distribution of annual rainfall at a particular site over a pre-determined range. Figure 2.13 shows the frequency interval analysis for the SILO rainfall stations in the Barossa PWRA. It can be seen that for the majority of sites, rainfall has an annual median close to 600 mm, with a 90th percentile range from 300 – 900 mm. Higher rainfall sites can be seen to be Williamstown and Lyndoch at Pewsey Vale, with a 90th percentile range from 450 – 1200 mm. These site are located at the southern end of the Barossa PWRA, in the Lyndoch Creek project zone.

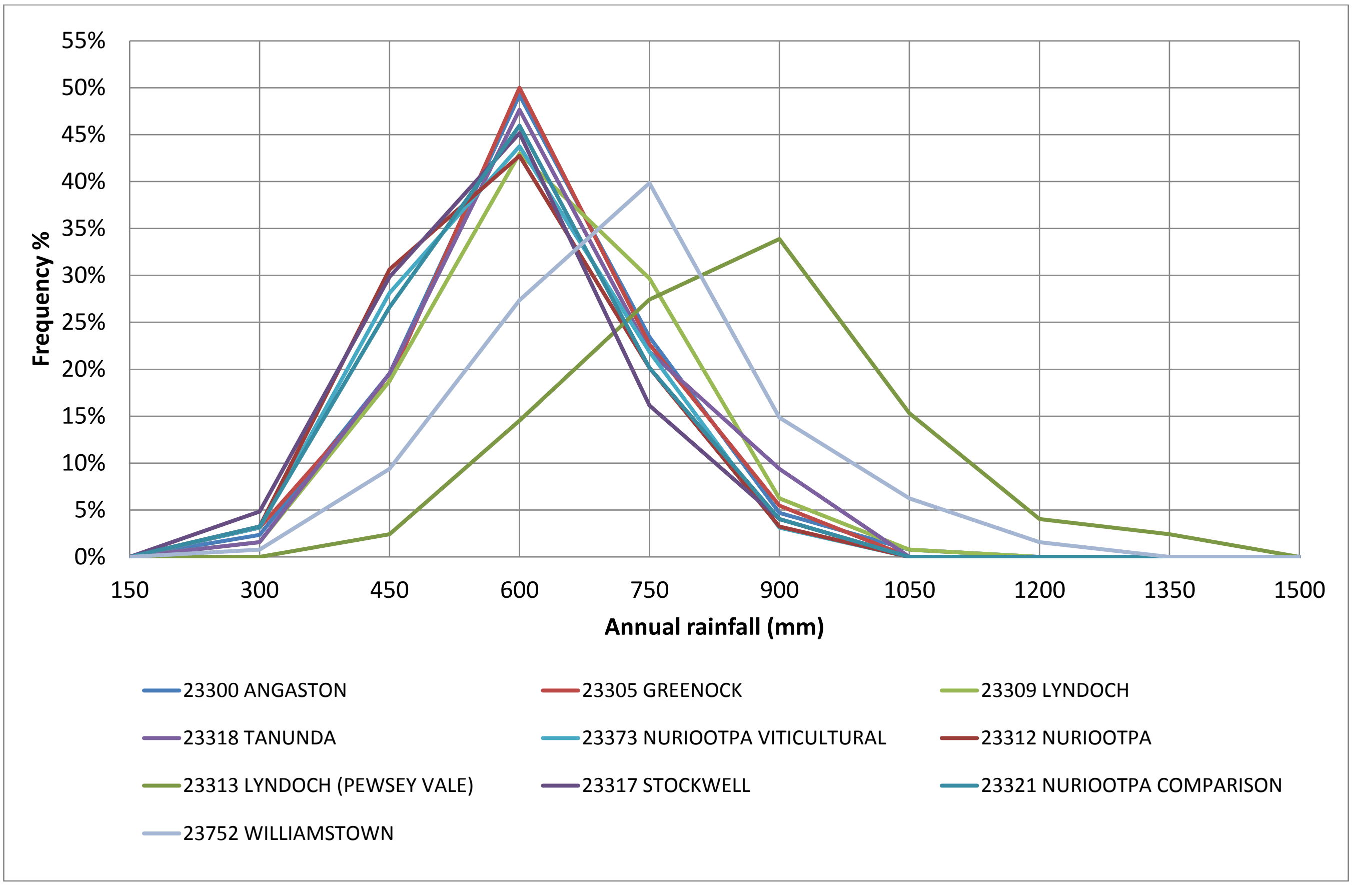



**Figure 2.13. Annual rainfall interval frequency analysis for rainfall sites in the Barossa PWRA**

In the previous study by Jones-Gill and Savadamuthu (2014), community rainfall data (Heggies Vineyard) was used in the model as this site covers an area of high rainfall that is not represented by other rainfall gauges. This dataset was also updated up to 2016, and residual mass curves were used to analyse trends between this site and other adjacent rainfall gauge sites. Figure 2.14 shows the residual mass curve for Heggies Vineyard alongside the five adjacent rainfall gauge sites for the period 1964 to 2016. This shows in general that the rainfall collected at Heggies Vineyard follows the same temporal trend as the other sites, but experienced wetter conditions during the decade from 1980 to 1990. The residual mass analysis further confirms the validity and consistency of this community dataset.

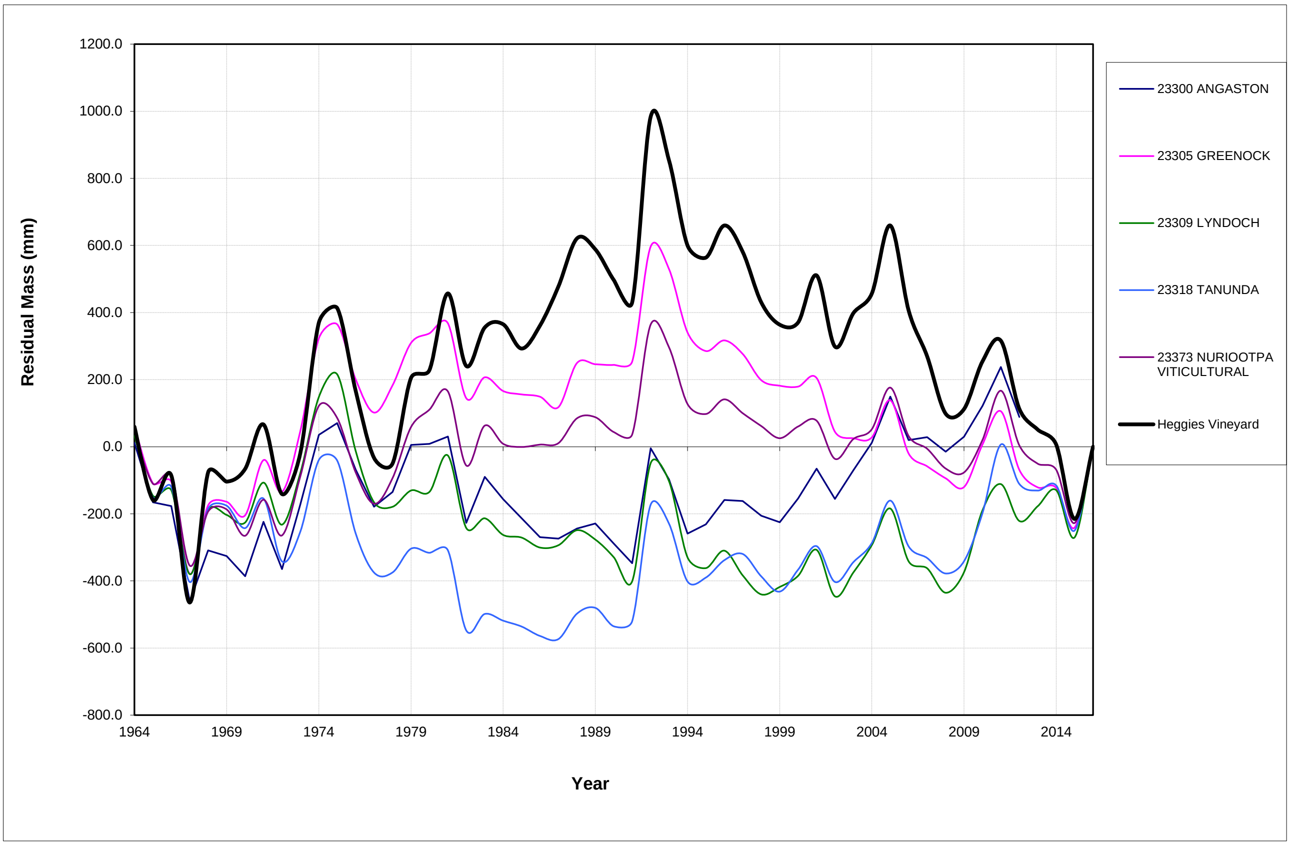



**Figure 2.14. Residual Mass curve for Heggies Vineyard and adjacent rainfall gauging stations**

## 2.3 Streamflow data

Jones-Gill and Savadamuthu (2014) used four operational streamflow gauging stations for the purpose of model calibration. Streamflow data was updated in this work for following gauging stations in this work:

- A5050533: This streamflow gauge captures flows in the North Para River at Mt McKenzie, which originate from the Upper Flaxman Valley project zone.
- A5050517: This streamflow gauge captures flows in the North Para River at Penrice, originating from the Upper and Lower Flaxman Valley and the Stone Chimney Creek project zones.
- A5050535: This streamflow gauge captures flows from the Tanunda Creek sub-catchment. Tanunda Creek is a major tributary to the North Para River.
- A5050502: This is the most downstream streamflow gauge in the Barossa PWRA, and captures flows in the North Para River at Yaldara from project zones except for Lyndoch Creek, Greenock Creek and Saltwater Creek.

Table 2.3 to Table 2.6 provide a comparison of streamflow statistics between the original datasets (1978/1992 – 2012), the extended datasets (1978/1992 – 2016), and the period since the previous study from 2013 to 2016.

At Yaldara, the mean annual streamflow for the periods 1978-2012 and 1978-2016 are very similar. The mean annual streamflow for 2013-2016 is slightly higher, due to the high flows experienced in 2016.

At Penrice, the mean annual streamflow is lower for the period 2013-2016 than both 1978-2012 and 1978-2016. At Tanunda Creek, the mean annual streamflow is higher for the period 2013-2016 than both 1978-2012 and 1978-2016.

Variations in annual flows at four operating gauging stations can be seen in Figure 2.15 to Figure 2.18.

**Table 2.3 Annual statistics for streamflow gauging station in the Barossa PWRA – A5050502**

| North Para River @ Yaldara | Catchment area Km2 | Mean annual streamflow ML | Mean annual streamflow mm | Min annual streamflow ML | Max annual streamflow ML |
|---|---|---|---|---|---|
| 1978-2016 | | 13332 | 35 | 896 | 63560 |
| 1978-2012 | 376 | 13320 | 35 | 896 | 63560 |
| 2013-2016 | | 13437 | 36 | 1150 | 30175 |

**Table 2.4 Annual statistics for streamflow gauging station in the Barossa PWRA – A5050517**

| North Para River @ Penrice | Catchment area Km2 | Mean annual streamflow ML | Mean annual streamflow mm | Min annual streamflow ML | Max annual streamflow ML |
|---|---|---|---|---|---|
| 1978-2012 | | 4926 | 42 | 149 | 23512 |
| 2013-2016 | 117 | 4376 | 37 | 77 | 9983 |
| 1978-2016 | | 4869 | 42 | 77 | 23512 |

**Table 2.5 Annual statistics for streamflow gauging station in the Barossa PWRA – A5050533**

| North Para River @ Mt McKenzie | Catchment area Km2 | Mean annual streamflow ML | Mean annual streamflow mm | Min annual streamflow ML | Max annual streamflow ML |
|---|---|---|---|---|---|
| 1978-2012 | | 2150 | 49 | 45 | 10812 |
| 2013-2016 | 44 | 2575 | 59 | 51 | 5460 |
| 1978-2016 | | 2218 | 50 | 45 | 10812 |

**Table 2.6 Annual statistics for streamflow gauging station in the Barossa PWRA – A5050535**

| Tanunda Creek @ Bethany | Catchment area Km2 | Mean annual streamflow ML | Mean annual streamflow mm | Min annual streamflow ML | Max annual streamflow ML |
|---|---|---|---|---|---|
| 1978-2012 | | 1828 | 87 | 107 | 8380 |
| 2013-2016 | 21 | 2420 | 115 | 348 | 4565 |
| 1978-2016 | | 1923 | 92 | 107 | 8380 |

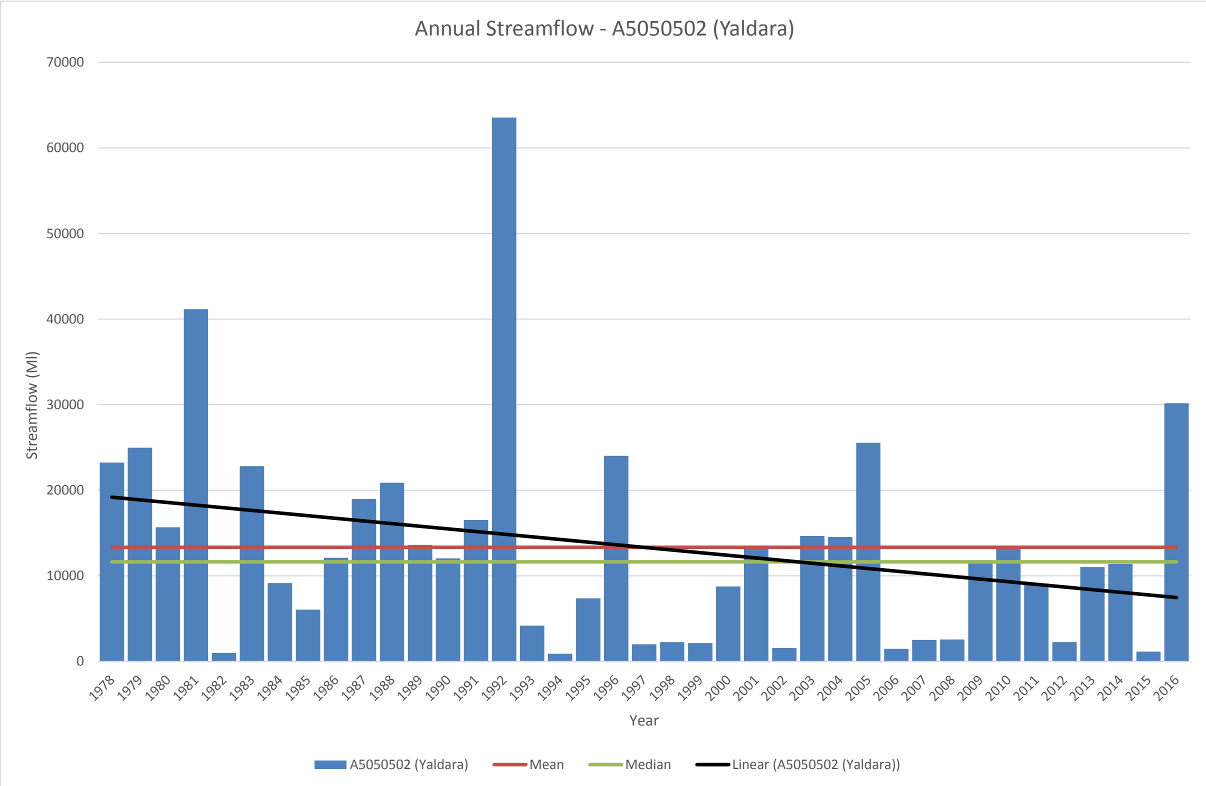



**Figure 2.15. Annual flow at Yaldara – A5050502**

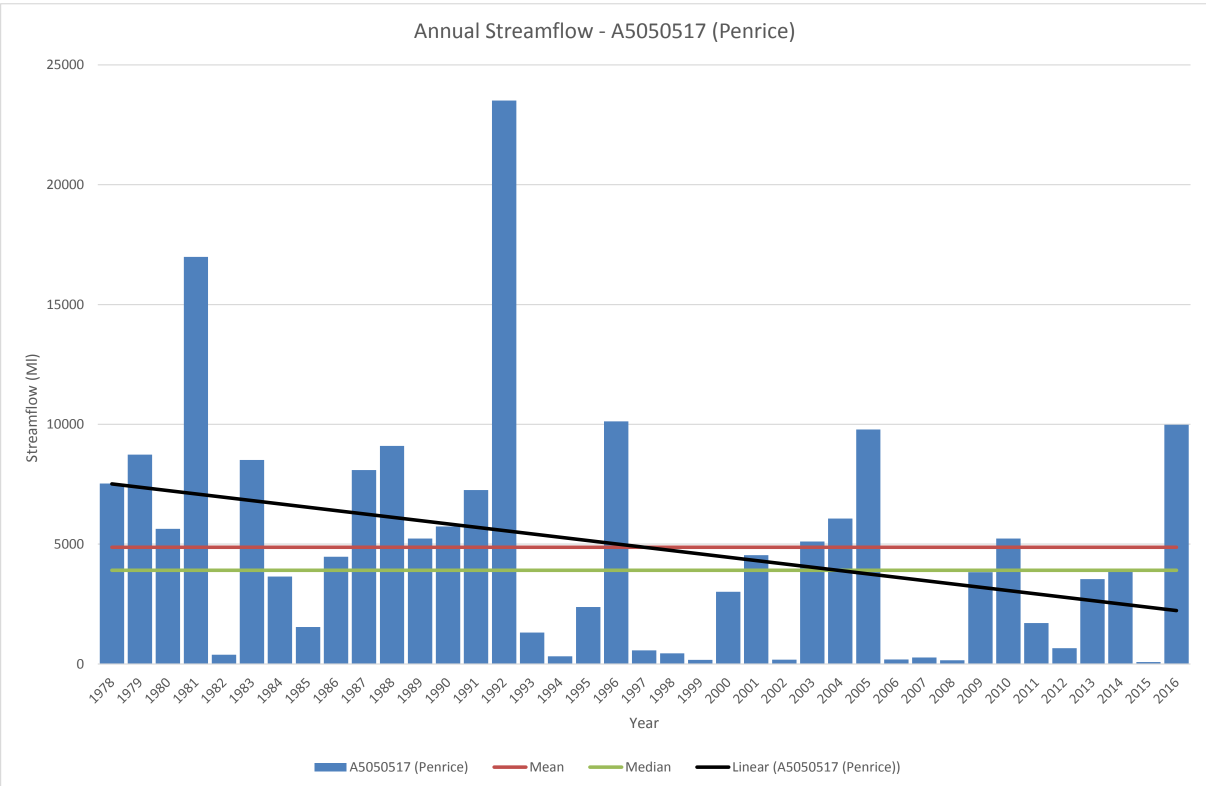



**Figure 2.16. Annual flow at Penrice – A5050517**

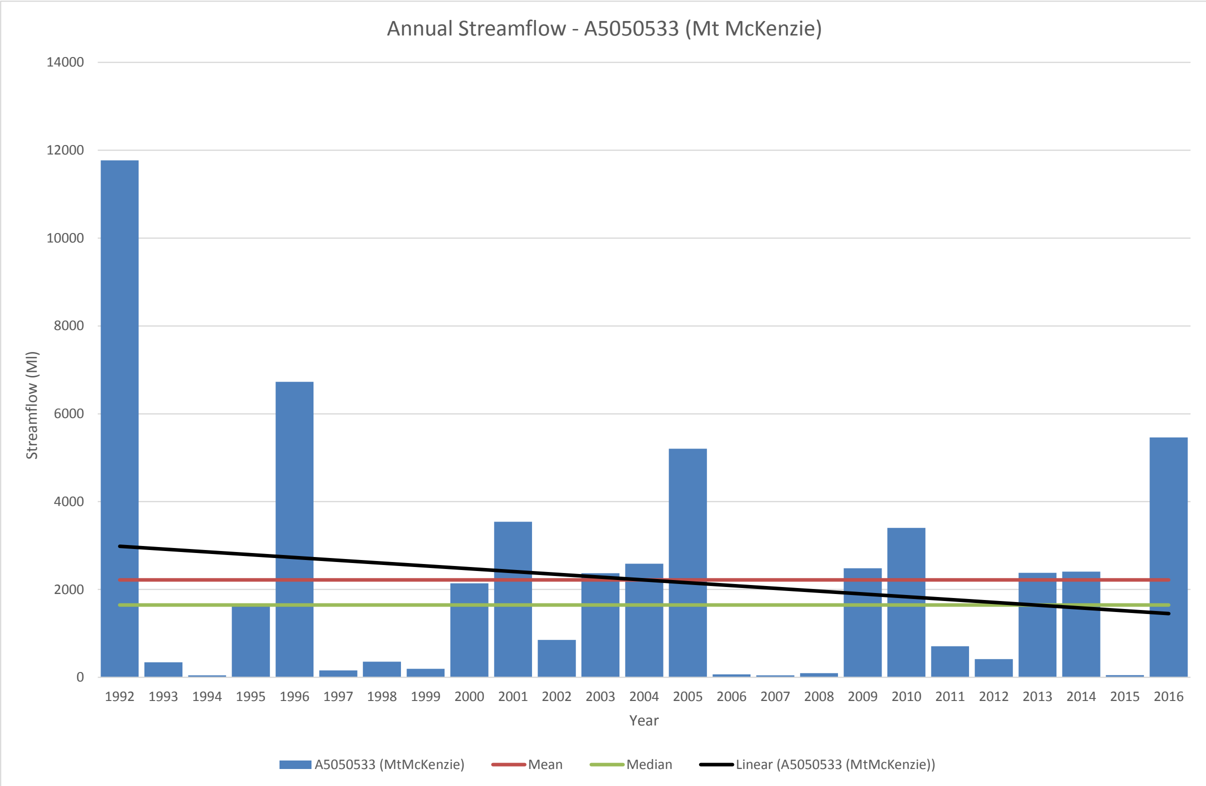



**Figure 2.17. Annual flow at Mt McKenzie – A5050533**

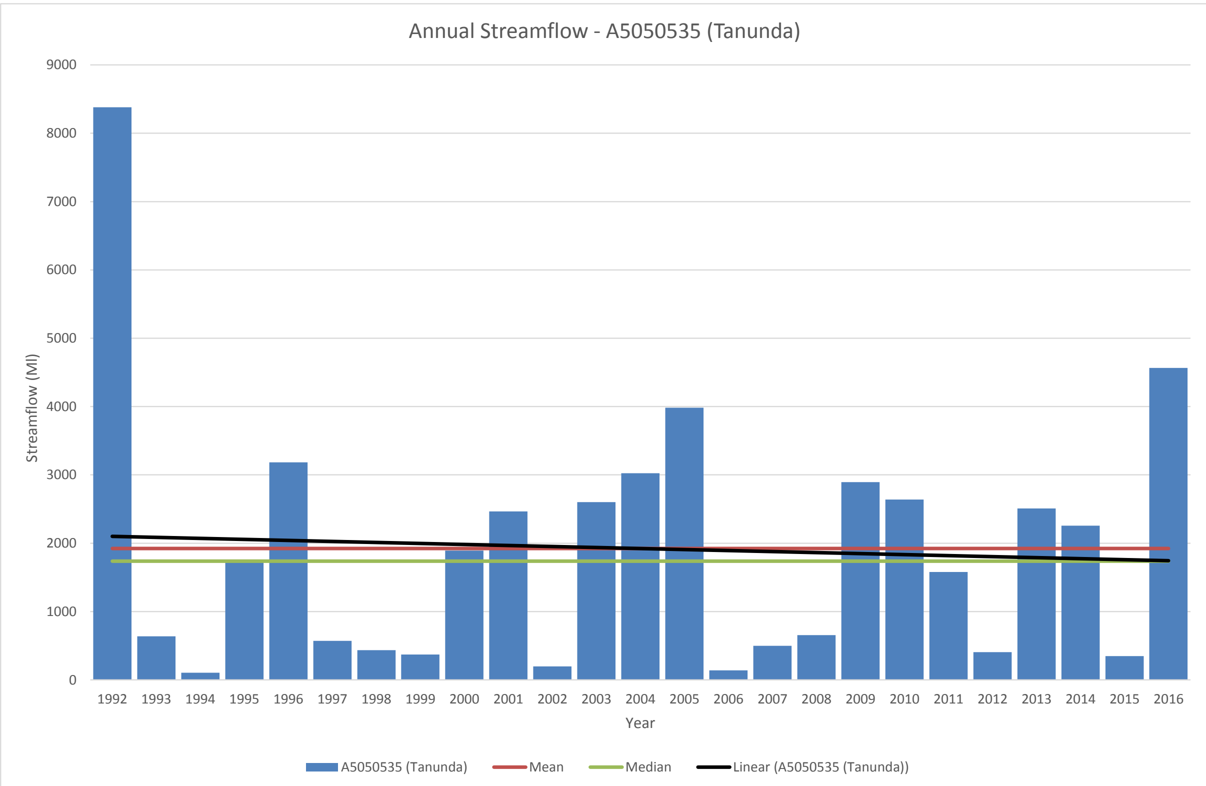



**Figure 2.18. Annual flow at Tanunda – A5050535**

Daily flow duration (FD) curves show the percentage of time for which a specified flow is equalled or exceeded over the flow record. Although they do not give information about timing of flows, FD curves provide a simple method of assessing and presenting the flow characteristics of a stream. From the shape of the FD curve, information about base flow, duration of 'no flow' conditions, flow variation and rainfall response can be inferred. These curves are used to compare flow characteristics between time periods, between catchments and before/after implementation of flow regulation/management regimes (McMahon and Mein, 1986, p. 58).

For each of the streamflow gauges, the daily FD curve is provided in (Figure 2.19) across the original period to 2012 (adopted from previous study) and the extended period to 2016. It can be seen that there are no significant alterations between analysed periods for each site. The high-flow end of the FD curve is very steep, indicating that runoff in these catchments is highly responsive to rainfall. The low-flow end of a FD curve is generally indicative of the groundwater contribution (baseflow) to streamflow and the potential for 'no-flow' conditions. Each of the sites have periods of no-flow conditions, which decrease with increasing gauging station catchment area. The most upstream gauge, Mt McKenzie (A5050533), has the greatest period of no flow conditions (~40%), while the most downstream gauge at Yaldara (A5050502) has the least period of no flow conditions (~15%).

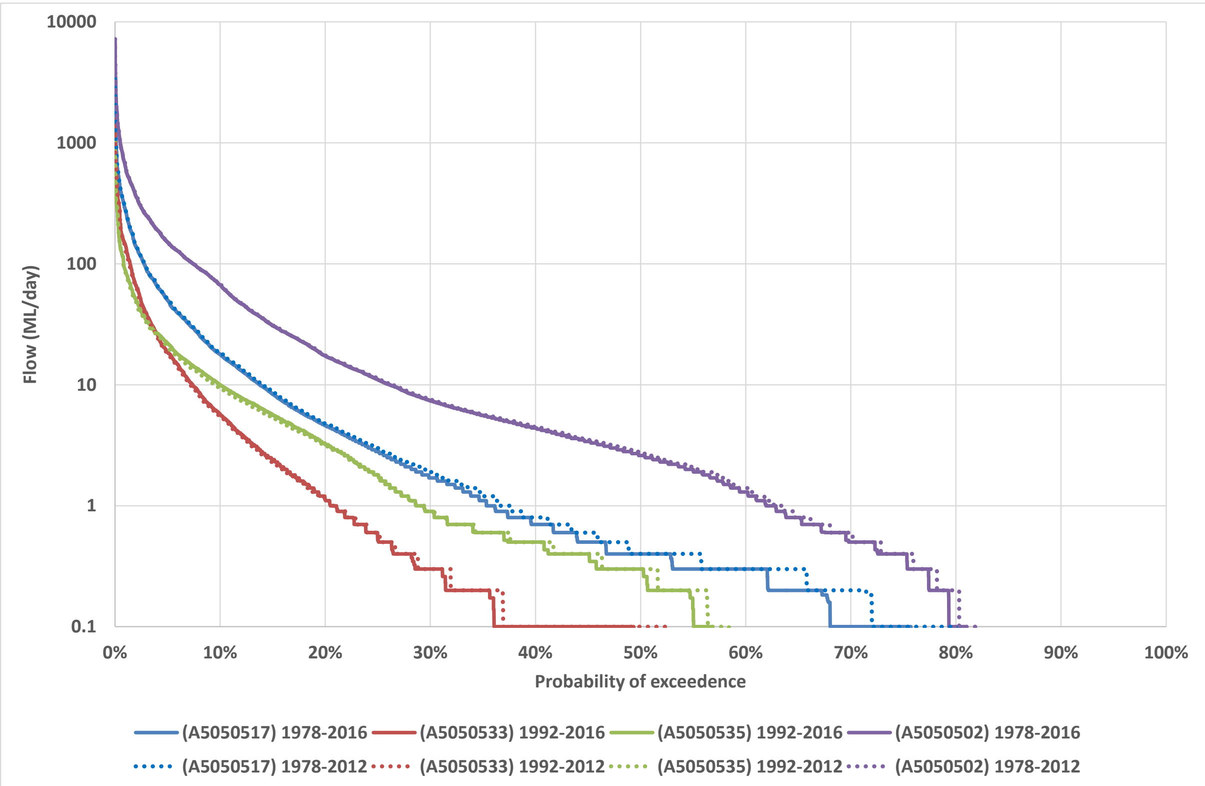



**Figure 2.19. Daily flow duration curves for the four operating streamflow gauges in the Barossa PWRA**

# 3 Hydrological modelling

Using the updated datasets described in preceding sections, the original hydrological model for the Barossa PWRA was re-calibrated to include updated rainfall, evaporation and streamflow records for the gauging stations within the Barossa PWRA.

Previous modelling of the Barossa PWRA lumped some farm dams together to minimise the level of complexity in the system (see Jones-Gill and Savadamuthu, 2014). Application of this approach made it difficult to update and include the "likely to be licensed" farm dams (at the time of assessment) within the Greenock Creek and Salt Water Creek project zones. Since these two project zones are not hydrologically connected to the rest of the Barossa PWRA (Figure 2.1), it was decided to develop a separate surface water model to represent individual farm dams within Greenock and Salt Water Creek project zones.

## 3.1 Model selection

Similar to previous study, the hydrological modelling platform used for this study was eWater Source IMS modelling platform (eWater Ltd., 2013), referred to as the 'Source model' from here on in the report. This modelling platform is a nationally recognised hydrological modelling platform that has been developed as part of an Australia-wide collaboration and which has been endorsed by the Australian Government. Source is a PC based rainfall-runoff water balance modelling platform. It incorporates some of the most widely used rainfall-runoff models in Australia (e.g. AWBM, SIMHYD and GR4J).

Within Source, a model is constructed as a series nodes and links which are connected based on the delineated drainage areas (sub-catchments) and drainage direction of the catchment being modelled. Each node/link can represent different components of the water balance, such as:

- Sub-catchments (rural catchments, urban catchments)
- Storages (off-stream and on-stream farm dams, reservoirs, etc.)
- Demands (from rivers/streams, storages)
- Transfers (weir and routing components)

## 3.2 Methodology

This study involved the development of a fully distributed surface water model for the Greenock Creek and Salt Water Creek project zones. This means the farm dams are not lumped and there is an individual node for every farm dam (licensed or non-licensed) within these two project zones (as outlined above).

Functional units (areas within a project zone with similar behaviour in terms of runoff generation) were adopted with no change from the previous study, in which they were determined based on consideration of a combination of soil characteristics and land use.

The partially distributed hydrological model for the remainder of the Barossa PWRA was recalibrated using updated observed daily rainfall, evaporation and streamflow records, water demand data and estimated catchment parameters extended to 31/12/2016. Note the original Barossa PWRA model was calibrated for the period 01/06/2003 to 01/06/2013, and validated over the period 01/06/1999 to 30/05/2003 (Jones-Gill and Savadamuthu, 2014). The catchment parameters from the calibrated model of the Barossa PWRA were then applied to the fully distributed model for Greenock Creek and Salt Water Creek project zones, given that recorded streamflow data were not available for Greenock and Salt Water creeks to calibrate and validate against. These models were then used simultaneously to generate simulated catchment runoff under various scenarios, to investigate the likely impacts of these scenarios on streamflow within the project zones.

Figure 3.1 is a screen shots of the hydrological models built in Source for the Barossa PWRA and Greenock Creek and Salt Water Creek project zones.

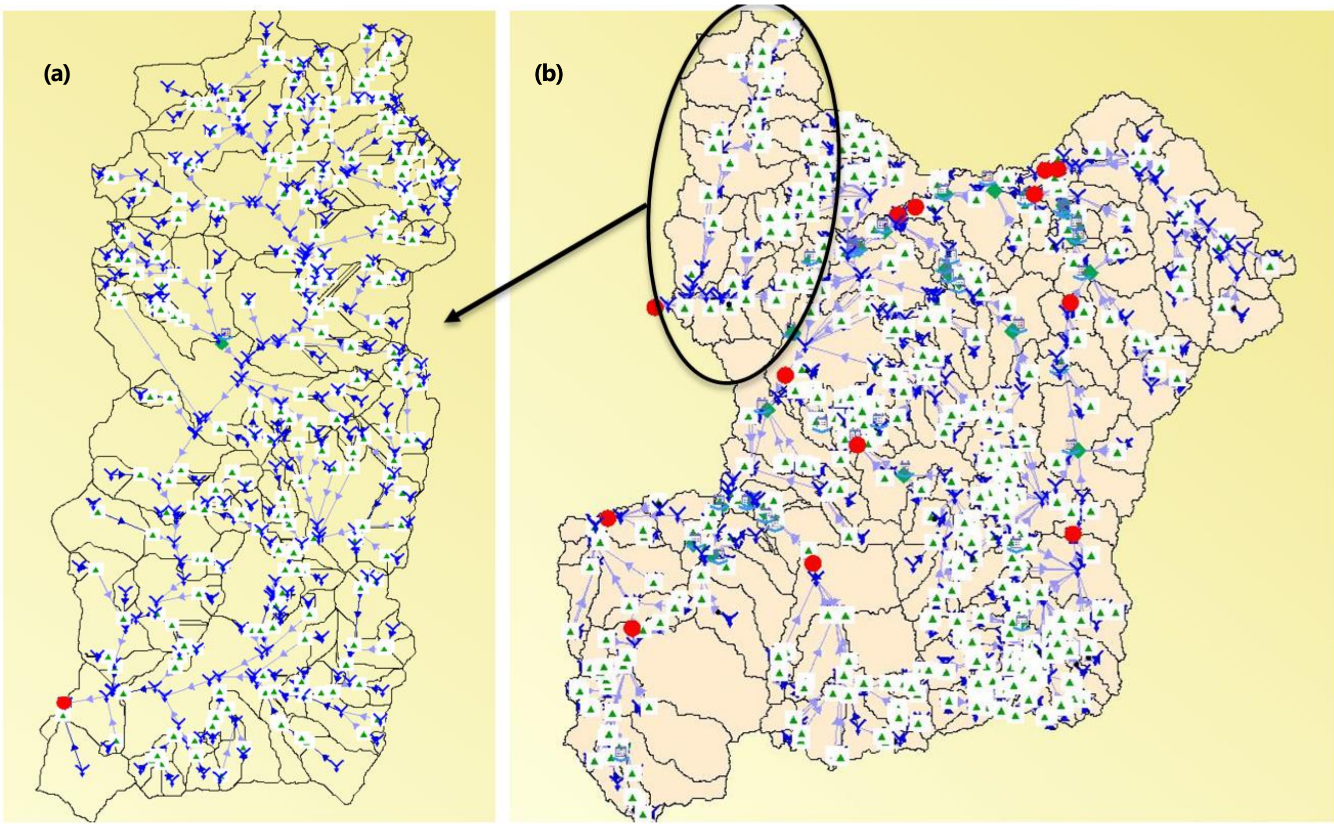



**Figure 3.1 Screenshot of source model for Barossa PWRA (a) Greenock Creek and Salt Water Creek model, (b) Barossa PWRA model, with the original inclusion of Greenock Creek and Salt Water Creek project zones circled**

## 3.3 Model calibration

Model calibration is a process of optimising or systematically adjusting model parameter values to get a set of parameters which provides the best estimate of the observed streamflow (Vaze, et al., 2012, p. 27). By comparing model generated streamflow data against observed streamflow records, the goodness of fit between the two datasets can be assessed. The iterative process of varying catchment input parameters is undertaken until a 'good fit' is achieved between the simulated and recorded datasets. The purpose of calibration is to ensure the model is able to adequately represent the hydrological behaviour of the catchment.

The strength of a model calibration is typically confirmed by a subsequent validation of the model, which uses the calibrated model to simulate a period outside the calibration period and compare the generated streamflow with the observed data over the period (Vaze, et al., 2012, p. 27). Validating the model thus improves confidence in the ability for the model to predict system behaviour under a variety of different scenarios.

Source's GR4J catchment rainfall-runoff model was used in this study and further described in Jones-Gill and Savadamuthu (2014). The input parameters that were varied during calibration were the parameters of the GR4J rainfall-runoff model for each functional unit across the catchment. Recorded or known input data (rainfall, evaporation, dam properties and water use) was not modified during calibration. GR4J has four parameters, and six functional units were considered. As such, there were a total of 24 model parameters to be calibrated.

For the purposes of this study, 'good correlation' involved visual and statistical comparison of recorded and simulated streamflow data at daily, monthly and annual timescales, as well as comparison of daily flow frequency data. This is further discussed in Section 3.3.3.

### 3.3.1 Calibration data

Ideally, rainfall-runoff models should be calibrated using a data set that incorporates a wide range of variability (e.g. high and low rainfall years, floods events and a series of drought years). Hence long-term, continuous, high quality data, combined with a good spatial coverage of data across the modelled catchment, provides the best basis for model calibration. Data adopted should also represent the current conditions in the catchment that will influence the rainfall-runoff processes. For example, the level of dam development will influence the degree to which rainfall is translated to streamflow. The final step of the model calibration process was to calibrate the model to daily stream flow records from four gauging stations for the period 01/06/2003 to 31/12/2016. This period represents a trade-off between using a long record of high quality data representing a range of climatic variability, as well as representing the current conditions of the catchment, post-prescription of the resource and when limited further development occurred.

As described in Section 2.3, there have been multiple continuous streamflow recordings made at sites within the Barossa PWRA. Four of these sites have good quality, long-term streamflow data suitable to use for re-calibration and updated data from these sites were used to re-calibrate the model.

Hydrological parameters were re-calibrated against the four streamflow records listed above concurrently (i.e. a multi-gauge approach), with the relevant functional units across the whole catchment used to capture the variability in flow across the Barossa PWRA.

### 3.3.2 Calibration methodology

Recalibration of this model for the extended period of 1/1/2003 to 31/12/2016 was undertaken using the Model-Independent Parameter Estimation and Uncertainty Analysis software, PEST (Doherty, 2005). PEST applies a local search procedure to calibrate the model parameters, and as such the initial parameter values identified from the first step are important to the final parameter values identified. Due to the model run times involved, the parallel version of PEST was used, enabling eight calibrations of the model to be run at the same time, dramatically speeding up run times to be in the order of a few days.

The other main advantage of using the PEST approach is that customised objective functions can be created to define how well a given set of model parameters represent the observed streamflow. Traditional objective functions, such as the NSE or Coefficient of Determination (R2) are based on the sum of squared differences between the modelled and observed flows. This approach tends to focus on fitting the model to the largest values in the time series, which 1) limits the model performance on the broader flow regime, particularly low flows, and 2) the largest flows in the time series are also often the most uncertain, outside the range of gaugings in the stage-discharge relationship. Due to this bias, recent studies have recommended adopting a multi-objective approach toward model calibration (e.g. Gupta et al., 1998).

As such, a combined objective function was adopted for calibration of the full model to the calibration period of 1/1/2003-31/12/2016. The objective function adopted was based on the sum of:

- squared errors on the square root transform of the daily flows. The square root transform reduces the magnitude of the flow range, providing a more balanced influence of the range of daily flows compared to the original values;
- squared errors in the monthly volumes. This component is used to ensure the model adequately represents the overall water balance correctly, where, particularly in ephemeral catchments with high flow variability, a good representation of the daily flows does not necessarily guarantee a suitable representation of the overall volume; and
- squared errors in the log transform of the flow duration curve. The flow exceeded at 30 percentile intervals was also calculated and compared to the observed to ensure the model represent the whole flow range well, particularly the low flows.

Each of the above objective functions were adjusted to have an equal weighting in the calibration process. This weighting approach was also applied across the four stream-flow gauges used in the calibration, so again, each gauge had an equal magnitude of influence on the objective function at the start of the PEST run. The combined objective function value was then minimised by adjusting the GR4J parameter values for the four functional units, to provide the best possible balance between the different components of the objective function across the four streamflow records available. A number of restarts of the PEST calibration process were undertaken to ensure robust combinations of model were identified. Time periods corresponding to poor observed data (indicated by quality codes of 90 or above) were ignored in both the observed and simulated records.

The range of model parameters considered are outlined in Appendix A, as well as the final calibrated parameter values. It can be seen that the calibrated parameter values are well within the ranges permitted for the calibration process, confirming that the ranges adopted were appropriate and did not influence the calibration process.

In interpreting the model parameter values it was found the negative values for the x2 parameter indicate that the calibrated model had an overall process of losing flow to groundwater, which is expected based on the analysis of losing and gaining streams in the region. The low values for the x4 travel time parameter are expected due to the small sub-catchments adopted for this model. The x3 parameter is also representative of the routed travel time for the stream within a sub-catchment, and again, due to the small sub-catchments, values toward the lower end of the typical range of values for this parameter are expected. Finally, the x1 parameter represents the soil storage volume, and values in the order of 300 mm are within the expected range for this parameter, and typical for South Australian catchments (Jones-Gill and Savadamuthu, 2014).

### 3.3.3 Re-calibration results

Re-calibration statistics and curves for the gauge at Yaldara (A5050502) used to calibrate the model are given in the following section. Calibration results for the other three gauges are provided in Appendix B.

**Table 3.1 Re-calibration statistics for A5050502 (Yaldara)**

| **A5050502** | **Annual** | | **Monthly** | | **Daily** | |
|---|---|---|---|---|---|---|
| **Yaldara** | *Observed* | *Modelled* | *Observed* | *Modelled* | *Observed* | *Modelled* |
| Mean (ML) | 10220 | 10226 | 867 | 871 | 29 | 29 |
| Median (ML) | 10071 | 11521 | 102 | 219 | 2.2 | 4.4 |
| R^2 | 0.95 | | 0.90 | | 0.56 | |
| NSE | 0.90 | | 0.84 | | 0.53 | |
| % Volume Difference | 0% | | 0% | | 0% | |

Figure 3.2 and Figure 3.3 are the annual and monthly time series for observed and modelled streamflow at the Yaldara gauge.

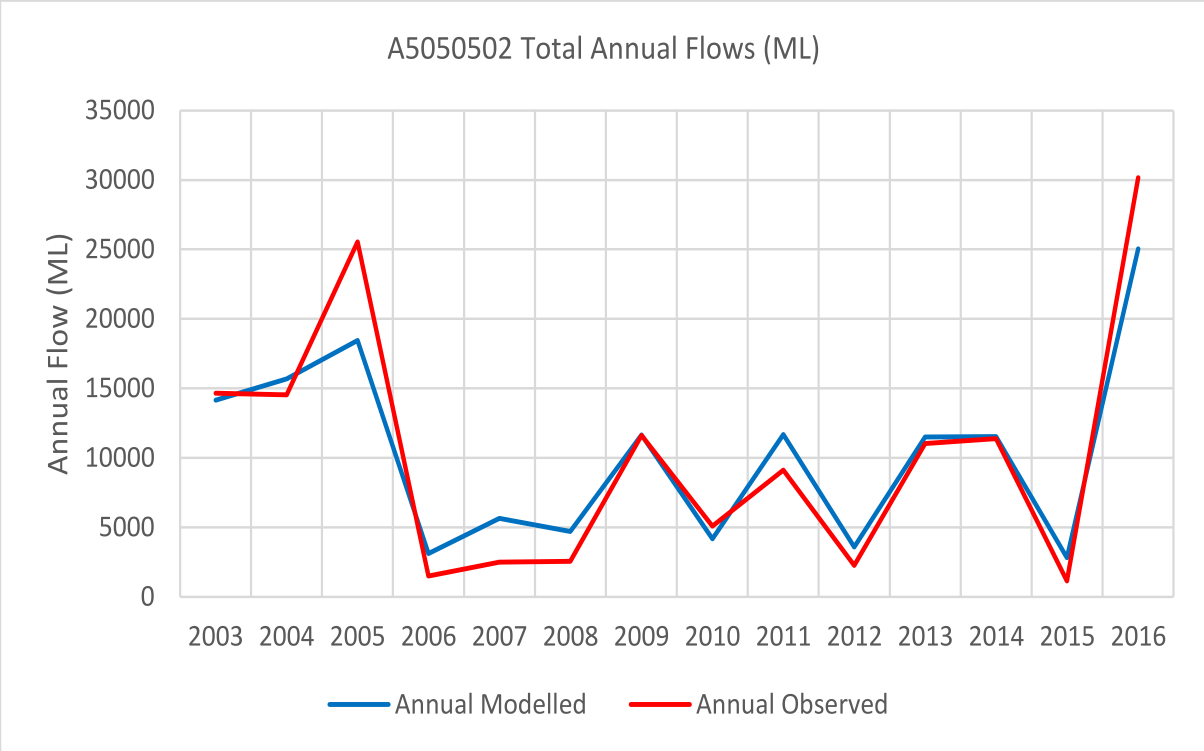



**Figure 3.2 Annual calibration chart for A5050502 (Yaldara)**

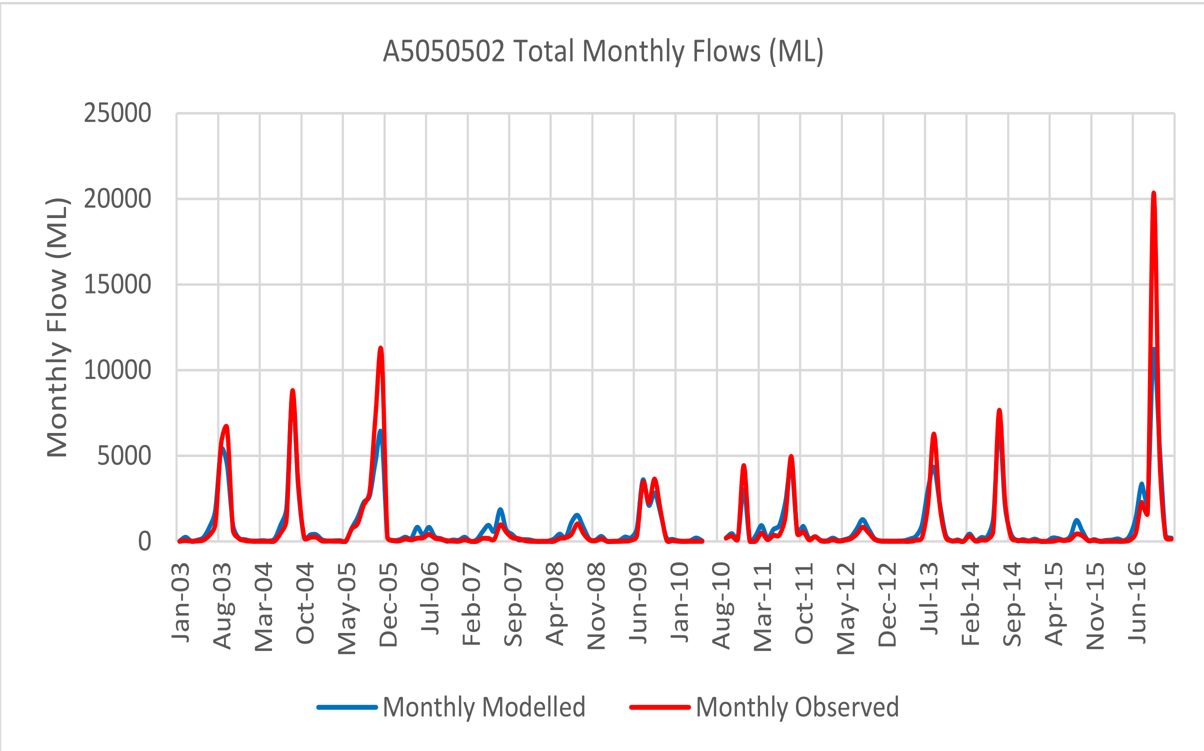



**Figure 3.3 Monthly streamflow calibration chart for A5050502 (Yaldara)**

Figure 3.4 is the daily flow duration curve for observed and modelled streamflow at the Yaldara gauge. Note data for the observed datasets has been excluded from these plots where data is missing or is of poor quality.

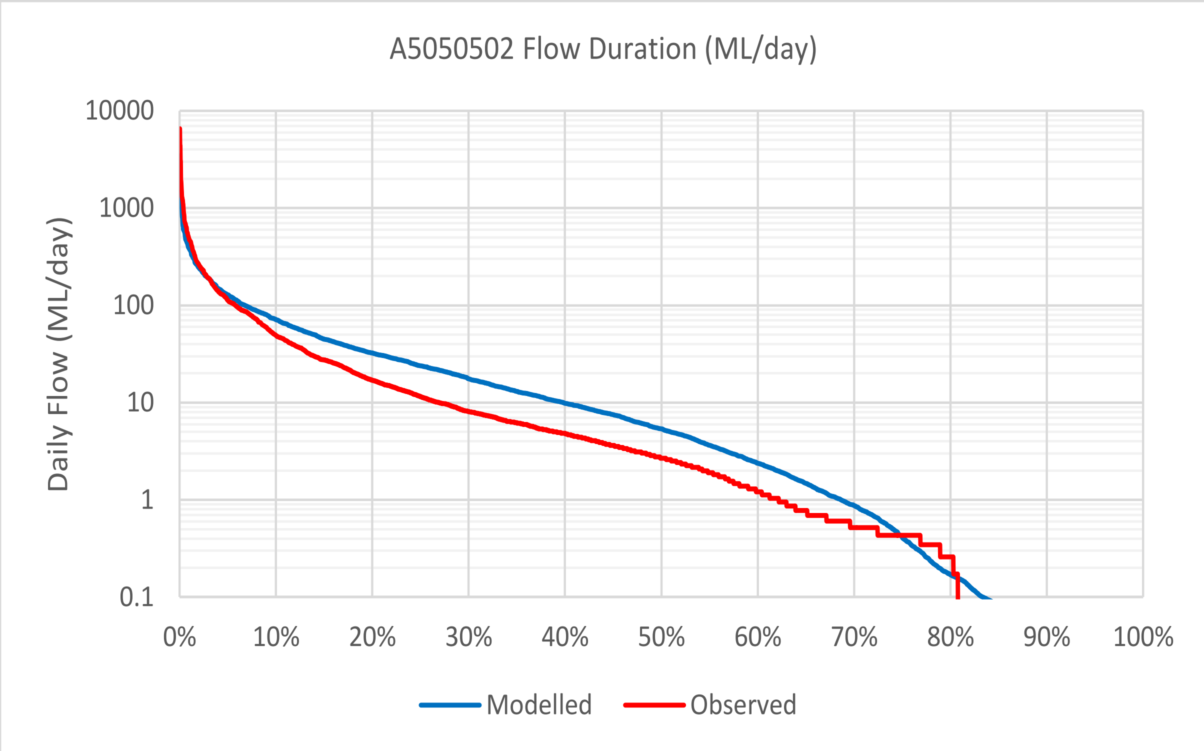



**Figure 3.4 Daily flow duration curve calibration for A5050502 (Yaldara)**

The calibration results are shown for a low flow year (Figure 3.5), an average flow year (Figure 3.6) and a high flow year (Figure 3.7).

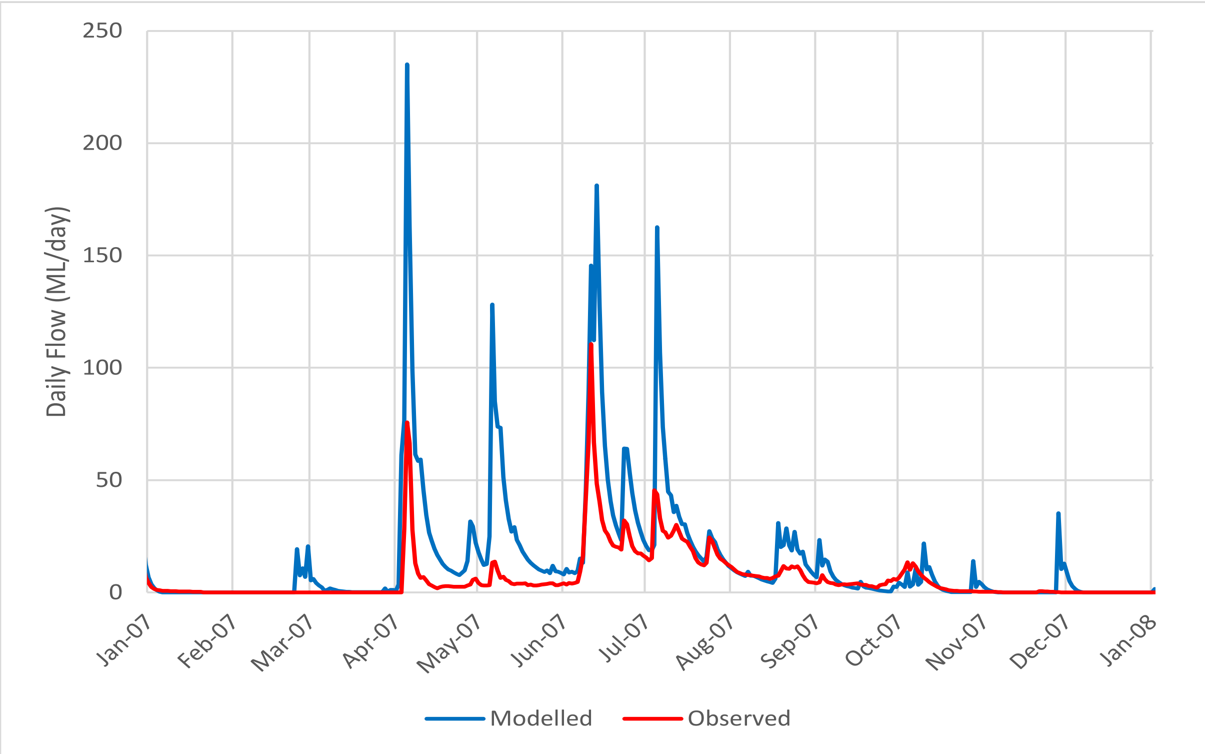



**Figure 3.5 Daily modelled and observed flows at Yaldara gauging station for a low flow year**

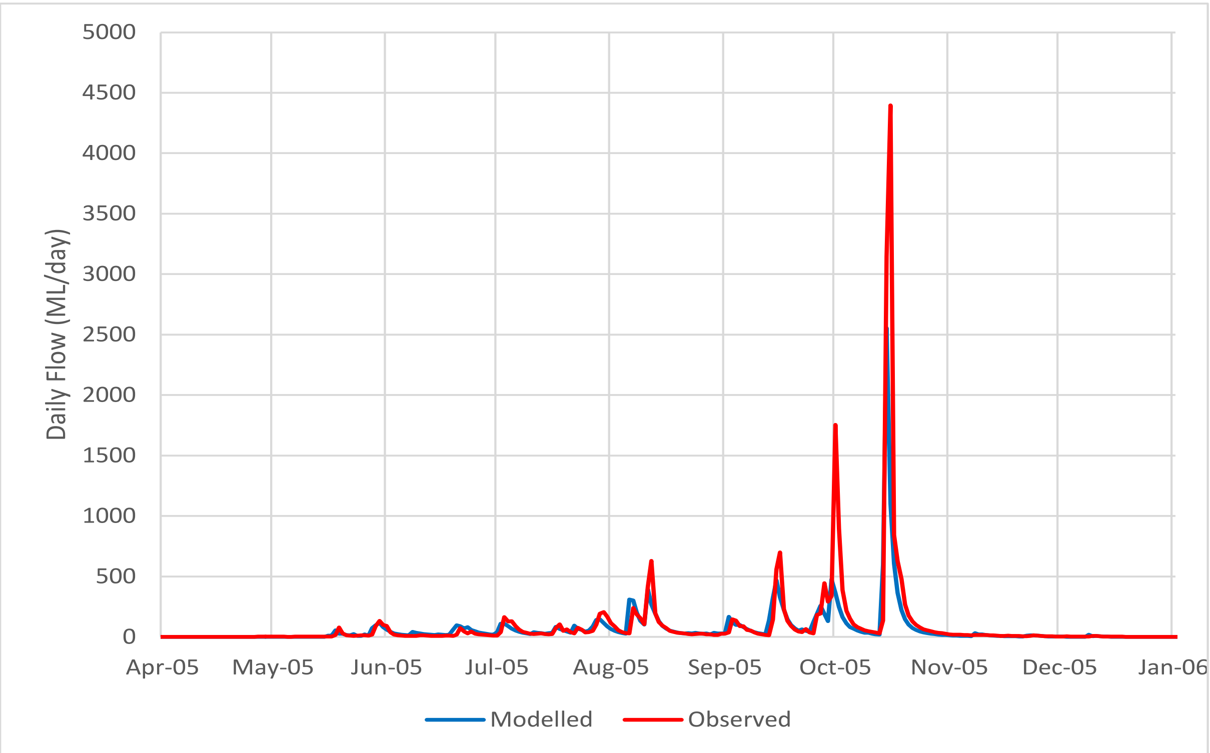



**Figure 3.6 Daily modelled and observed flows at Yaldara gauging station for a high flow year**

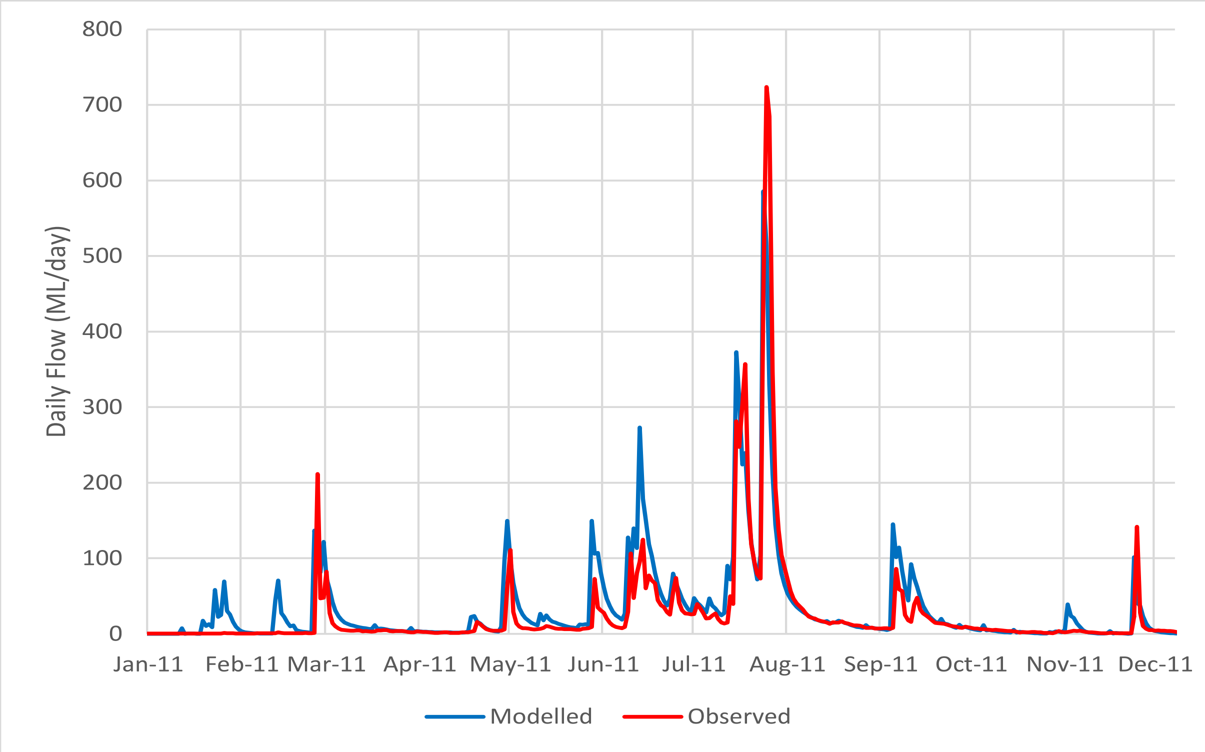



**Figure 3.7 Daily modelled and observed flows at Yaldara gauging station for an average flow year**

### 3.3.4 Model performance and limitations

The $R^2$ and NSE values (Table 3.1) for the each of the streamflow gauges used for calibration indicate a good correlation between the observed and modelled data. For all gauges, annual and monthly correlations are better than the daily correlations. Investigations of the daily hydrographs indicate, that in general, the model is able to simulate most of the flow events and their durations quite closely to the recorded events. However, the difficulty in the model performance appears to be in simulating the magnitude of those events, in particular the high flow events. The simulated high flows are generally lower than the observed high flows, and particularly later in the wet part of the seasonal cycle (Figure 3.2, Figure 3.5 and Figure 3.6). High flow events are particularly reflected by the NSE values, which range from 0.75 for the Tanunda Creek gauge to 0.32 for the Penrice gauge. As the objective function used (section 3.3.2) uses square root or log transforms of the daily flow, the model calibration has focused on a more balanced representation of the flow regime, as opposed to focusing on high flows, as are reflected by the NSE score.

The monthly calibration charts indicate that flows early in the flow season tend to be overestimated, while flows toward the end of the flow season tend to be underestimated. Overall volume bias values across the catchment are variable, with no bias at the end of the system at Yaldara, but 21% higher at the Tanunda Creek gauge and 29% lower at the Penrice gauge. This difficultly in reflecting the seasonal water balance is expected, and is most likely due to the difficulties involved in simulating individual streamflow events during particular seasons, for example:

- Late autumn to early winter events, or 'break-of-season' events. These are the first runoff events, occurring during the period of initial catchment 'wetting up' followed by soil saturation (Jones-Gill and Savadamuthu, 2014).
- Late spring events, which are mostly driven by base flows and which are groundwater dependent (Jones-Gill and Savadamuthu, 2014). Modelling these events is difficult due to the complex nature of surface-groundwater interactions. This is particularly true for the Barossa PWRA, which is predominantly underlain by a fractured rock aquifer (Jones-Gill and Savadamuthu, 2014).
- Summer events which are more rainfall-intensity driven are difficult to model using only daily rainfall input data (Jones-Gill and Savadamuthu, 2014).

The other common challenge in catchment modelling is representation of the spatial variability in runoff generation within an area, with streamflow gauges not capturing this variability. In the case of this study, the hydrological model was calibrated to streamflow measured at the outlet of Upper Flaxman Valley, Lower Flaxman Valley and at the outlet of the Barossa PWRA at Yaldara. While soil characteristics and land use data have been used in the model to represent the variation of runoff generation across the project zones, additional streamflow data at least at the outlets of the other main tributaries (Duck Ponds Creek, Angaston Creek, Jacob Creek, Lyndoch Creek, Greenock Creek and Salt Water Creek) would further increase the confidence levels of representing the flow from those sub-catchments in the model.

# 4 Scenario modelling

Scenario modelling, in this study, was used to investigate the likely impacts of different management scenarios on flow regimes within and across the study area. Outputs from scenario modelling are expected to be used to assess impacts on other factors, such as flow regime requirements of WDEs within the Barossa PWRA.

The primary objective of the scenario modelling undertaken in this study was to provide modelled daily flow data sets to assess the impacts of different management options on flow regimes related to the EWRs of the Barossa PWRA.

All scenarios (except climate change analysis) in this study were run over the period 1 January 1980 to 31 December 2016, referred to as the 'modelling period' for the rest of this report. This is derived from a period of datasets that are long enough to represent the variability in rainfall in the region. For the purposes of this study, the period 1980 to 2016 was chosen as it represents the longest period of streamflow records available within the Barossa PWRA, and this period also represents a long record of the recent rainfall variability. Model outputs were generated at nodes representing the project zone outlets across the PWRA. Analysis of model flow outputs from the different scenarios are presented in this report for annual, monthly and daily time-steps.

## 4.1 Impact of farm dam on flow regime

To assess the impact of farm dams on flow regime, the calibrated hydrological models were run over the modelling period under following conditions and the modelled daily flows at the end of all project zones were compared;

- **Without development condition**: Farm dams and watercourse extractions removed.
- **Recent use condition**: Demand from farm dams and watercourse extractions set at recent (2005-2013) extraction rates.
- **Full allocation condition**: Demand from farm dams and watercourse extractions equal to full allocations.

### 4.1.1 No extractions scenario

This scenario represents the 'without development' condition (i.e. no farm dams and no watercourse extractions), and modelled flow generated from this scenario is used for (i) estimating the amount of water available (resource capacity), (ii) representing the current level of water use as a proportion of the resource capacity and (iii) producing a base case to estimate the potential impacts of current development on the Barossa PWRA's surface water resources.

Runoff generated from catchment areas, without farm dams and watercourse extractions, which is termed 'Resource Capacity', is generally used as the base volume from which water can be allocated sustainably from runoff capturing farm dams. The modelled mean annual runoff for the period 1980 to 2016 represents the resource capacity for the region, and the estimated volumes for the individual project zones within the Barossa PWRA are provided in Table 4.1 and Figure 4.1.

The resource capacity estimates are expressed in both volumetric (ML) and depth (mm) units. Resource capacity expressed as depth is calculated by dividing resource capacity expressed in ML by the catchment area expressed in square kilometres. The resource capacity represents the average runoff depth generated from an area, and is a useful metric when comparing different areas (different project zones in this study) for their runoff generation capability.

**Table 4.1 Resource capacity estimates for project zones**

| Project zone | Area (km$^2$) | Resource capacity (ML (mm)) |
|---|---|---|
| Upper Flaxman Valley | 44.3 | 2299 (52) |
| Stone Chimney Creek | 15.0 | 362 (24) |
| Mid Flaxman Valley | 19.8 | 259 (13) |
| Lower Flaxman Valley | 37.8 | 800 (21) |
| Duck Ponds Creek | 40.3 | 443 (11) |
| Upper Angaston Creek | 12.6 | 606 (48) |
| Lower Angaston Creek | 5.1 | 120 (24) |
| Transition Zone | 29.8 | 1274 (43) |
| Barossa Valley Floor | 63.1 | 1935 (31) |
| Upper Tanunda Creek | 21.7 | 1809 (83) |
| Lower Tanunda Creek | 9.7 | 262 (27) |
| Upper Jacob Creek | 40.2 | 2996 (75) |
| Lower Jacob Creek | 7.1 | 175 (25) |
| Barossa Valley Gorge | 25.0 | 689 (28) |
| Lyndoch Creek | 60.3 | 3222 (53) |
| Salt Water Creek | 19.6* | 423 (22) |
| Greenock Creek | 36.5* | 886 (24) |
| Total | | 18,560 (38) |

**Areas have been updated for Greenock Creek and Salt water Creek as part of new catchment delineation in this study.*

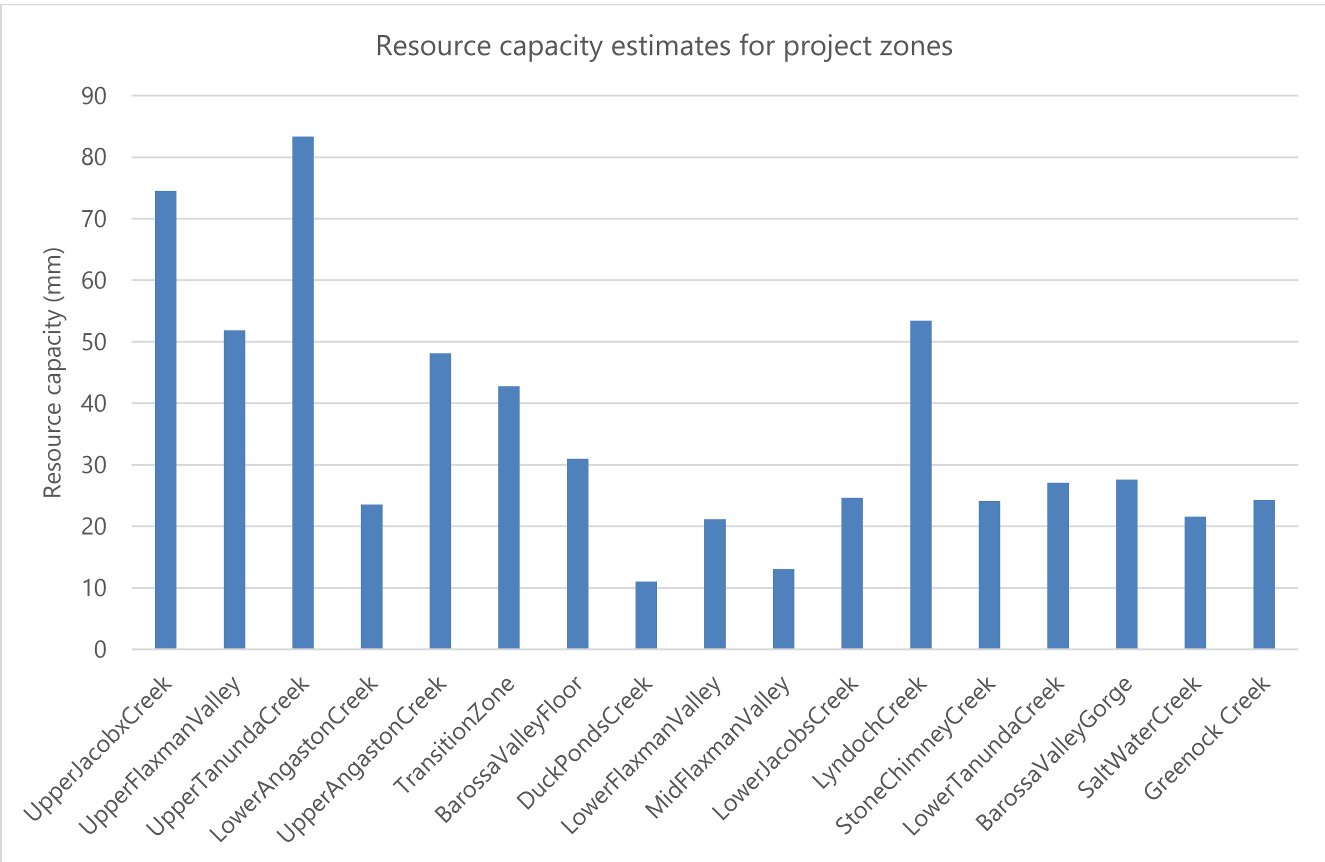



**Figure 4.1 Resource capacity estimates for project zones in the Barossa PWRA**

Updated resource capacities in Figure 4.1 indicate that the headwater zones in the high rainfall areas of Upper Tanunda Creek, Lyndoch Creek, Upper Jacob Creek and Upper Flaxman Valley are the higher runoff generating project zones within the Barossa PWRA. These are also the project zones with some of the highest levels of farm dam development within the Barossa PWRA (Table 2.2). Conversely, the drier project zones of Duck Ponds Creek and both the Mid and Lower Flaxman Valleys generate some of the lowest runoff within the Barossa PWRA, but also have the lowest levels of farm dam development.

The total surface resource capacity of the Barossa PWRA is estimated to be 18.6 GL (41 mm when expressed in flow depth). This varies across the project zones, ranging from 70 mm to 80 mm in the high rainfall zones of Upper Jacob Creek and Upper Tanunda Creek to around 11 mm in the Duck Ponds Creek and Mid Flaxman Valley project zones.

In addition, the current full allocations from farm dams, as well as recent use (2005-2013), plus an estimate of stock and domestic use, was compared with the resource capacity of each project zone, in order to quantify the level of demand compared with available water within each project zone. Similar to the previous study, data presented in Table 4.2 and Figure 4.2 does not include data on watercourse extractions, as it is more meaningful to express them as a proportion of a total flow passing through the project zone (which in the case of the non-headwater project zones, is the cumulative runoff from upstream project zones). Even without including data on watercourse extractions, the current estimated use from five of the seventeen project zones is greater than 25% of resource capacity, noting that 25% is defined as the sustainable extraction limit defined for the Western Mount Lofty Ranges PWRA (AMLR NRM Board, 2013). Six of project zones have a current estimated use that is close to, or greater than, 20% of resource capacity, which is the sustainable extraction limit for the Eastern Mount Lofty Ranges PWRA (SAMDB NRM Board, 2013). For each project zone, the current estimated use is at least greater than 5% of resource capacity, which is the sustainable extraction limit for both the WMLR and EMLR if low flows are not allowed to flow through the catchments (either bypassing or being released from all existing licensed dams and from all unlicensed dams greater than 5 ML).

The data also indicates that, in most of the project zones, recent use from licensed dams has been lower than the allocated volume.

**Table 4.2 Use from dams as a proportion of resource capacity**

| Project zone | Resource Capacity (RC) (ML (mm)) | Percentage of total use/demand from dams compared to resource capacity | |
|---|---|---|---|
| | | Allocated volume plus S&D demand | Recent use plus S&D demand |
| Upper Flaxman Valley | 2299 (52) | 38% | 23% |
| Stone Chimney Creek | 362 (24) | 52% | 37% |
| Mid Flaxman Valley | 259 (13) | 16% | 15% |
| Lower Flaxman Valley | 800 (21) | 9% | 6% |
| Duck Ponds Creek | 443 (11) | 10% | 8% |
| Upper Angaston Creek | 606 (48) | 4% | 5% |
| Lower Angaston Creek | 120 (24) | 16% | 15% |
| Transition Zone | 1274 (43) | 19% | 13% |
| Barossa Valley Floor | 1935 (31) | 23% | 12% |
| Upper Tanunda Creek | 1809 (83) | 12% | 11% |
| Lower Tanunda Creek | 262 (27) | 79% | 35% |
| Upper Jacob Creek | 2996 (75) | 20% | 10% |
| Lower Jacob Creek | 175 (25) | 47% | 81% |
| Barossa Valley Gorge | 689 (28) | 15% | 15% |
| Lyndoch Creek | 3222 (53) | 9% | 6% |
| Salt Water Creek | 423 (22) | - | 36% |
| Greenock Creek | 886 (24) | - | 31% |

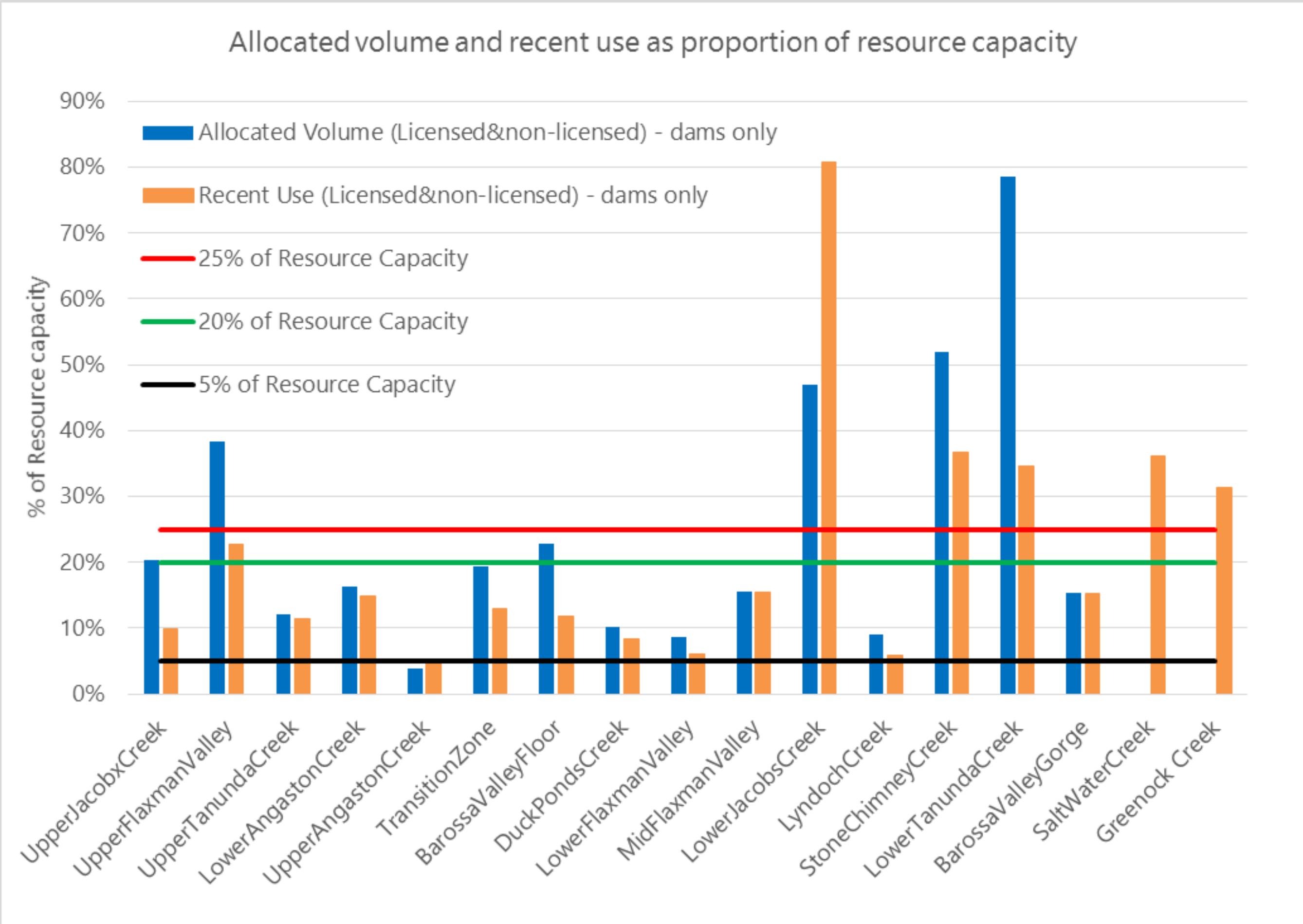



**Figure 4.2. Allocation and recent use as proportion of resource capacity**

### 4.1.2 Recent use scenario

This scenario represents the recent level of water use (both metered licensed extractions and estimated stock and domestic use) within the Barossa PWRA at the time of assessment. The distribution of dams is based on a 2010 aerial survey. For licensed farm dams, the capacity was based on water license details, while capacities for non-licensed dams were estimated using a formula based on surface area. Use from licensed farm dams and watercourse extractions was based on average metered water use data for the period 2005-2013, and estimated to be 30% of capacity for non-licensed farm dams. This scenario uses the same model set up as the one used for calibrating the model, except that the model run period has been extended to start in 1980, as opposed to 2003. It should be noted that while the actual daily rainfall and evaporation data are used in the model for the modelling period (1980 to 2016), the annual variation in the number of farm dams, their capacity and extraction from them during that period is not represented in the model. As such, this scenario represents recent use projected over the entire modelling period, as opposed to representing the historical conditions.

Results of the modelling and further analysis of data for the seventeen project zones indicates that the current level of development (farm dams and watercourse extractions) has potentially reduced the average annual runoff in the Barossa PWRA for the period of assessment by around 17%. This reduction is much higher (greater than 50%) during drier years. This reduction also varies across the project zones and is dependent on a number of factors including farm dam density and rainfall and runoff variability. Reduction in average annual runoff generated in each project zone under recent use condition can be seen in Figure 4.3.

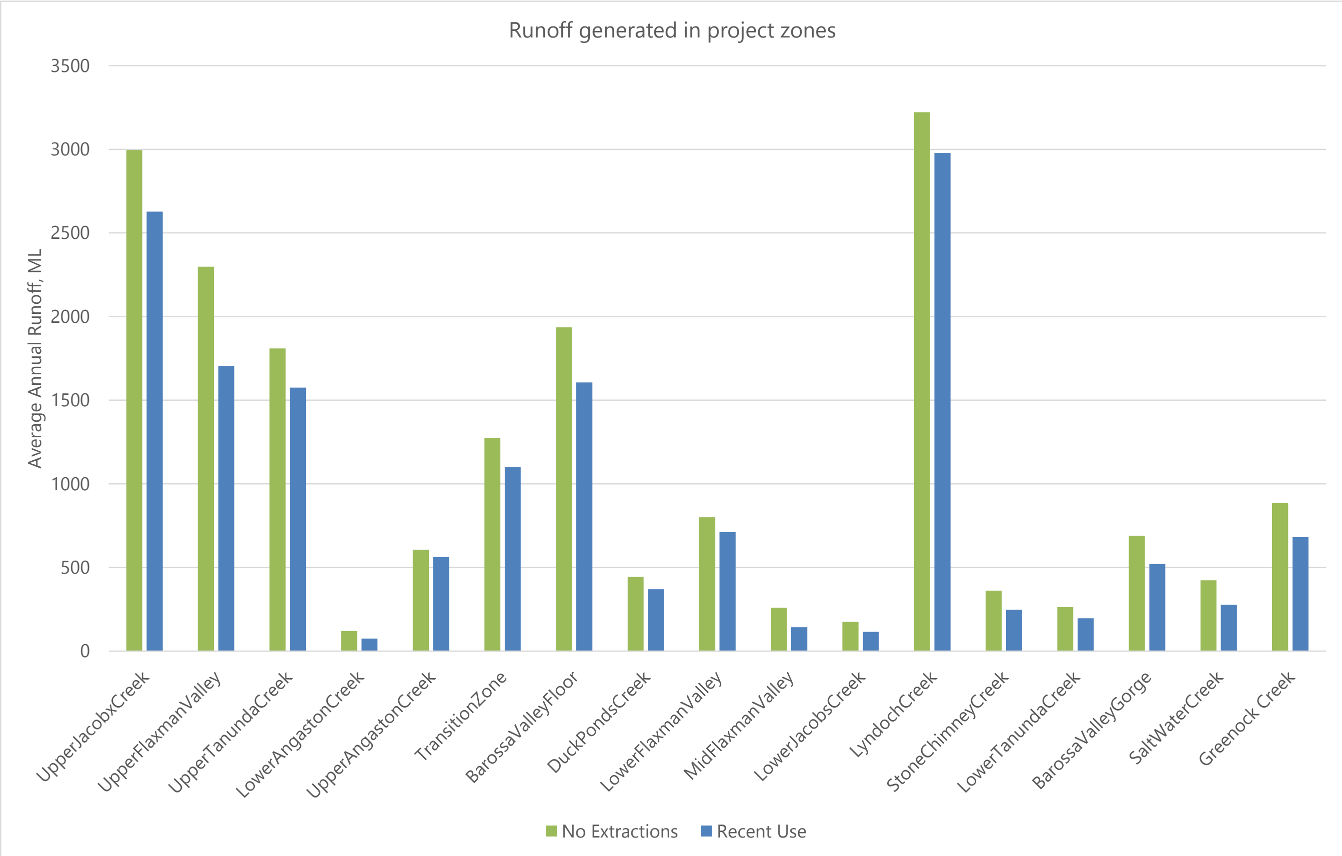



**Figure 4.3 Average annual runoff generated in project zones in the Barossa PWRA under "no extraction" and "recent use" scenarios**

Comparison of daily flow exceedance percentiles[1] is a standard and an effective way of comparing the impact on flow regimes between scenarios, as analysis of daily flows patterns is more critical than annual and monthly flow volumes when analysing EWRs. Comparison of daily flows between the recent use and no extractions scenarios was undertaken for each of the project zones.

The results obtained are consistent with previous study in that

(i) The highest impact of farm dams is on low flows, in particular during late autumn /early winter when the first runoff generating higher rainfall events occur,

(ii) Farm dams have minimal impact on winter high flows, as the dams are potentially full and spilling during the high flow season and

(iii) The extent of these impacts varies across project zones depending on the factors discussed in the earlier paragraph.

Figure 4.4 illustrates the impacts of recent use on daily flows at the outlet of Upper Flaxman Valley project zone. It illustrates the higher impacts of dams on low and median flows, with lower impacts on higher flows. This pattern of impact was observed across all project zones, with the degree of impact varying based on the level of farm dam development in the project zones.

[1] Percentage of time during the analysis period when flows where equalled exceeded a certain value. For example, if the 10th %ile exceedance value were 5 ML/d, it means that daily flows were equal to or above 5 ML for 10 percent of the analysis period. And, if the period of analysis were a year, then the flows would have been 5 ML and above for 36.5 days

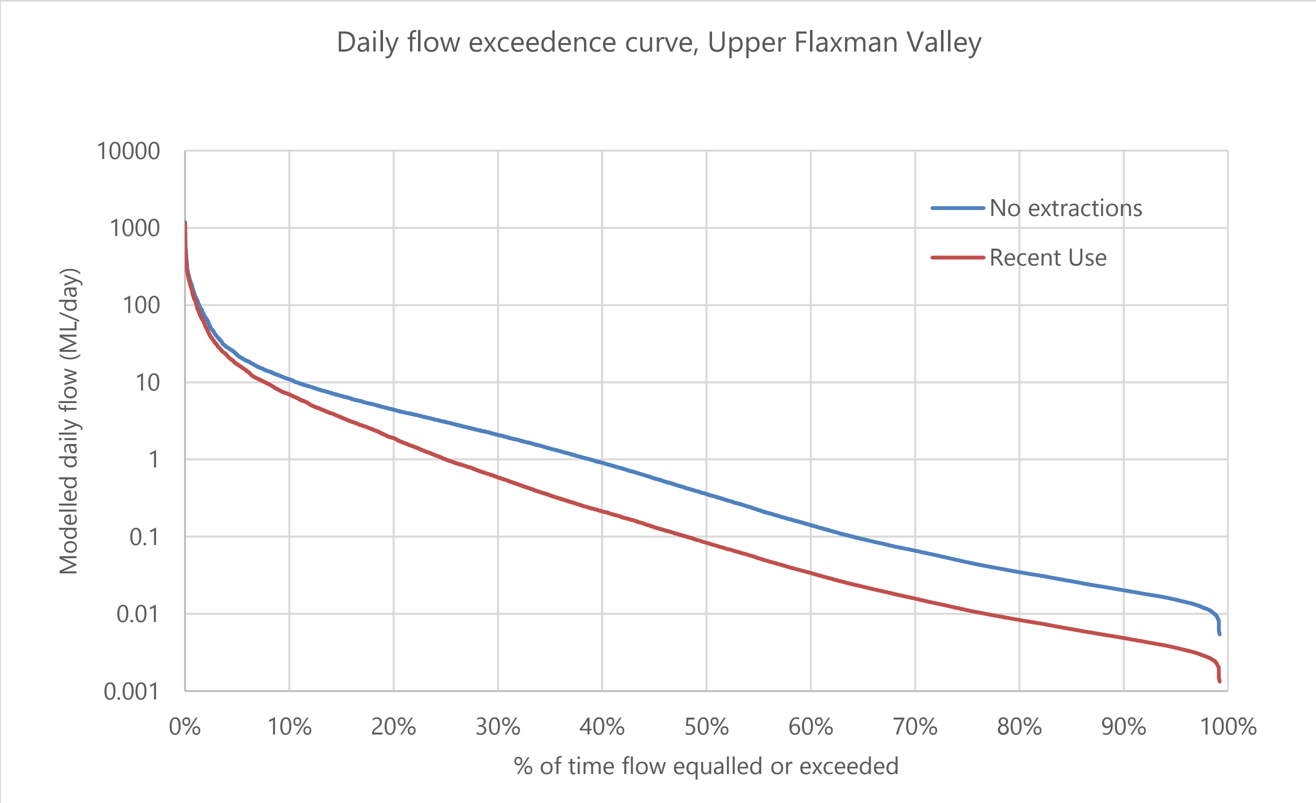



**Figure 4.4 Daily flow duration curves for Scenario 1 and Scenario 3, Upper Flaxman Valley**

### 4.1.3 Full allocation scenario

This scenario is designed to estimate the impact on flow regime if all licensed users used their full allocation. With the annual demand from the licensed farm dam and watercourse extraction model nodes were set at the volumes that were allocated to them. Reduction in average annual runoff generated in each project zone under full allocation condition can be seen in Figure 4.5.

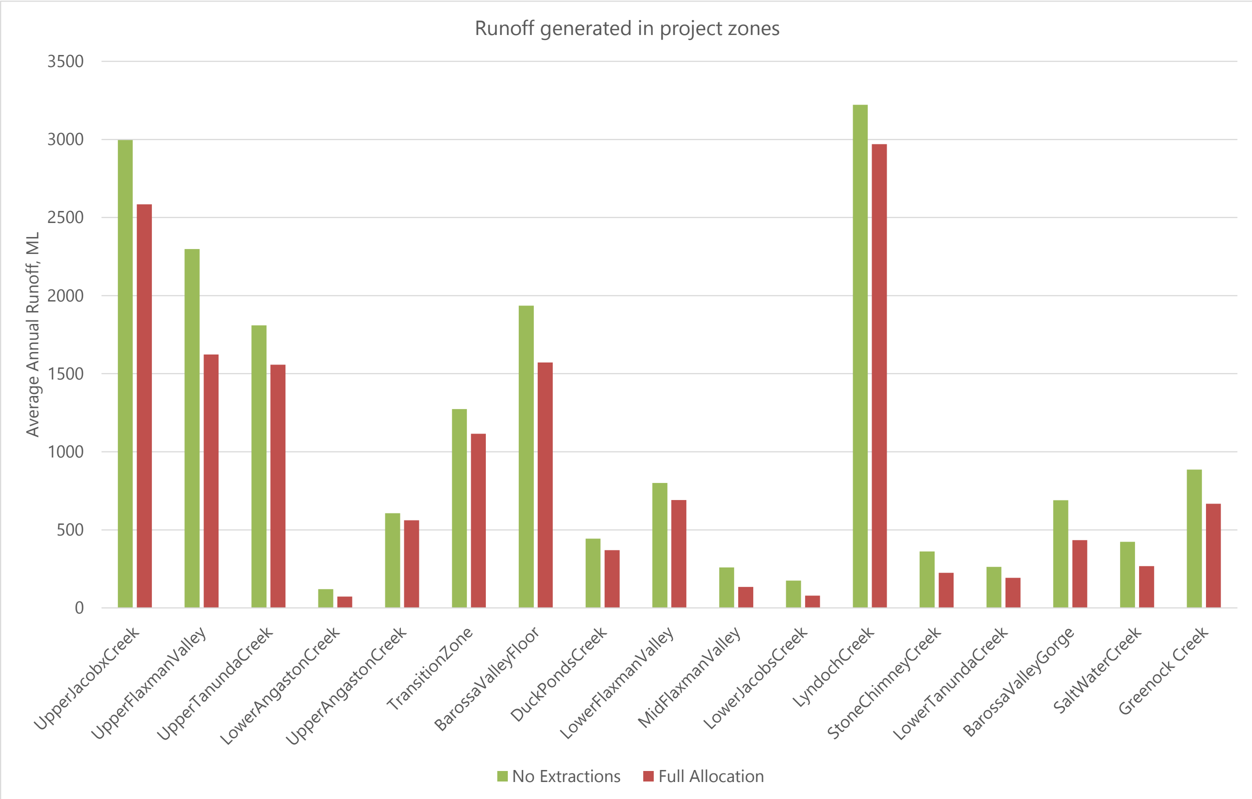



**Figure 4.5 Average annual runoff generated in project zones in the Barossa PWRA under "no extraction" and "full allocation" scenarios**

The results, as illustrated in Figure 4.6, indicate that:

- Reductions in flow are predicted across all the project zones when full allocations are used, in comparison to flows generated under recent use scenario, expected since recent use in most of the project zones is lower than the actual allocated volumes.
- The estimated reductions in flow are generally less than 5% in all flow categories across the project zones, with some exceptions. The largest reductions are mostly present at low ($80^{th}$ percentile) to median ($50^{th}$ percentile) flows in receiving zones. This includes the project zones of Lower Flaxman Valley (approximately 50% reduction in low flows and 40% reduction in median flows), Lower Jacobs Creek (approximately 80% reduction in median flows) and Barossa Valley Gorge (over 30% reduction in low and 15% reduction in median flow). Estimated reductions are much lower in the Duck Ponds Creek, Upper Jacob Creek and Lyndoch Creek project zones. This again reflects the extent of farm dam development, and is also a reflection of the proportion of licensed to non-licensed extractions within each project zone, with project zones having a higher proportion of licensed to non-licensed farm dams showing higher impacts.
- The impact on low flows ($80^{th}$ percentile) is minimal in the headwater project zones of Upper Flaxman Valley, Upper Tanunda Creek and Upper Jacobs Creek, in comparison to the impacts due to recent extractions, as additional volumes being extracted from the licensed dams are expected to have minimal impacts on low flows and much higher impacts on median ($50^{th}$ percentile) and high ($20^{th}$ percentile) flows. This is the reverse in the case of the receiving project zones, as there are more watercourse extractions than runoff capturing farm dams in those project zones. This results in more of the low flows being diverted or extracted by the watercourse extractions, and hence higher impacts on low flows in comparison to median and high flows.

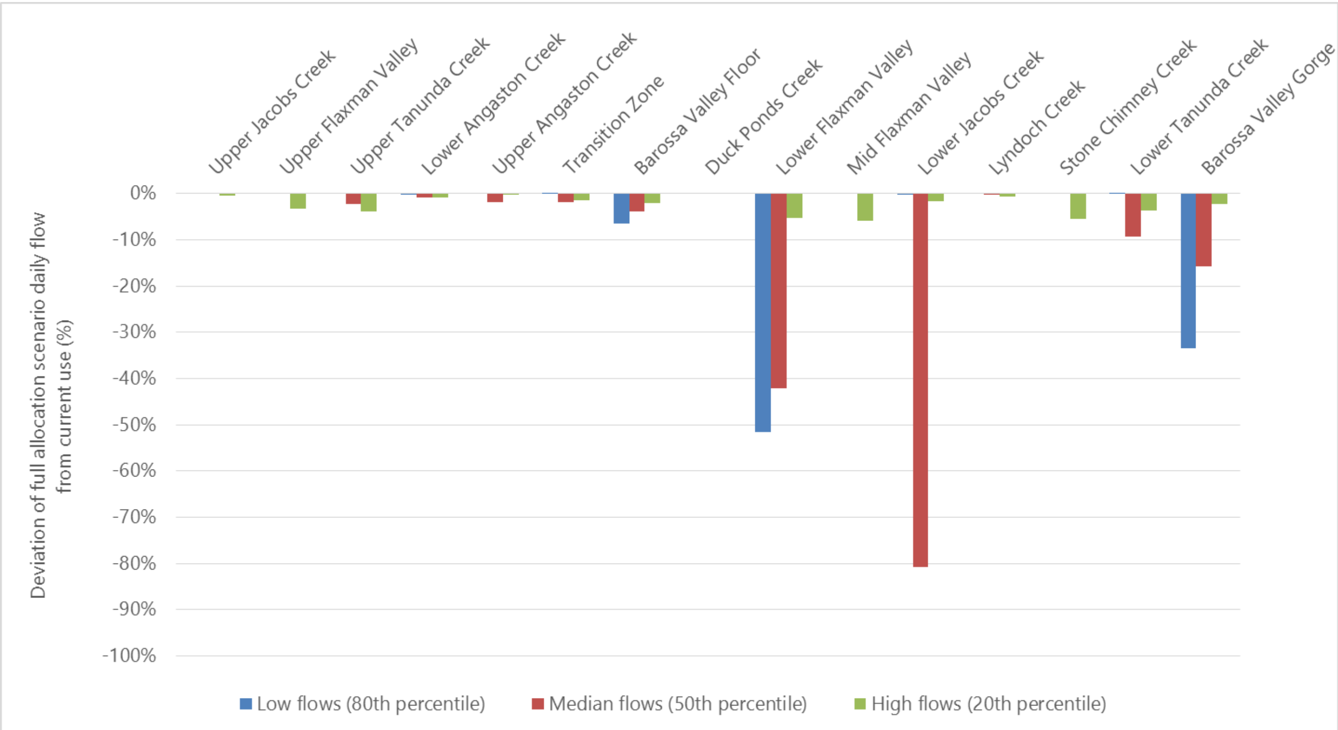



**Figure 4.6 Deviation of Full Allocation scenario daily flows from Recent Use scenario daily flows**

## 4.2 Impact of urban development on flow regime

The hydrological models were run over the modelling period under recent use conditions with and without inclusion of urban areas. The results in each case were compared to assess the impact of urban development on modelled daily flows at the end of each project zone.

For this scenario the reduction in generated runoff with removal of urban areas was higher for the project zones with higher density of urban areas, such as Transition, Barossa Valley Floor and Upper Angaston zones, with the highest reduction (25mm) in Transition zone (Figure 4.7 and Table 4.3). It is estimated that exclusion of urban runoff will result in reduction of average annual flows at the outlet of the Barossa PWRA by nearly 14%. This means that urban runoff is estimated to account for nearly 14% of average annual flows at the outlet of the Barossa PWRA.

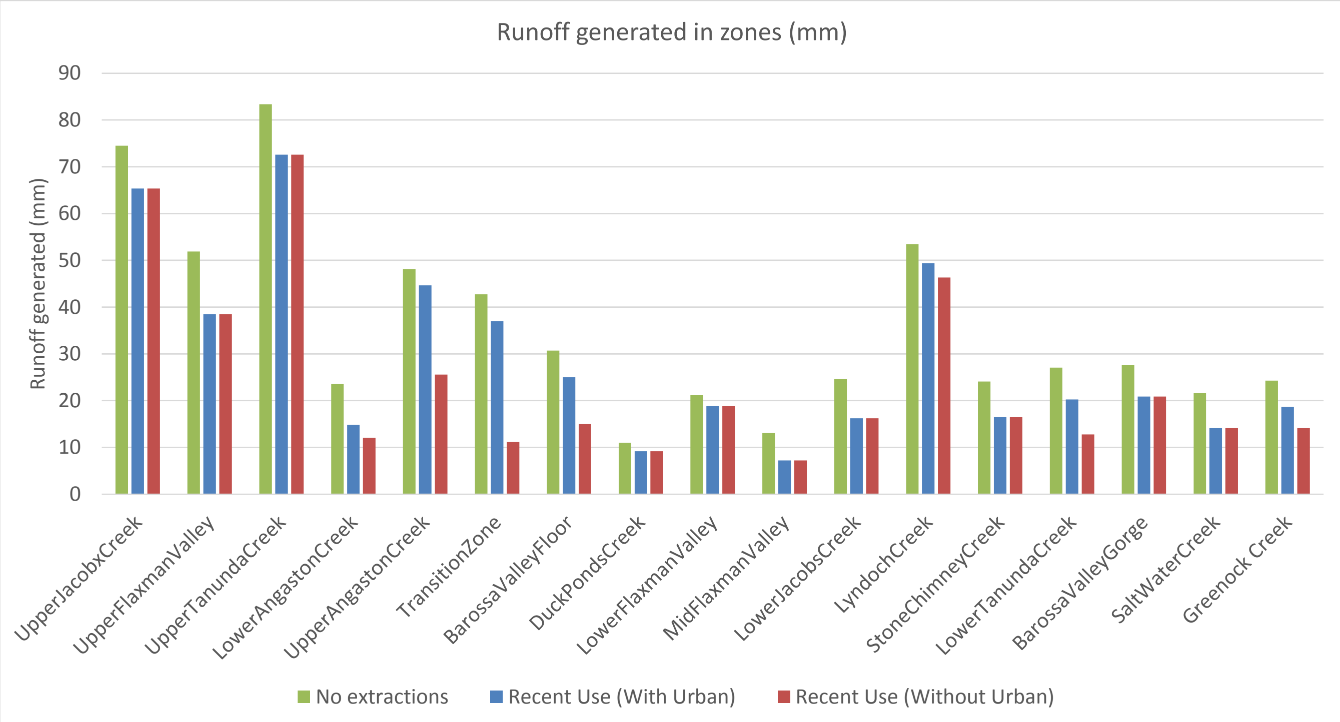



**Figure 4.7 Annual runoff generated in project zones under no extraction scenario (green), recent use scenario scenarios with urban runoff (blue) and without urban runoff (red)**

**Table 4.3 Annual runoff generated in project zones under recent use scenario scenarios with urban runoff and without urban runoff**

| Project zone | Annual runoff generated in project zones, mm | |
|---|---|---|
| | With Urban Runoff | Without Urban Runoff |
| Upper Flaxman Valley | 38.5 | 38.5 |
| Stone Chimney Creek | 16.5 | 16.5 |
| Mid Flaxman Valley | 7.2 | 7.2 |
| Lower Flaxman Valley | 18.8 | 18.8 |
| Duck Ponds Creek | 9.2 | 9.2 |
| Upper Angaston Creek | 44.6 | 25.6 |
| Lower Angaston Creek | 14.8 | 12.1 |
| Transition Zone | 37.0 | 11.2 |
| Barossa Valley Floor | 25.0 | 15.0 |

| Project zone | Annual runoff generated in project zones, mm | |
|---|---|---|
| | With Urban Runoff | Without Urban Runoff |
| Upper Tanunda Creek | 72.6 | 72.6 |
| Lower Tanunda Creek | 20.3 | 12.8 |
| Upper Jacob Creek | 65.4 | 65.4 |
| Lower Jacob Creek | 16.2 | 16.2 |
| Barossa Valley Gorge | 20.9 | 20.9 |
| Lyndoch Creek | 49.4 | 46.3 |
| Salt Water Creek | 14.1 | 14.1 |
| Greenock Creek | 18.7 | 14.1 |

To summarise the impact of current urban development on the flow regime, annual runoff generated in all project zones in the Barossa PWRA was compared for conditions with and without urban development. Figure 4.8 shows the estimated reduction in runoff (in mm) for a range of annual rainfall totals. The plot indicates that the difference between 'with urban' and 'without urban' runoff increases in an approximately linear fashion with increasing annual rainfall.

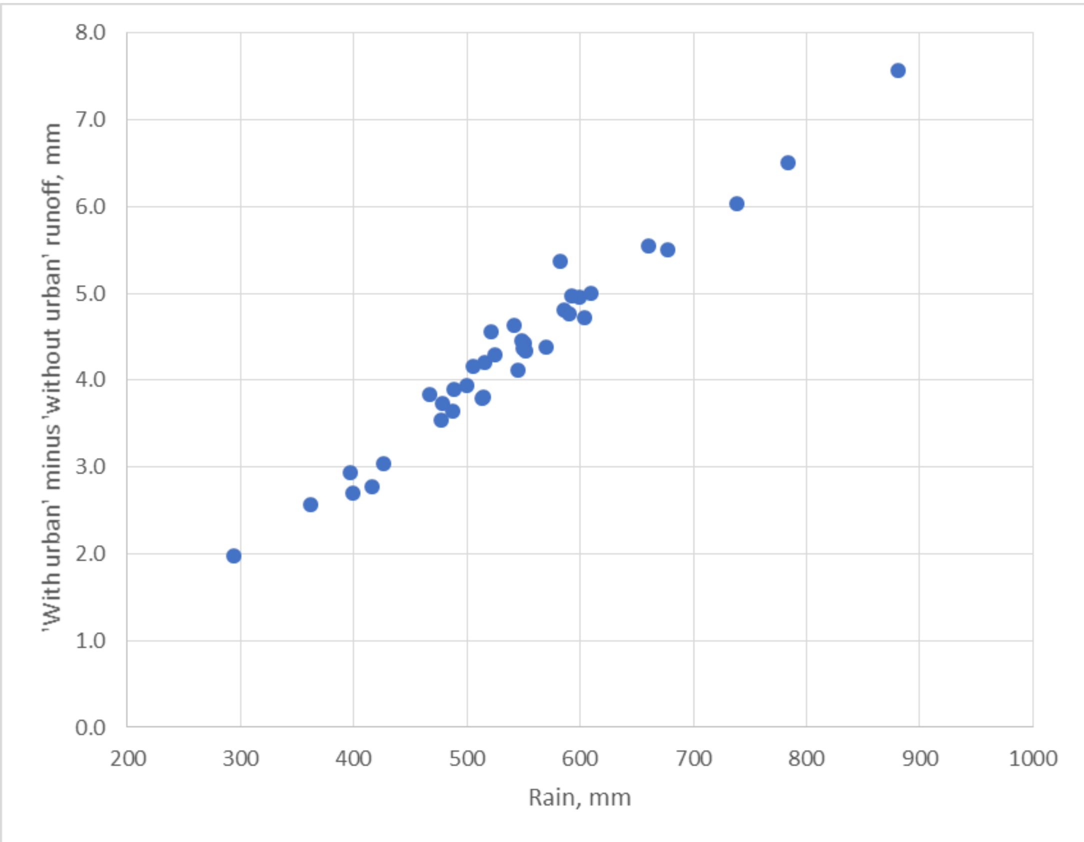



**Figure 4.8 Difference in runoff (in mm) between with and without urban development conditions for various annual rainfall totals**

## 4.3 Impact of climate change on flow regime

This section describes the analysis of the likely changes to the flow regimes in Barossa PWRA at project zones scale, under a range of projected future climate scenarios. While changes in climate are projected by General Circulation Models (GCMs), the processes controlling the conversion of change in climate into changes in water availability occur at a smaller scale, and therefore require local scale investigations on a case-by-case basis. The hydrological models developed for the Barossa PWRA were used to assess the potential impact of future climate scenarios.

As described in Cetin et al. (2015), it is not the intention of climate change analysis to predict the likely changes in flow regimes over the next century. The GCM outputs provide a projection of the changes in climate for a range of scenarios (e.g. high emission or intermediate emission), which can be converted through the use of hydrological models to a range of possible changes in flow regimes.

### 4.3.1 Climate data

To enable the evaluation of climate change impacts on surface water resources, it was deemed important to identify the most appropriate climate change projections for use in analysis. This study used downscaled climate projections data that was developed as part of a Goyder Institute project, “SA Climate Ready Data” (Goyder Institute for Water Research, 2015).

At the time of writing, SA Climate Ready included the most comprehensive set of downscaled climate projections data available for South Australia. Data is available for six climate variables (rainfall, temperature maximum, temperature minimum, areal potential evapotranspiration, solar radiation, vapour pressure deficit), using the following two emission scenarios, through to 2100;

- Intermediate Representative Concentration Pathways (RCP4.5)
- High Representative Concentration Pathways (RCP8.5)

The RCP4.5 and RCP8.5 scenarios are representative of increases in atmospheric greenhouse gas concentrations through the 21$^{st}$ century that result in global radiative forcing, by 2100, of 4.5 W/m$^2$ and 8.5 W/m$^2$ respectively, which corresponds to $CO_2$ levels of approximately 550 ppm and 940 ppm by 2100.

The key features of SA Climate Ready include:

- Data is aligned to the South Australian NRM regions, so it is directly relevant to regional scale adaptation planning;
- Detailed data that was generated using an approach that has been successfully applied for hydrological impact research in Southern Australia;
- Selection of GCMs based on their ability to represent the influence of climate drivers such as the Indian Ocean Dipole and the El Niño-Southern Oscillation on South Australia’s climate; and
- Results that were tested through an “application test bed”, verifying the applicability of the climate projections data to hydrological modelling in South Australia.

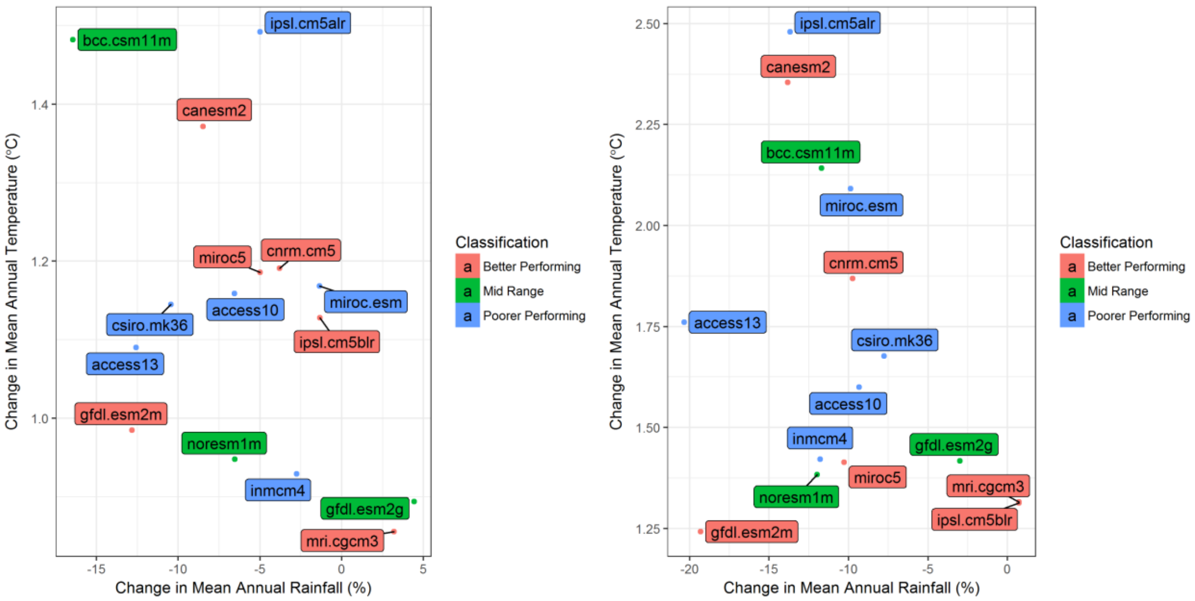
For further information on this dataset and how it was produced see:
*https://data.environment.sa.gov.au/Climate/SA-Climate-Ready*

### 4.3.2 GCM selection

The SA Climate Ready data set includes projections from 15 different GCMs, two emission cases, and 100 replicates of the projected climate from 2005 to 2100 (plus a baseline period from 1900 to 2005) for each combination of GCM and emission case. This represents 285 000 years of simulation, and was considered to be computationally intensive to simulate changes in streamflow for all climate projections available for the Barossa PWRA. As such, a subset of GCMs that represent the range of climate projections were identified to be used in this study.

The GCM selection approach used was based on the Climate Futures approach (Whetton et al. 2012), which involves classifying the projected changes in climate by a suite of GCMs into separate categories based on the relative frequency of GCMs projecting a similar trend. The projected changes in mean annual temperature and mean annual rainfall were used as two variables to evaluate the variability in projections from the range of GCMs. The analysis was undertaken for one weather station that had downscaled data available (Williamstown) that is located close to the study area. The time horizon of 2100 has been used to assess the projected changes in mean annual temperature (in degrees) and mean annual rainfall (as a percentage) derived from the downscaled GCM projections.

Two emission scenarios were considered in this study; an intermediate emission (RCP4.5) scenario and a high emission (RCP8.5) scenario, and the projected changes in rainfall and temperature for all fifteen GCMs for Williamstown is plotted in Figure 4.9. (Labels represent different GCMs).




(a) (b)

**Figure 4.9 GCM projections for Williamstown for 2100 – (a) RCP4.5 and (b) RCP8.5**

There is a considerable range in both rainfall and temperature projections for 2100 for the Williamstown weather station, particularly for the high emission scenario. Six of the fifteen GCMs considered were identified as better performing as part of the SA Climate Ready Project (Goyder Institute for Water Research, 2015). The following three of these six GCMs were selected to include in the modelling for this study;

- mri.cgcm3: projects the least reduction in rainfall and temperature for both emission scenarios, considered as "best case".
- cnrm.cm5: projects the average reduction in rainfall and temperature for both emission scenarios, considered "most likely case".
- gfdl.esm2m: projects the most reduction in rainfall for both emission scenarios, considered as "worst case".

### 4.3.3 Scenario analysis framework

In order to assess the long-term impact of climate change on flow regime at project zone scale, using the hydrological models developed in this study, climate projections for rainfall and PET from the three selected GCMs (i.e. mri.cgcm3, cnrm.cm5 and gfdl.esm2m) for the two emissions scenarios (RCP4.5 and RCP8.5) were incorporated as model inputs into the hydrological models. To automate analysis, R scripts were written to run 100 realisations of climate data (produced as part of SA Climate Ready project) for each combination of GCM and emission scenario, as inputs to the rainfall-runoff models, enabling an estimate of variability in flow regime due to future climate projections for 2100. This analysis was performed for each of the use scenarios (current use and full allocation).

It is important to note that the absolute values for modelled results are influenced by errors introduced by the downscaling processes (Westra et al, 2014). Therefore, the results should be interpreted as the projected changes in flow regimes when compared to the historical baseline period (1961 – 2005) in a given year. Note that this historical baseline period represents modelled rainfall rather than observed over this period, and thus each GCM and climate realisation combination has a unique historical baseline data set with which to assess relative change of climate projections. For context, the variability in data (rainfall, PET, flows) simulated over the baseline period is also presented in each graph.

To illustrate the variability in data derived from different GCM and emission scenarios, results are presented as box-plots with the format given in Figure 4.10.

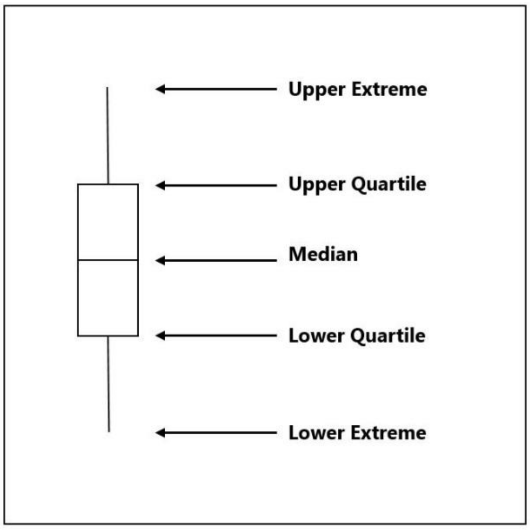



**Figure 4.10 Box-plot configuration used to illustrate the climate change projection results**

The box-plots for each parameter analysed were calculated using the following methodology:

1. For each climate realisation of a given GCM, the median value was calculated over the historical baseline period (1961 to 2005).
2. For the same GCM/climate realisation as in step 1, annual values were calculated for each year of the modelled period (1961 – 2100), encompassing the historical baseline period data set, and the two future emissions scenario data sets.
3. The percentage change of each annual value from the data sets calculated in step 2 from the historical baseline median value (step 1) was calculated using the following formula:

   Annual percentage change = [Annual value – Median baseline value] / [Median baseline value] x 100%

4. The annual percentage changes (step 3) across all GCM/climate realisations were combined into a single table, sectioned on a decadal basis, and box-plots calculated for each of the three data sets (i.e. historical and two future emissions scenarios).

### 4.3.4 Changes in annual rainfall and potential evapotranspiration

For the intermediate emission scenario (RCP4.5) the median annual rainfall for each decade fluctuates between -5% and -10% below the median historical baseline ("Historical") up to around 2050. The variability in annual rainfall increases slightly from 2050 onward (Figure 4.11). This reduction increases slightly for the high emission case, particularly after 2050, where the median annual rainfall fluctuates between -10% and -30% below the median historical baseline.

The median annual PET for each decade increases between 3-6% above the median historical baseline under the intermediate emission scenario. The increase is more pronounced under the high emission scenario, between 5-11% above the median historical baseline (Figure 4.12).

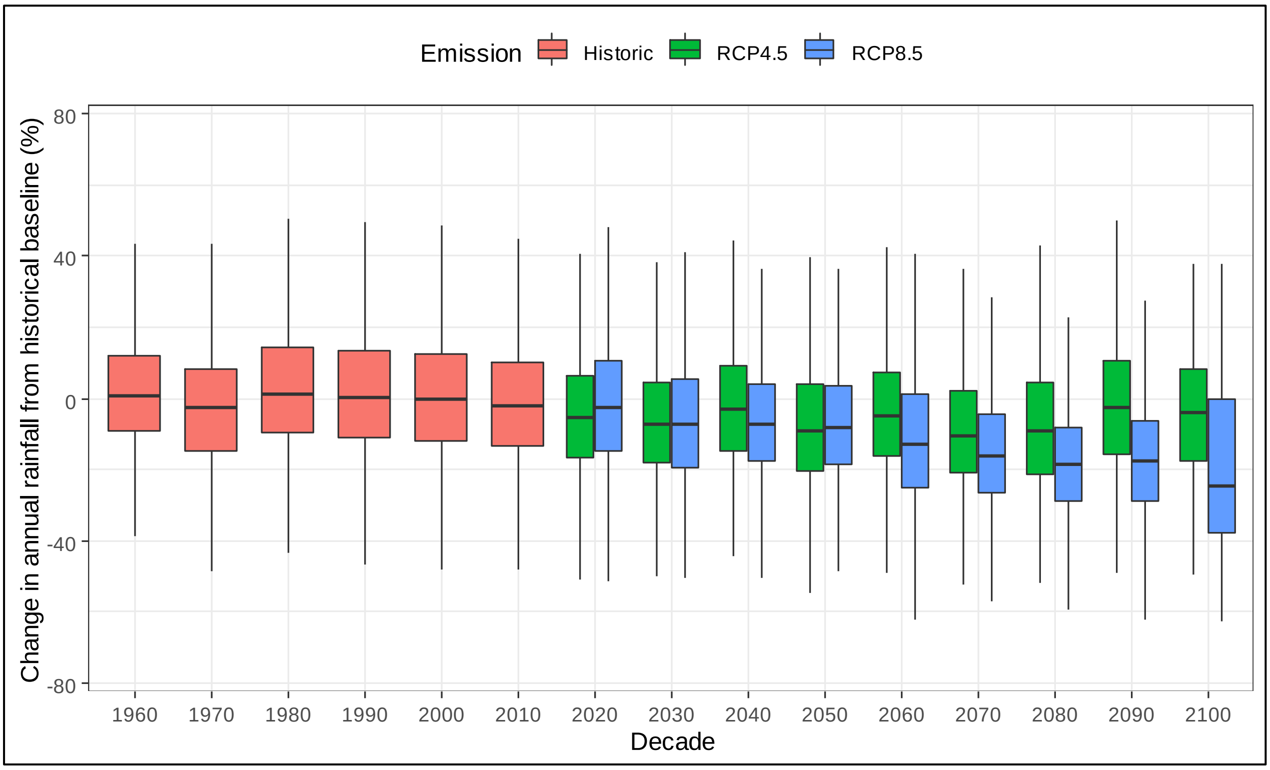



**Figure 4.11 Change in annual rainfall from historical baseline for two emission scenarios (RCP4.5 and RCP8.5)**

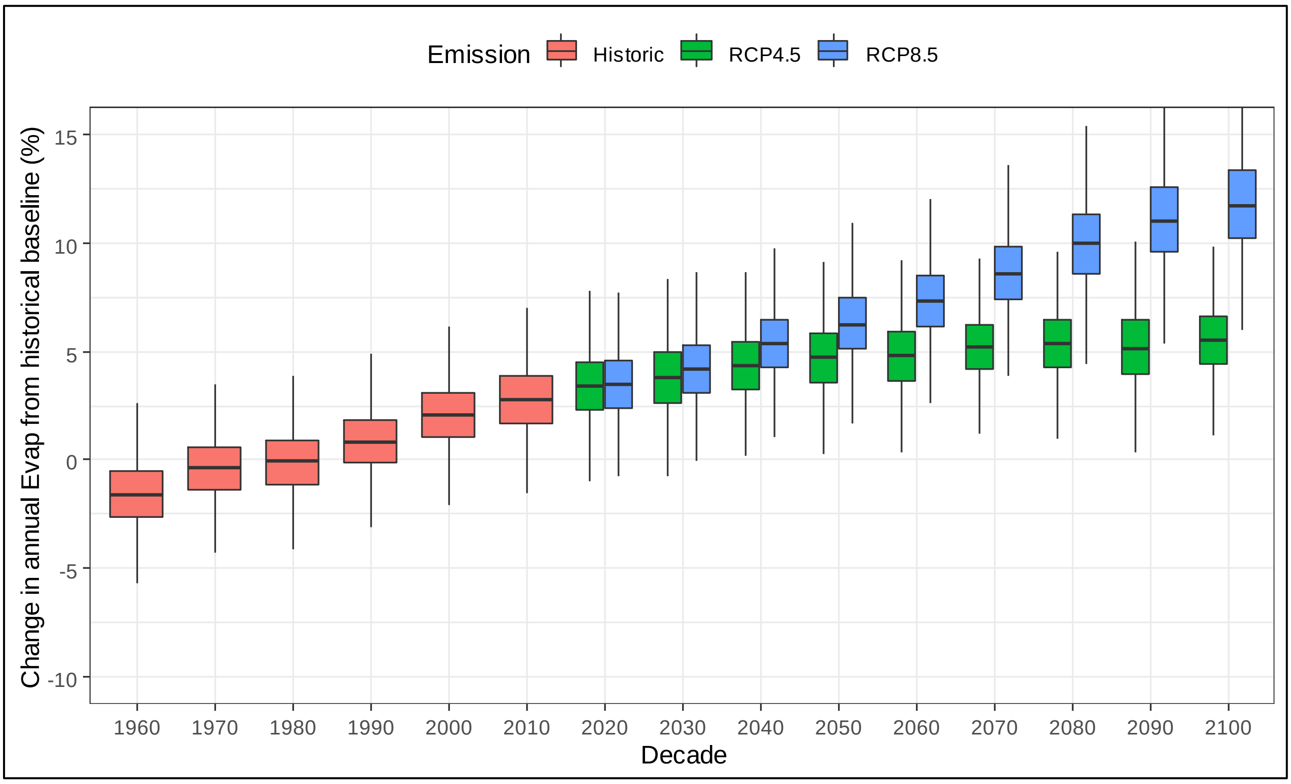



**Figure 4.12 Change in annual PET from historical baseline for two emission scenarios (RCP 4.5 and RCP 8.5)**

### 4.3.5 Changes in annual flows under climate projections

As outlined above, the climate projections were used as inputs to the hydrological models to produce the daily streamflow at the end of each project zone in the Barossa PWRA up to 2100. The model set up used was that used for calibrating the model, with the model run period modified for the future climate period. This means the models represent the recent level of water use and current urban development ('*Current use*' scenario). It was assumed that there are no further changes in these parameters for the future projection period, and that the calibrated rainfall-runoff relationship represented by the GR4J parameters is suitable for the future climate condition.

The main purpose of modelling streamflow based on climate projections is to provide input to future analysis of water availability for both consumptive and non-consumptive use. As an example of the changes to streamflow, Figure 4.13 and Figure 4.14 present changes in annual volume and the number of no flow days in each year at the end of the Upper Flaxman Valley project zone, compared to historical baseline conditions.

Analysis of model outputs indicates that the combination of the projected reduced rainfall and increased PET results in reduced streamflow. As an example, for the decade of 2080 the median annual streamflow reduced by approximately 50% for the intermediate emissions case, and approximately 75% for the high emissions case. This pattern of impact was observed across all project zones, with the degree of impact varying based on the level of farm dam development in the project zones.

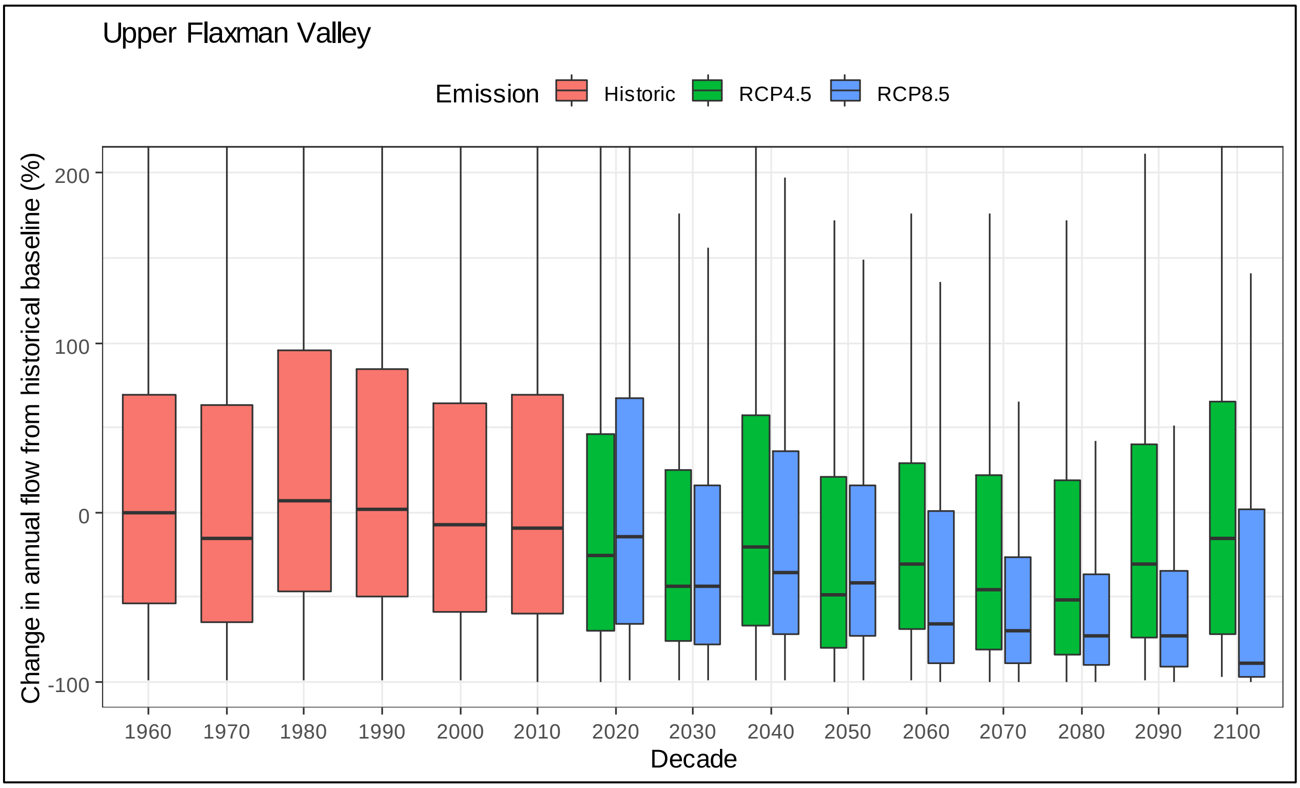



**Figure 4.13 Change in annual flow from historical baseline for two emission scenarios (RCP4.5 and RCP 8.5) under *Current Use* scenario**

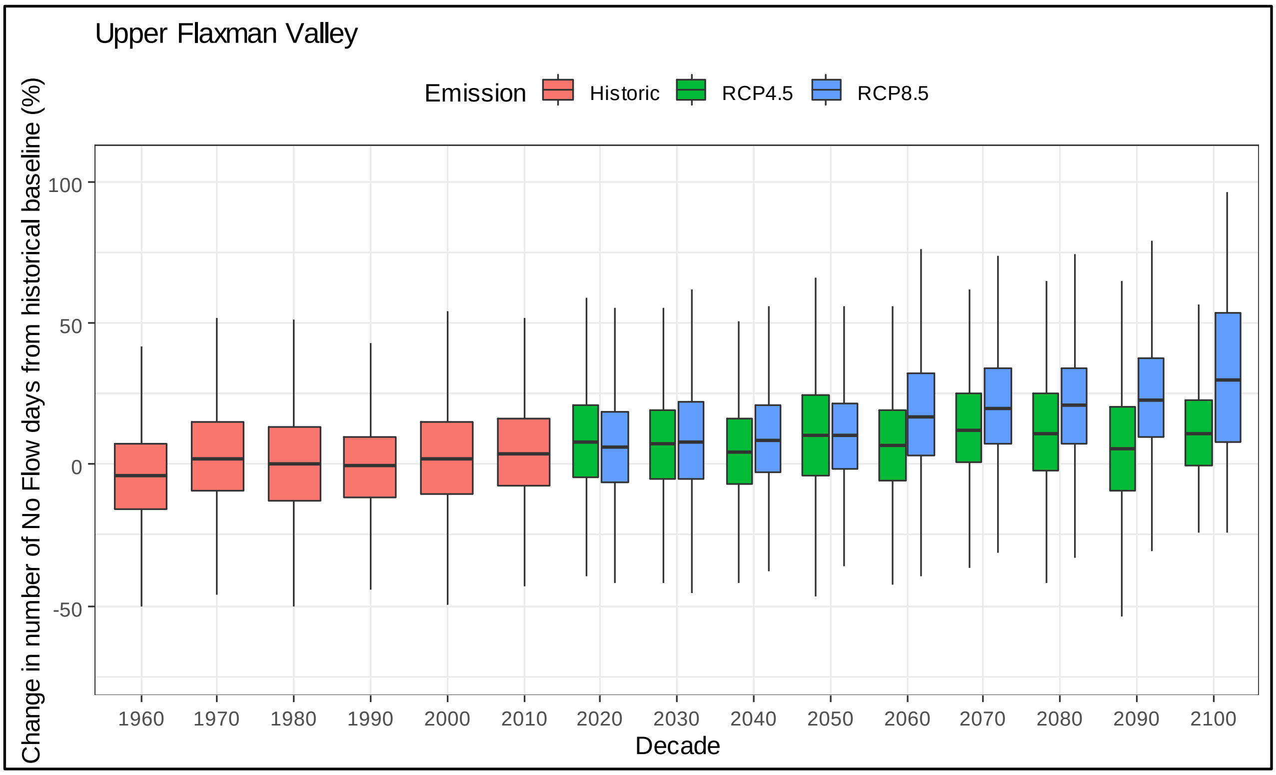



**Figure 4.14 Change in number of no flow days from historical baseline for two emission scenarios (RCP 4.5 and RCP 8.5) under *Current Use* scenario**

# 5 Summary of results

This section provides a summary and discussion of the results of the hydrological investigations undertaken for the Barossa Prescribed Water Resources Area, with the main scope of this study being:

- Extension of the modelling period to include recent climate and streamflow data, in particular the high flow events of 2016;
- Update of the dam information (location, volume, surface area) for the Greenock Creek and Salt Water Creek zones, to better represent surface water resource development in that area;
- Assessment of the impact of a number of scenarios on the flow regime, including:
  - Farm dam development
  - Urban development
  - Climate projections
- Provision of modelled outputs for further hydro-ecological analysis

**Data update**

Modifications and updates were made to the farm dam, rainfall and streamflow input data-sets to the hydrological model of the Barossa PWRA. A particular focus of the updates included refinement of farm dam estimates within the Greenock Creek and Salt Water Creek project zones as a result of further assessments of the dams, with 80 dams reclassified from the original non-licensed usage assumption to "likely to be" licensed. The assessment resulted in an update to the modelled farm dam properties (surface areas and volumes) in these project zones.

A total of 1780 farm dams in the Barossa PWRA were accounted for within the assessment, of which 14% were licensed. Larger farm dams, with 10 ML capacity or greater, make up only 10% of the total number of farm dams, but contribute to 72% of the total storage capacity. The largest farm dams (> 100 ML) constitute 25% of total storage capacity while being only 1% of the total number of farm dams.

The rainfall datasets, extending to 2012 in previous work, were updated up to December 2016 for all sites, and trend analysis performed. The majority of rainfall stations exhibited similar trends for the period 1889 to 2016, showing a wetter than average period at the start of the dataset (up to early 1920s), followed by average rainfall up to 1960, and a drier than average period to the end of the dataset – with the exception of 2016, which was a wetter than average year.

Streamflow data was updated for four main operational streamflow gauging stations. For each of the streamflow gauges, the daily FD curves were developed across the original period to 2012 (adopted from previous study) and the extended period to 2016. There were no significant alterations between analysed periods for each site. Each of the sites have periods of no-flow conditions, which decrease with increasing gauging station catchment area. The most upstream gauge, Mt McKenzie (A5050533), has the greatest period of no flow conditions (~40%), while the most downstream gauge at Yaldara (A5050502) has the least period of no flow conditions (~15%).

**Hydrological modelling**

This study involved the development of a surface water model for the Greenock Creek and Salt Water Creek project zones that is fully distributed, meaning the farm dams are not lumped and there is an individual node for every farm dam (licensed or non-licensed) within these two project zones (as outlined above). Functional units (areas within a project zone with similar behaviour in terms of runoff generation) were adopted with no change from previous study, in which they were determined based on consideration of a combination of soil characteristics and land use.

The partially distributed hydrological model for the remainder of the Barossa PWRA (the original model) was recalibrated using updated observed daily rainfall, evaporation and streamflow records, water demand data and estimated catchment parameters. The catchment parameters from the calibrated model of the Barossa PWRA were then applied to the fully distributed model for Greenock Creek and Salt Water Creek project zones. These models were then used simultaneously to generate simulated catchment runoff under various scenarios, to investigate the likely impacts of these scenarios on streamflow within the project zones.

Recalibration of the original model for the extended period of 1/1/2003 to 31/12/2016 was undertaken using the Model-Independent Parameter Estimation and Uncertainty Analysis software, PEST. Statistical analysis of the calibration results indicates a good correlation between the observed and modelled data for the each of the streamflow gauges used for calibration. For all gauges, annual and monthly correlations are better than the daily. The monthly calibration charts indicate that flows early in the flow season tend to be overestimated, while flows toward the end of the flow season tend to be underestimated. Overall volume bias values across the catchment are variable, with no bias at the end of the system at Yaldara, but 21% higher at the Tanunda Creek gauge and 29% lower at the Penrice gauge. This difficultly in reflecting the seasonal water balance is expected and is most likely due to the difficulties involved in simulating individual streamflow events during particular seasons.

The other common challenge in catchment modelling is representing the spatial variability in runoff generation within an area, with streamflow gauges not capturing this variability. In the case of this study, the hydrological model was calibrated to streamflow measured at the outlet of Upper Flaxman Valley, Lower Flaxman Valley and at the outlet of the Barossa PWRA (Yaldara). While soil characteristics and land use data have been used in the model to represent the variation of runoff generation across the project zones, streamflow data, at least at the outlets of the other main tributaries Duck Ponds Creek, Angaston Creek, Jacob Creek, Lyndoch Creek, Greenock Creek and Salt Water Creek, would further increase the confidence levels of representing the flow from those sub-catchments in the model.

**Scenario modelling**

Scenario modelling was used to investigate the likely impacts of different management scenarios on flow regimes within and across the study area. Three main areas of assessment on flow regime impacts were performed, including:

1. Impacts of farm dams on flow regime, covering no extraction, recent use and full allocation scenarios,
2. Impact of urban development on flow regime, comparing modelled outputs with and without urban areas included, and
3. Impact of climate change on flow regime, using climate projection data to assess future trends.

The first two assessments used the period from 1980 to 2016, which represented the longest period of streamflow records available within the Barossa PWRA, while the third assessment used the ClimateReadySA projected dataset extending from 2005 to 2100.

Results of the modelling indicated that the current level of development (farm dams and watercourse extractions) has potentially reduced the average annual streamflow in the Barossa PWRA by around 17%, and over 50% for drier years, with location specific variability also influenced by farm dam density and runoff characteristics. Increasing extractions from current usage to full allocations resulted in an increase in flow reduction, with the estimated reductions being greatest in receiving zones such as the Lower Flaxman Valley, Lower Jacobs Creek and Barossa Valley Gorge project zones, and much lower in headwater zones such as Duck Ponds Creek, Upper Jacobs Creek and Lyndoch Creek project zones. This variability is a reflection on the extent of development and the proportion of licensed to non-licensed use within each zone, with zones having a higher proportion of licensed to non-licensed use showing greater impacts.

The removal of urban development resulted in a reduction in generated runoff, with project zones that include a higher density of urban areas, such as Transition, Barossa Valley Floor and Upper Angaston zones, showing the greatest reduction in flows. It was estimated that the exclusion of urban runoff would result in a reduction of average annual flows at the outlet of the Barossa PWRA by nearly 14%.

The long-term impact of climate change on flow regime at zone scale was considered. For the intermediate emission scenario (RCP4.5) the median annual rainfall for each decade fluctuated between -5% and -10% below the mean historical baseline ("Historical") up to around 2050. The variability in annual rainfall increased slightly from 2050 onward. This reduction increased slightly for the high emission case, particularly after 2050, and the median annual rainfall fluctuated between -10% and -30% below the mean historical baseline. The median annual PET for each decade increased between 3-6% above the mean historical baseline under the intermediate emission scenario. The increase was pronounced under the high emission scenario, between 5-11% above the mean historical baseline.

Analysis of model outputs indicates that the combination of the projected reduced rainfall and increased PET results in reduced streamflow. As an example, for the decade of 2080 the median annual streamflow reduced by 50% for the intermediate emissions case, and 75% for the high emissions case. This pattern of impact was observed across all project zones, with the degree of impact varying based on the level of farm dam development in the project zones.

The daily time series modelled outputs were used to estimate the deviation of daily flows generated under the different scenarios from daily flows generated under current use scenario. This was undertaken by comparing the low (80$^{th}$ percentile), median (50$^{th}$ percentile) and high (20$^{th}$ percentile) daily flows generated under the different management scenarios to the flows generated under 'recent use' scenario. The results of analysis are summarised for all the project zones in Table 5.1.

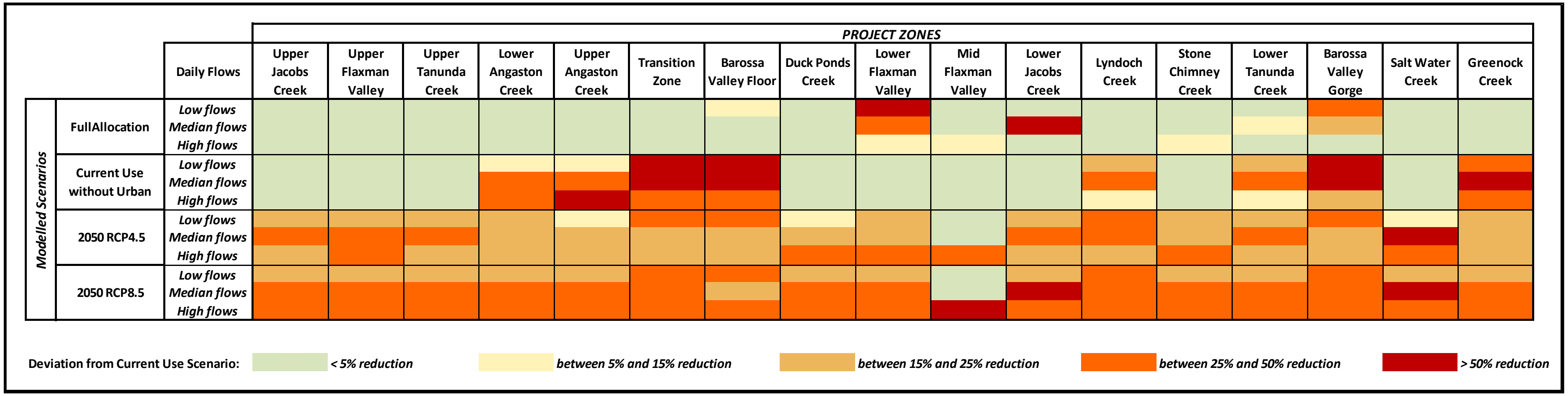
The results suggested that the reduction of daily flows under the full allocation scenario from those under the recent use scenario were generally less than 5%, with some exceptions. The largest reductions calculated were generally present at low and median flows in receiving project zones, including Lower Flaxman Valley (25% to 50% reduction under median and over 50% under low flows), Lower Jacobs Creek (over 50% reduction under mid-range flows), and Barossa Valley Gorge (15% to 25% reduction under median flow ranges and 25% to 50% under low flows).

The reduction of daily flows under the 'current use without urban' scenario was generally more substantial than those for full allocation, scenario and covered the full flow range in a number of project zones. The largest flow reductions were calculated in zones downstream of Lower Flaxman Valley, including Transition Zone, Barossa Valley Floor, Barossa Valley Gorge, Angaston Creek (Upper and Lower), Lower Tanunda Creek and Lyndoch Creek. Greenock Creek was also shown to have a large reduction in flows under current use without urban across the full flow range.

Under both climate change scenarios (2050 RCP4.5 and 8.5), reduction in flows exceeding 15% were observed in majority of project zones and across all flow ranges. Only the Mid Flaxman Valley showed a reduction of less than 5%, under low and median flow ranges. The reductions were more pronounced under the high emissions climate change scenario (2050 RCP8.5), which generally showed reductions of over 25% from current use. The highest reductions in this case were also mostly present under median to high flow ranges.

The results of this investigation will inform the amendment of the Water Allocation Plan (WAP) for the Barossa PWRA, by providing the scientific basis and data for establishment of surface water resource capacity, environmental water requirements and provisions, and ultimately in establishment of environmentally sustainable extraction limits for the PWRA.

**Table 5.1 Summary of impacts on flow regime under different scenarios**



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# 7 Appendices

## A. Re-calibrated rainfall-runoff parameters for Barossa PWRA model

Table 7.1 gives the re-calibrated GR4J parameters for each functional unit of the Barossa PWRA hydrologic model.

**Table 7.1 Calibrated GR4J parameters for each functional unit of the Barossa PWRA hydrologic model**

| GR4J model parameter | x1 | x2 | x3 | x4 |
|---|---|---|---|---|
| Description | maximum capacity of the production store | groundwater exchange coefficient | one day ahead maximum capacity of the routing store | time base of unit hydrograph UH1 |
| Units | mm | mm | mm | days |
| Median value | 350 | 0 | 90 | 1.7 |
| 80 % Confidence interval | 100-1200 | -5 to 3 | 20-300 | 1.1-2.9 |
| Range used for model calibration | 50 to 500 | -8 to 1 | 1 to 100 | 0.5 to 8 |
| **Calibrated model parameters for function units** | | | | |
| Functional unit 1 | 338.85 | -4.09 | 11.07 | 1 |
| Functional unit 2 | 295.87 | -0.87 | 25.74 | 1 |
| Functional unit 3 | 291.79 | -7.73 | 34.23 | 1 |
| Functional unit 4 | 291.79 | -7.73 | 34.23 | 1 |
| Functional unit 5 | 295.87 | -0.87 | 25.74 | 1 |
| Functional unit 6 | 295.87 | -0.87 | 25.74 | 1 |

## B. Re-calibration results

*A5050533 (Mt McKenzie)*

The re-calibration statistics for the Mt McKenzie gauge, which captures flows from the Upper Flaxman Valley sub-catchment, for the period 01/06/2003 to 31/12/2016 are provided in Table 7.2. Comparison between modelled and observed annual, monthly and daily flow data are presented in Figure 7.1, Figure 7.2 and Figure 7.3, respectively.

**Table 7.2 Calibration statistics for A5050533 (Mt McKenzie)**

| A5050533 | Annual | | Monthly | | Daily | |
|---|---|---|---|---|---|---|
| Mt McKenzie | *Observed* | *Modelled* | *Observed* | *Modelled* | *Observed* | *Modelled* |
| Mean (ML) | 1961 | 1583 | 163 | 132 | 5.8 | 4.7 |
| Median (ML) | 2371 | 1712 | 2.2 | 3.8 | 0.1 | 0.1 |
| R^2 | 0.95 | | 0.92 | | 0.75 | |
| NSE | 0.83 | | 0.86 | | 0.74 | |
| % Volume Difference | 19% | | 19% | | 19% | |

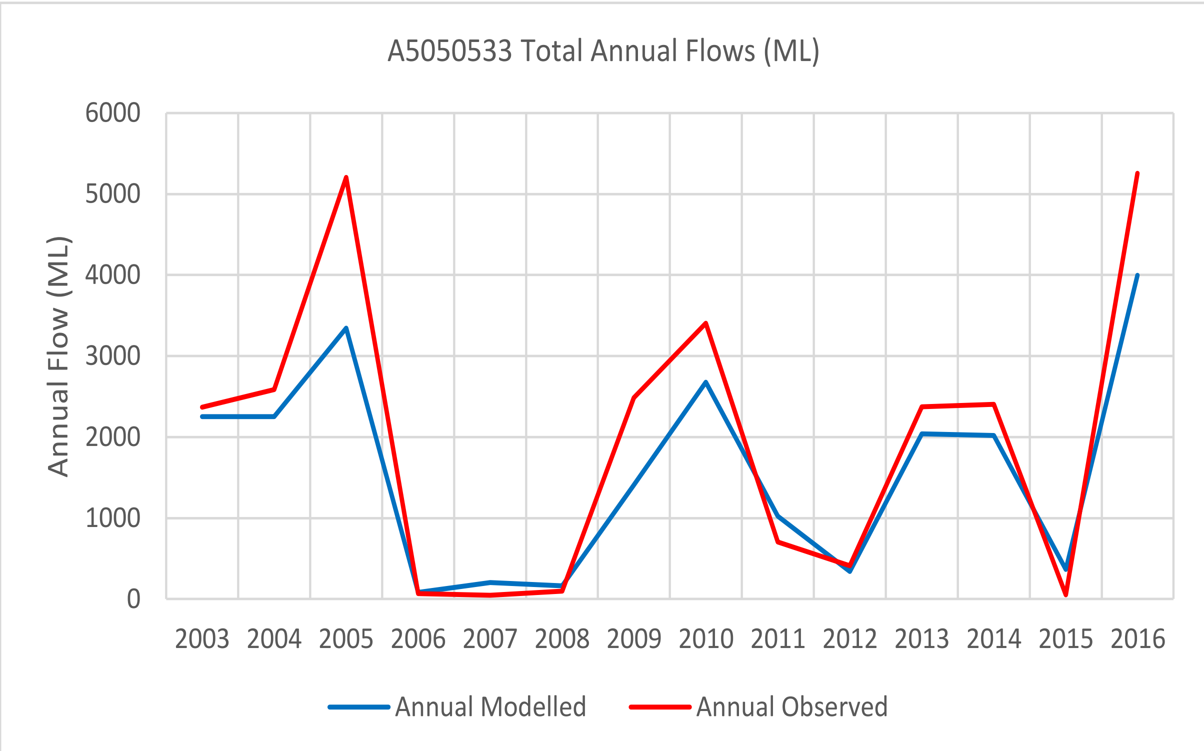


**Figure 7.1 Annual calibration chart for A5050533 (Mt McKenzie)**

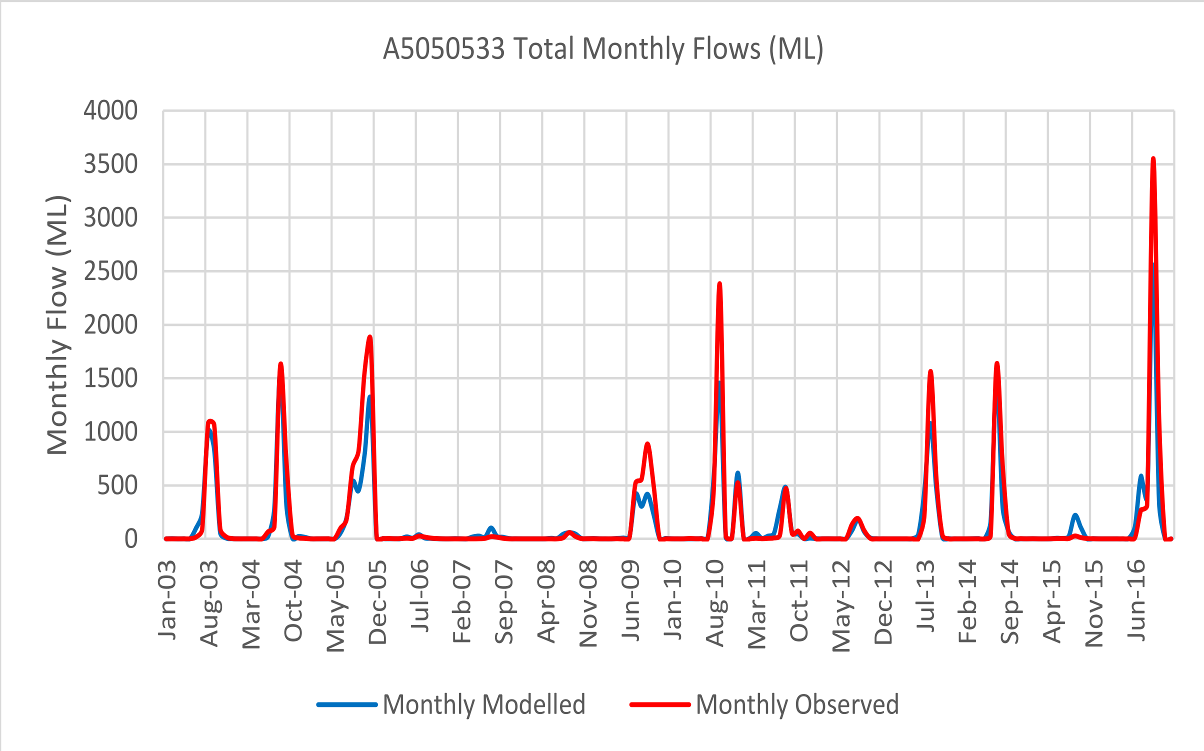


**Figure 7.2 Monthly streamflow calibration chart for A5050533 (Mt McKenzie)**

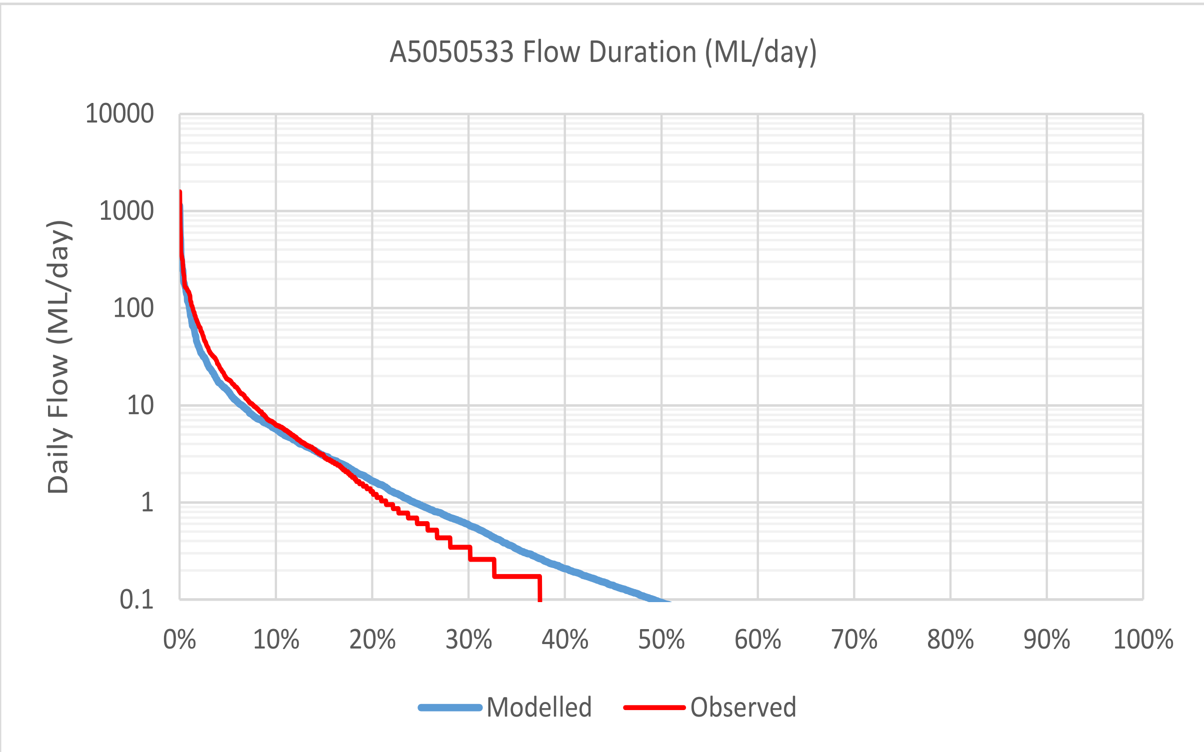


**Figure 7.3. Calibration daily flow duration curve for A5050533 (Mt McKenzie)**

### *A5050517 (Penrice)*

The calibration statistics for the Penrice gauge, which captures flows from the Upper and Lower Flaxman Valley sub-catchments and the Stone Chimney Creek sub-catchment are provided in Table 7.3. Comparison between modelled and observed annual, monthly and daily flow data are presented in Figure 7.4, Figure 7.5 and Figure 7.6 respectively.

**Table 7.3 Calibration statistics for A5050517 (Penrice)**

| **A5050517** | **Annual** | | **Monthly** | | **Daily** | |
|---|---|---|---|---|---|---|
| **Penrice** | *Observed* | *Modelled* | *Observed* | *Modelled* | *Observed* | *Modelled* |
| Mean (ML) | 3589 | 2548 | 299 | 212 | 10.4 | 7.4 |
| Median (ML) | 3603 | 2495 | 7 | 6.5 | 0.3 | 0.2 |
| R^2 | 0.94 | | 0.94 | | 0.33 | |
| NSE | 0.69 | | 0.79 | | 0.32 | |
| % Volume Difference | -29% | | -29% | | -29% | |

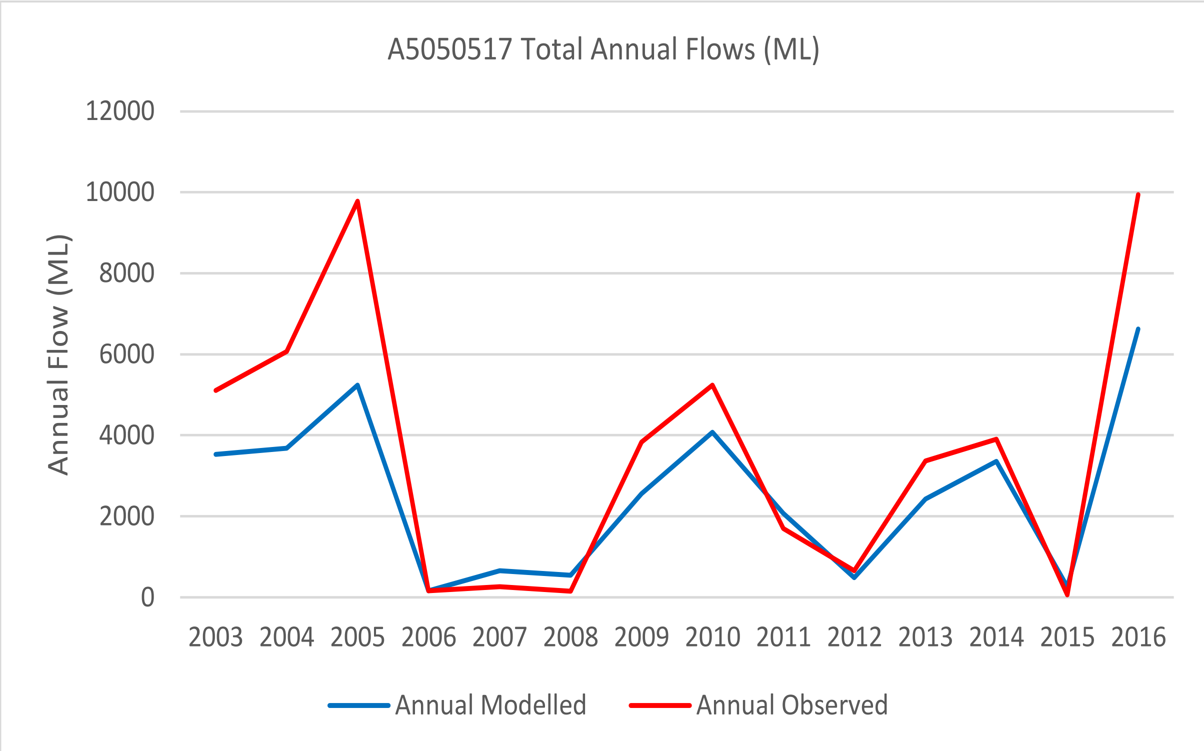


**Figure 7.4 Annual calibration chart for A5050517 (Penrice)**

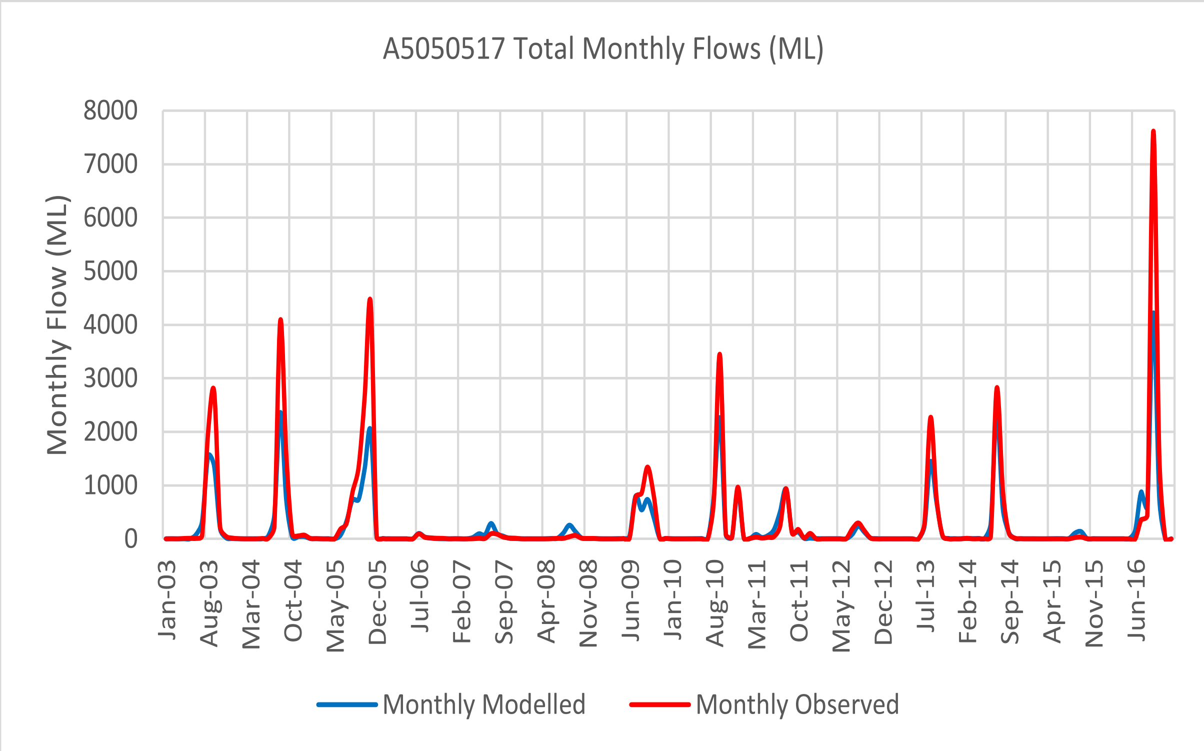


**Figure 7.5 Monthly streamflow calibration chart for A5050517 (Penrice)**

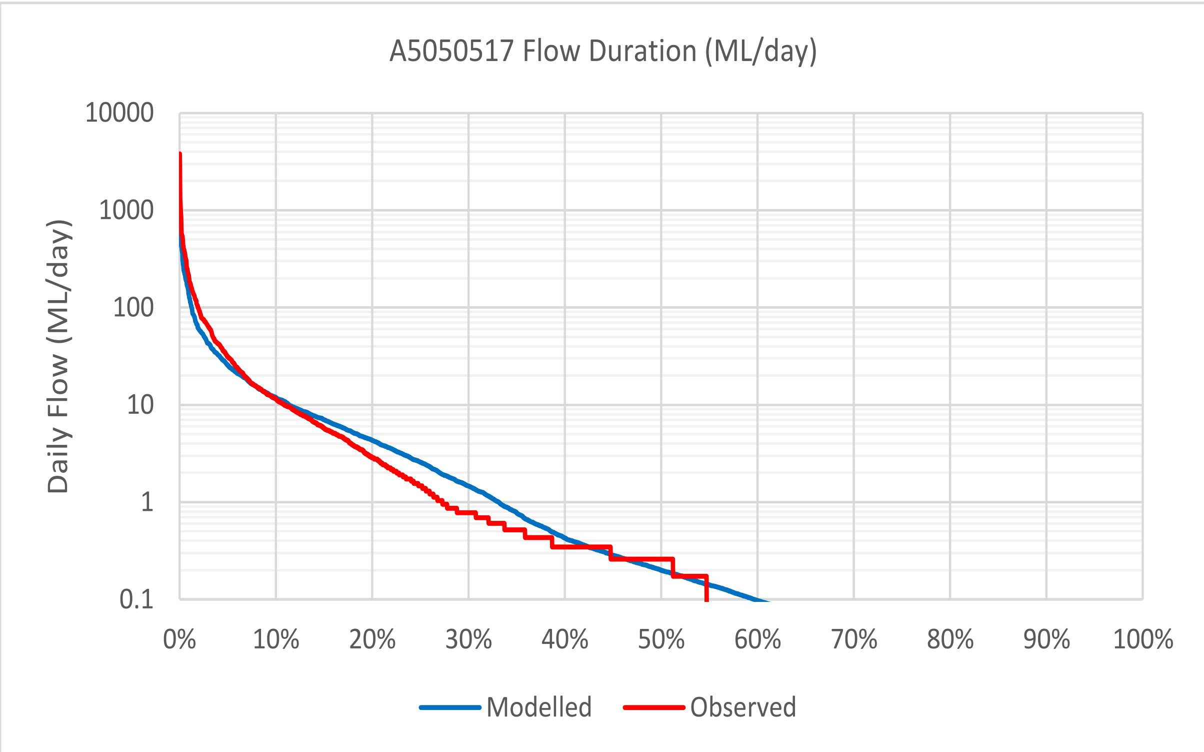


**Figure 7.6 Calibration daily flow duration curve for A5050517 (Penrice)**

### *A5050535 (Tanunda Creek)*

The calibration statistics for the Tanunda Creek gauge, which captures flows from the Tanunda Creek sub-catchment, are provided in Table 7.4. Comparison between modelled and observed annual, monthly and daily flow data are presented in Figure 7.7, Figure 7.8 and Figure 7.9 respectively.

**Table 7.4 Calibration statistics for A5050535 (Tanunda Creek)**

| **A5050535** | **Annual** | | **Monthly** | | **Daily** | |
|---|---|---|---|---|---|---|
| **Tanunda Creek** | *Observed* | *Modelled* | *Observed* | *Modelled* | *Observed* | *Modelled* |
| Mean (ML) | 1842 | 1450 | 154 | 121 | 5.2 | 4.0 |
| Median (ML) | 2090 | 1487 | 11 | 14 | 0.3 | 0.3 |
| R^2 | 0.94 | | 0.91 | | 0.84 | |
| NSE | 0.80 | | 0.82 | | 0.75 | |
| % Volume Difference | 21.3% | | 21.3% | | 21.3% | |

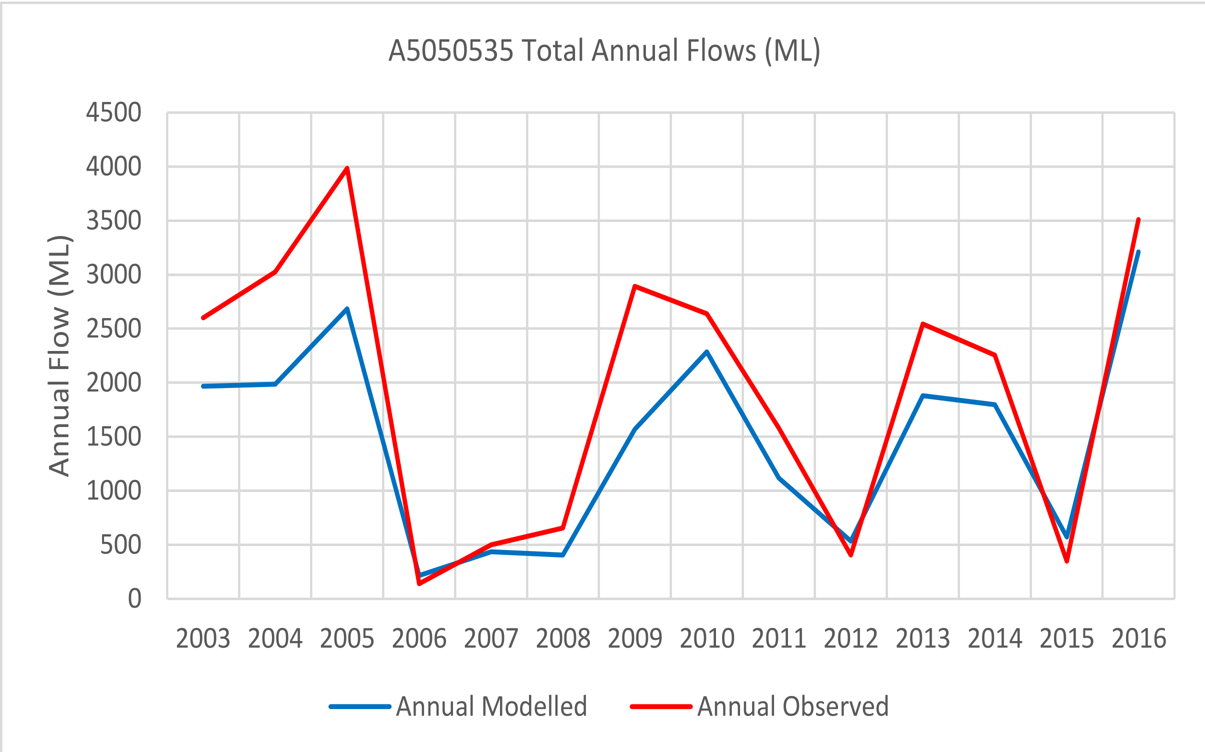


**Figure 7.7 Annual calibration chart for A5050535 (Tanunda Creek)**

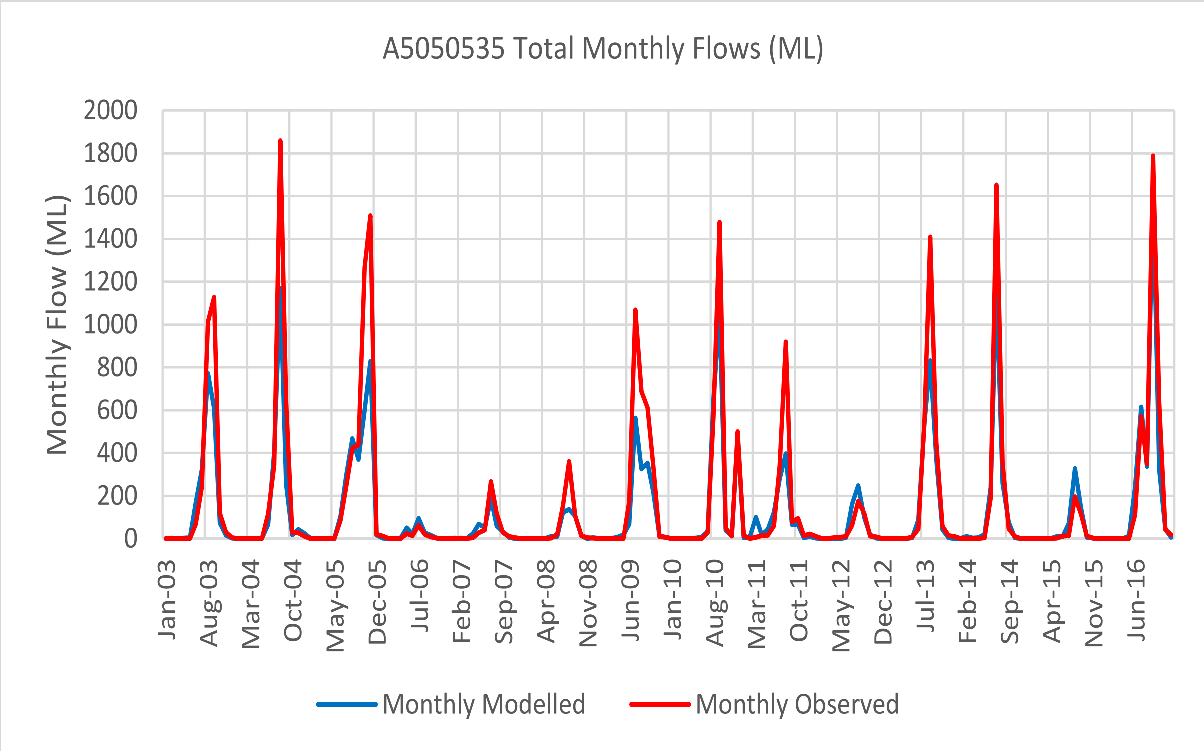


**Figure 7.8 Monthly streamflow calibration chart for A5050535 (Tanunda Creek)**

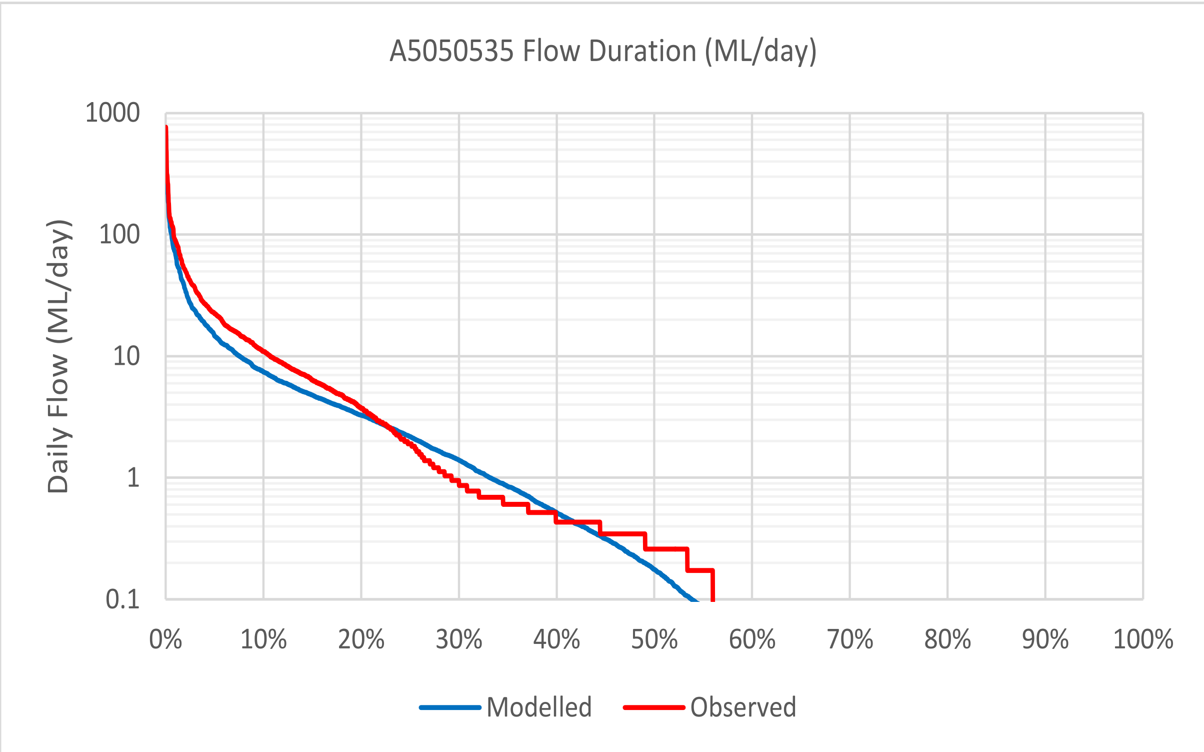


**Figure 7.9 Calibration daily flow duration curve for A5050535 (Tanunda Creek)**

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