Review of Hydrological Monitoring and Operational Information for the Drains, Watercourses, Wetlands and Regulators in the Upper South East. Part One: Climatological Information

DWLBC Report 2004/58

Government of South Australia

Department of Water, Land and Biodiversity Conservation

Review of Hydrological Monitoring and Operational Information for the Drains, Watercourses, Wetlands and Regulators in the Upper South East

Part One: Climatological Information




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This project is part of the Upper South East Drain and Watercourse Surface Water Modelling Project forming part of the Upper South East Dryland Salinity and Flood Management Program

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Cover Photographs (clockwise, starting top left)

Pluviograph station (A2390567), Crump Weir on Fairview Drain d/s Keilira Road, Drain M d/s Reedy Creek convolution, Log Crossing Bridge.

FOREWORD

South Australia's water resources are fundamental to the economic and social well-being of the State. Water resources are an integral part of our natural resources. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between rainfall, vegetation and other physical parameters. Development of surface and groundwater resources changes the natural balance and causes degradation. If degradation is small, and the resource retains its utility, the community may assess these changes as being acceptable. However, significant stress will impact on the ability of a resource to continue to meet the needs of users and the environment. Degradation may also be very gradual and take some years to become apparent, imparting a false sense of security.

Management of water resources requires a sound understanding of key factors such as physical extent (quantity), quality, availability, and constraints to development. The role of the Knowledge and Information Division of the Department of Water, Land and Biodiversity Conservation is to maintain an effective knowledge base on the State's water resources, including environmental and other factors likely to influence sustainable use and development, and to provide timely and relevant management advice.

Bryan Harris
Director, Knowledge and Information Division
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EXECUTIVE SUMMARY

The Upper South East Dryland Salinity and Flood Management Program (USE Program) was developed in the early 1990s to address community concerns about dryland salinisation, waterlogging and ecosystem fragmentation and degradation. One of the long-term objectives of the USE Program is to establish an adaptive management system for the whole region, designed to manage the available water within the catchment. In order to develop such a system, a complete understanding of water availability and how this water moves through the drains, watercourses and wetlands is essential. This has led to a Drain and Watercourse Modelling Study. The first stage of this is a data collection and analysis phase that will form a fundamental basis for the development of a hydrological time-series model. This technical report contains the assessment of meteorological information (rainfall and evaporation) across the region.

Rainfall Daily rainfall data from more than 100 stations was examined. Long term records were available at 17 stations and medium length records at an additional 15 representative stations. Those stations available should provide a good representation of catchment rainfall. Analysis of the data from these records showed that:

- Average annual rainfall increases from approximately 480 mm/year at Keith in the north to 850 mm/year at the southern end of Bakers Range Drain near Kalangadoo in the south;
- The longer term datasets showed no overall discernable trend in annual totals although significant decreases have been evident since the higher rainfall periods in the 1950s and 1970s and since which time annual variability appears to have decreased;
- Between 75 and 80 percent of annual rainfall occurs between April and October and these higher rainfall months appear primarily responsible for the majority of the differences in annual rainfall between stations;
- Variability in monthly totals is higher between November to March than for the remainder of the year;
- Rainfall during individual months was not shown to be responsible for observable trends in annual rainfall totals. Instead, it appears that particular combinations of months or *seasons* are more influential. A transitional season that defines the periods between summer and winter (April to May and September to November) was found to have the highest influence on annual totals, particularly in drier areas; and
- The decade from 1946 to 1955 appears to be the wettest on record, and since this period the magnitudes of above average decades have decreased.

Evaporation The availability of daily pan evaporation data across the South East region is limited with only two suitable stations available (that are still operating) at Mount Gambier and Padthaway. In addition, both sunshine hours and temperature data used to calculate potential evaporation are only recorded together at the station in Mount Gambier. Analysis of the data from these records showed that:

- Average annual pan evaporation varies from 1320 mm at Mount Gambier up to 1560 mm at Padthaway with an average potential evaporation at Mount Gambier of 920 mm;
- Significant decreasing trends in annual totals were observable with the pan evaporation data showing the largest decreases;
- The distribution of mean values over the year is the reverse of that for mean monthly rainfall data since evaporation is inversely correlated to rainfall;

- Decreasing trends in evaporation totals during the summer months (December to March) are evident and evaporation during these months appear to have the most significant impact on annual trends and totals;
- A relationship was developed between mean annual rainfall and mean annual evaporation to provide a more scientific basis for the calculation of evaporation factors to represent spatial evaporation variability; and
- It is strongly recommended that additional stations that measure either pan evaporation or sunshine hours and temperature are installed across the region.

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1. INTRODUCTION

1.1 Purpose

A comprehensive review of hydrological monitoring and operational information for the drains, watercourses, wetlands and regulators in the Upper South East (USE) has been undertaken as the first stage of a Drain and Watercourse Modelling Project within the USE Dryland Salinity and Drainage Program. From this review, technical reports that collate all currently available information and detail the methodology and results of this assessment have been produced. These will provide a fundamental basis for the development of a hydrological time-series model for the region and to determine additional monitoring requirements. This report forms part of this review, focusing on meteorological information.

1.2 Background

The Upper South East region of South Australia is approximately 17,000 km^2 and includes the rural towns of Keith, Padthaway, Naracoorte, Kingston SE, Lucindale, Salt Creek and Tintinara as shown in Figure 1. The topography comprises a series of remnant sand dune ranges aligned in a northwest to southeast direction and separated by inter-dunal flats with sandy-clay soils. The low surface relief ensured that surface water flooding and extended periods of inundation was a common occurrence (NRCSA, 1993). For this reason, dryland salinisation is not a recent phenomenon in the USE and was naturally present in small areas before the land was first cleared. These historic saline areas occurred where shallow watertables existed and poorly developed natural drainage systems resulted in the evaporation of excess surface water.

Over the last 20 years there has been an acceleration in the rate of dryland salinisation experienced across the region. This is considered to be the result of a number of interacting factors (NRCSA, 1993). Land clearance dramatically increased in the late 1940s and 1950s, with the removal of native vegetation cover and the establishment of perennial lucerne. This was almost completely destroyed by the lucerne aphid in the late 1970s and since that time, increased groundwater recharge has caused the rise in groundwater levels. In addition, altered drainage lines and extensive uncoordinated private drainage have increased water flows and the impact of surface flooding in the area. Native vegetation and wetlands have also been adversely affected by salinisation and flooding to varying degrees, with some systems becoming waterlogged, some affected by salt accumulation and others being deprived of water by drainage systems.

The Upper South East Dryland Salinity and Flood Management Program (USE Program) was developed in the early 1990s to address community concerns about dryland salinisation, waterlogging and ecosystem fragmentation and degradation. One of the long-term objectives of the USE Program is to establish an adaptive management system for the whole region, designed to manage the available water within the catchment. In order to develop such a system, a complete understanding of water availability and how this water moves through the drains, watercourses and wetlands is essential. This has led to the Drain and Watercourse Modelling Study of which this report forms part of the first stage.

1.3 Objectives and Methodology

The primary objective of the Drain and Watercourse Modelling Study is to develop a hydrological time-series model that describes the movement of water through the drains, watercourses, wetlands, swamps and regulatory structures in the Upper South East. Such models provide a technical foundation for the consideration of future management options and decisions.

It is intended that the hydrological model describe catchment rainfall-runoff processes while explicitly incorporating the spatial distribution of all physical features that control or influence runoff and its movement through the region. This allows for a better understanding of the hydrological processes and subsequently offers the most flexible means to facilitate a meaningful assessment of various operating strategies. Such an assessment includes the identification and evaluation of potential impacts and risks to specific environmental assets due to varying diversion operations and storage management strategies. This allows comparisons between approaches to be made before physical trials are undertaken.

This Drain and Watercourse Modelling Study has been sub-divided into a number of stages that are briefly described in the following:

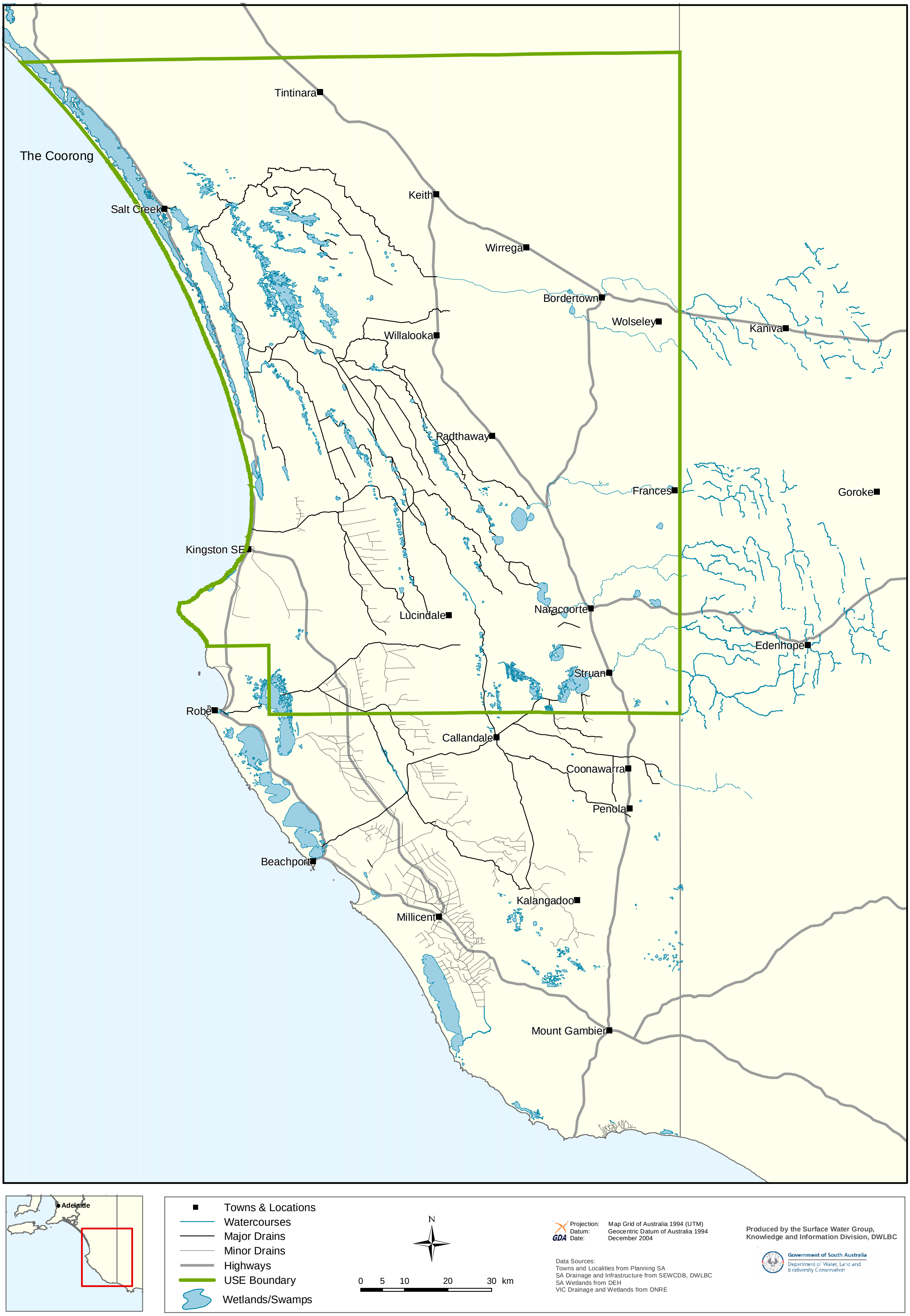
<u>Stage One</u>

- Monitoring Information (rainfall, evaporation, water level, flow, salinity)
  - Identification of monitoring locations and data availability;
  - Processing and statistical analysis of rainfall and evaporation data, including both short and long-term statistics and trends;
  - Collation, audit and review of water level, flow and salinity data quality; and
  - Recommendations to address additional monitoring requirements.
- System and Operational Information
  - Identification of drains, watercourses, wetlands and swamps, their physical characteristics and water flow paths within the system;
  - Identification of diversion/regulatory structures, their operational regimes and availability of operational data; and
  - Identification of gaps in existing information.

<u>Stage Two</u>

- Model Datasets
  - Preparation of rainfall and evaporation data files and quantification of rainfall spatial variability;
  - Revision of hydrological data (water level, flow) based on field investigations and preparation of data files; and
  - Revision of the physical characteristics and the development of surface area to volume relationships for wetlands and swamps based on field surveys.
- Model Construction
  - Definition of sub-catchments; and
  - Development of system layout within modelling platform that describes the generation, storage and movement of water throughout the region.

Figure 1 The Upper South East Region.



<u>Stage Three</u>

- Model Calibration
  - Selection of a rainfall-runoff model for each sub-catchment; and
  - Calibration of parameters including assessment of parameter appropriateness.

<u>Stage Four</u>

- Model Scenario Evaluation
  - Quantification of the linkage between hydrology and ecology in the development of management rules and operational strategies that provide acceptable drainage and maintain wetlands and swamps;
  - Evaluation of these management rules and operational strategies to further environmental flow studies and so assist in the development of optimal environmental management plans; and
  - Identification and recommendation for additional requirements and improvements to regulatory infrastructure to meet the demands of future management regimes.

As described above, the first stage of this study is the collation of information required to construct and evaluate the hydrological model. This has been documented in a three part report, each focusing on a particular aspect of this stage. In particular:

Part One: Climatological Information

- availability and quality of climatological and hydrological data relating to rainfall and evaporation;
- an analysis of available rainfall and evaporation data at daily, monthly, annual and decadal timescales, including long-term trends; and
- consideration and recommendation of additional monitoring locations.

Part Two: Hydrological Information

- availability of monitoring data relating to water level, flow and salinity through drains and watercourses and water level and salinity within wetlands and swamps;
- data summary report for each monitoring location including site characteristics and instrumentation, type and quality of recorded data, proximity of any flow regulation structures and suitability of data for modelling; and
- consideration and recommendation of additional monitoring locations.

Part Three: System Operation

- an understanding of the drain and watercourse system including water flow paths and the location and operational regime of diversion/regulatory structures; and
- the identification of all storages (wetlands, swamps and runaway holes) and an understanding of their hydrological characteristics.

This report forms Part One: Climatological Information of Stage One of the Drain and Watercourse Modelling Project.

2. RAINFALL

The hydrological computer model to be developed for this study transforms rainfall falling on the catchment into runoff. The volume of rainfall directly affects the volume of runoff; the higher the rainfall, the higher the potential runoff. A good understanding of both the volume and variability of rainfall over a catchment is important if a realistic transformation to runoff is to be obtained. As such, it is also important to identify deficiencies in the rainfall network so that over time improvements in localised relationships between rainfall and runoff can be attained.

2.1 Data Availability and Processing

Daily rainfall data in the south east of South Australia and in western Victoria is collected primarily by the Bureau of Meteorology (BOM), with only a small number of sites operated by the South Eastern Water Conservation and Drainage Board (SEWCDB). While there are over 100 daily rainfall stations distributed across the South Australian portion of the study area alone, many of these have been closed or do not contain data for the last 15 years. This is the period for which there is available flow/runoff data to calibrate a model. A large proportion of the Morambro, Naracoorte and Mosquito Creek catchments are located in western Victoria. Therefore, a number of stations in this region were also evaluated.

Figure 2 shows the location of rainfall stations across the region and with the dark yellow area highlighting those rainfall stations that were evaluated. While this encompasses an area larger than that concerned with the Upper South East (USE) Program, runoff is generated outside of this arbitrary boundary and flows into the program area. Hence, these areas will be modelled and all rainfall stations in areas that will be represented in the drain and watercourse model were evaluated.

The available data from each station was examined and stations were initially categorised by the potential use of the data in model calibration. The methodology for this considered:

- current operational status of site;
- for closed sites, existence of a nearby site that could be used to continue the record;
- length and period of record; and
- quantity of missing and aggregated data.

Table 1 shows the stations that were identified as having good long term records that could be both used for hydrological modelling as well as for examining rainfall patterns and trends in the region. Table 2 then presents additional stations that can be used in the model. This ensures that the observed spatial variability of rainfall at catchment, major sub-catchment and minor sub-catchment scales is replicated and any localised events are modelled. These stations are identified in Figure 3.

Rainfall isohyets are also shown in Figure 2. These are lines of equal average rainfall and have been generated using data from stations with at least 30 years of recent data. Across the region, the isohyets generally extend in a north-east to south-west direction. Although the values of these isohyets are under review and will not specifically be used during hydrological modelling, they do provide an indication of the spatial variability of rainfall across the region.

Table 1 Long Term Representative Rainfall Stations.

Station Number	Location	Period of Record	Percentage of Missing (Accumulated) Data
025507	Keith	1906-2003	1.5 (0.1)
025518	Wirrega (Taunton)	1910-2003	0.7 (1.3)
025519	Wolseley Wise Farm Equipment	1896-2003	3.3 (5.0)
026003	Callendale	1923-2003	7.5 (1.8)
026007	Frances	1896-2003	0.1 (2.3)
026009[1]	Kalangadoo	1915-2003	0.7 (9.0)
026010	Kingston (Keilira Station)	1913-2003	10.5 (0.1)
026012	Kingston SE	1896-2003	0.4 (7.1)
026014	Lake Leake (Yurnga)	1898-2003	4.2 (1.5)
026015 / 026104	Naracoorte (Lochaber) / Naracoorte (View Bank)	1923-2003	1.1 (0.5)
026016	Lucindale Post Office	1896-2003	1.3 (3.0)
026017	Padthaway (Marcollat)	1935-2003	0.6 (0.2)
026023 / 026099	Naracoorte / Naracoorte Aerodrome	1896-2003	0.4 (0.3)
026025	Penola Post Office	1896-2003	0.1 (7.0)
078078	Kaniva	1896-2003	1.5 (0.6)
079011	Edenhope Post Office	1896-2003	5.0 (3.2)
079018	Goroke (Kangawall)	1901-2003	3.4 (0.2)

Table 2 Additional Representative Rainfall Stations.

Station Number	Location	Period of Record	Percentage of Missing (Accumulated) Data
025525	Bordertown (Inglewood)	1952-2003	1.6 (0.1)
025546	Tintinara (Richards)	1969-2003	0.7 (0.2)
025550 / 025561	Bordertown (Monard) / Wolseley (Honiton)	1973-2003	0.0 (0.8)
026037	Bordertown (Yacca Vale)	1959-2003	1.0 (0.1)
026054	Kingston (Mount Scott)	1969-2003	0.7 (0.1)
026062	Naracoorte (Bettws-Y-Coed)	1969-2003	0.0 (0.3)
026065	Salt Creek (Pitlochry Outstation 1)	1968-2003	10.1 (3.5)
026069	Lucindale (Greenvale)	1969-2003	0.5 (0.1)
026075	Wrattonbully (Joeville)	1967-2003	0.0 (0.1)
026078	Avenue (Downer)	1973-2003	1.1 (0.7)
026083	Salt Creek (Pitlochry Homestead)	1975-2003	1.1 (1.3)
026084	Salt Creek (Kendal Station)	1974-1999	3.4 (0.3)
026088	Willalooka (Yardookra)	1979-2003	19.4 (2.4)
026091	Coonawarra	1985-2003	4.7 (0.4)
079083	Benayeo	1973-2003	0.0 (0.2)

Figure 2 Rainfall Stations Across South Eastern South Australia and Western Victoria.

Figure 3 Representative Rainfall Stations Across South Eastern South Australia and Western Victoria.

The data processing stage involves the disaggregation of aggregated data, the infilling of missing data and the assessment of consistency within each record. The methods used are described later in this section.

Appendix A.1 provides information for all stations across the region. For those stations that were still operational, periods of missing/accumulated data have been detailed. For other stations, their usefulness in translating or extending current stations is examined.

2.1.1 Missing Data

The majority of data sources contain missing segments. Missing data in daily rainfall records may occur in two forms: when a value has not been recorded on a particular day(s) but the cumulative total has been recorded on a subsequent day; or where the data is missing due to a recording error.

The first type are referred to as accumulated records and may be disaggregated over the total number of missing days. SKM (2000) disaggregated the rainfall data at these stations for the period up to 1998 using the method described in Porter and Ladson (1993). This assumes that the influence of the rainfall at nearby stations to the station where accumulated data is to be disaggregated is inversely proportional to the distance between the stations. Using a number of nearby stations reduces the uncertainty from using data from a single station. This method was also used to disaggregate data within the period 1999-2003 and if required, will also be used for the future disaggregation of rainfall data as it becomes available. The full procedure is given in Appendix A.1.

Stations with missing data due to recording errors were infilled by using data from a nearby station. The nearby station was chosen as the one with the highest correlation between daily values that had data concurrent with the missing period. To infill the missing period, the daily rainfall value at the nearby station was then adjusted by the ratio of the concurrent mean annual rainfalls of the two stations. The full procedure and correlations between the rainfall stations are presented in Appendix A.1.

2.1.2 Data Consistency

To identify the occurrence, magnitude and nature of trends within long time series records the double mass curve technique (Grayson *et al*.; 1996) is often used. It is constructed by plotting the accumulated values of two time series against each other. A break in slope or a gradual change in curvature will reveal a change in the constant proportionality between the two sets of data. This indicates the presence of a trend such as in measured rainfall due to localised station conditions. For example, changes in instrument exposure at a station resulting from the growth of obstructive vegetation. The method is often used to establish the presence of such changes within rainfall records and adjustments can subsequently be made to affected data sets to ensure consistency of record.

In this study the consistency of each rainfall record was confirmed by constructing a double mass curve using an average of the monthly rainfall from eight to ten neighbouring stations. Using an average of a number of records reduces inconsistencies that may be present in any one record. Many of the rainfall records considered required some adjustment and the full procedure and analysis are presented in Appendix A.1.

2.1.3 Extension of Data Records

Many of the long-term daily rainfall stations have records beginning in 1896. The records from the remainder of these long-term stations were also extrapolated back to 1896 to create records of over 100 years across the region. This allows for the examination of extended wet and dry rainfall periods and the subsequent effect on runoff and water availability for wetlands and swamps. The extension was done by using proportional relationships with nearby sites and are documented in Appendix A.1.

2.2 Data Analysis

Analysis of the rainfall data at each station suitable for hydrological modelling was undertaken at annual, monthly and decadal time scales. The rainfall regime and its variability at each of these time scales affects runoff and hence surface water availability differently. For example, the amount and distribution of rainfall at a monthly time scale influences the timing and volume of runoff that will occur at varying times throughout the year. Rainfall variability at an annual time scale affect the total volume of runoff that a catchment will produce.

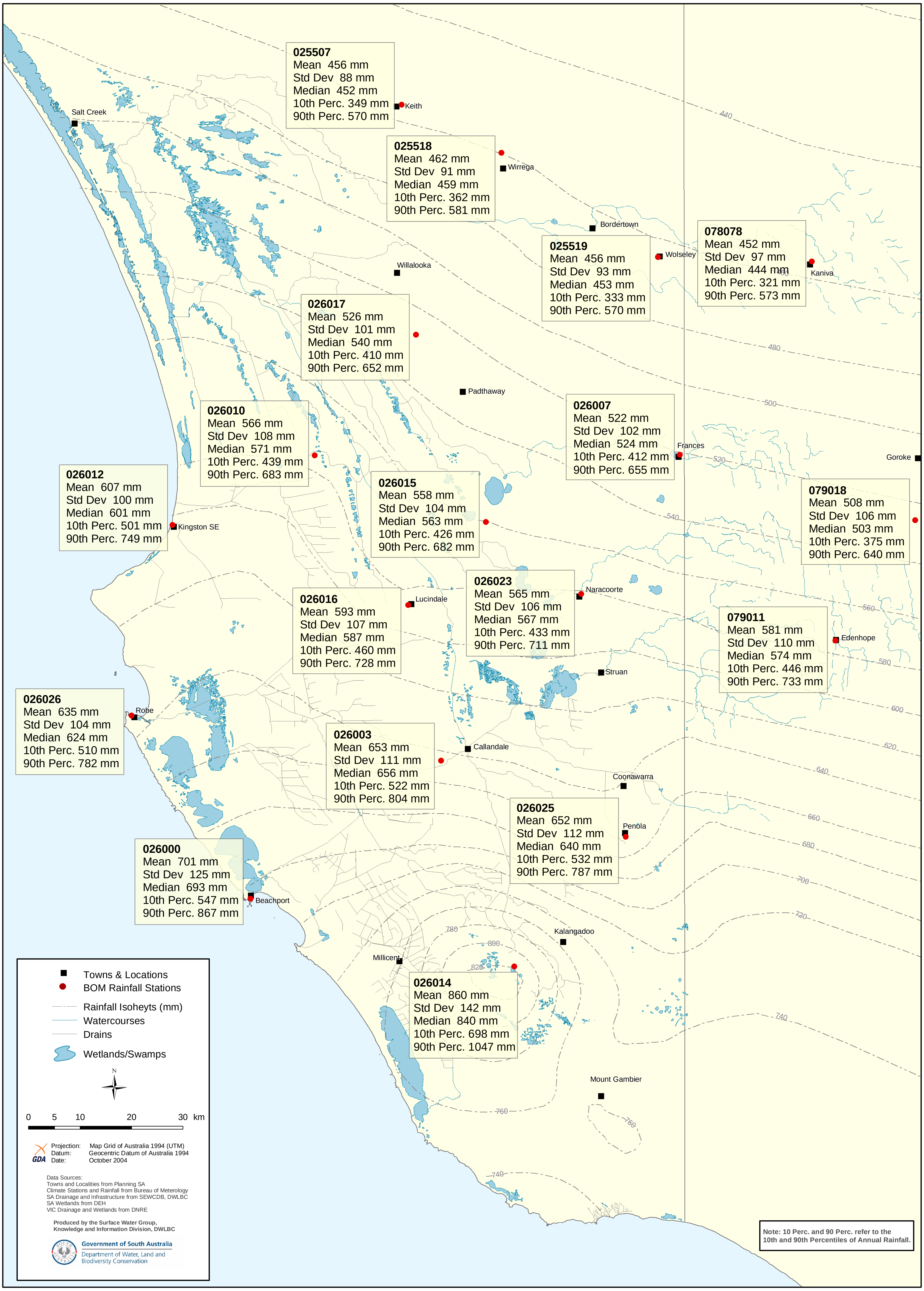
2.2.1 Annual Rainfall

Annual rainfall was found to increase from north to south across the region. In the area surrounding Keith and the northern catchment drains, average values are around 480 mm/year. These increase to 850 mm/year at the southern end of the Bakers Range Drain near Kalangadoo. Figure 4 highlights these regional trends, showing the mean and median annual rainfall and the standard deviation of the annual rainfall for the stations with long-term records. The standard deviation provides an indication of the variability of the annual rainfall; the lower the standard deviation, the less variability of annual totals around the mean. As with the mean values, the standard deviations tend to increase from north to south such that the higher the mean average rainfall, the higher the variability about that value.

Average annual rainfall at the point locations shown in Figure 4 are generally consistent with the isohyet values. This supports the use of the relative position and values of these isohyets to determine rainfall factors. These factors can be applied to the rainfall data, allowing the representation of rainfall spatial variability to be incorporated into the catchment model.

Another measure of the variability of annual rainfall is to examine the 10^{th} and 90^{th} percentiles. These are also shown in Figure 4. The 10^{th} percentile represents the threshold of the lowest 10 percent of the recorded values and there is a 10 percent probability that the annual rainfall in any given year will be lower than this value. Conversely, the 90^{th} percentile is the value that exceeds all but 10 percent of the recorded values such that there is also a 10 percent probability that the annual rainfall in a given year will be greater than this value. The closer the values at these two percentiles, the lower the variability. For reference, the median rainfall is the 50^{th} percentile.

Figure 4 Long-Term Rainfall Trends Across South Eastern South Australia and Western Victoria.



Long-term changes in annual rainfall totals can be observed using trendlines and residual mass curves. A trendline is a linear function that indicates whether the long term annual rainfall is increasing, decreasing or stable. When using trendlines to compare long-term trends in annual totals between stations, it is important to recognise the period over which the trend has been calculated. The nature of a trendline is highly dependent on its start and finish point within the data, and an extension or reduction of the record length can change the apparent trend.

A residual mass curve is the cumulative deviation of a set of data from the mean value of that data. A positive (upward) sloping curve indicates years of higher than average rainfall while a negative (downward) sloping curve indicates years with lower than average rainfall.

From the analysis of annual rainfall totals a number of conclusions could be made, in particular:

Long-Term Stations

- At the long-term representative stations with records greater than 80 years, no discernable trends or only very slightly increasing or decreasing trends were evident. In general, those stations with records beginning in 1896 showed no trend or only slightly increasing trends, while stations without data for the first one to two decades of the 1900s showed a slight downwards trend.
- Figure 5 presents the annual totals from the station 025507 at Keith, also highlighting the variability of individual years around the long-term mean value. The trends observed in the data examined here differ from a number of similar studies undertaken in the Mount Lofty Ranges (Cresswell, 1991; Savadamuthu, 2002; Savadamuthu, 2003; Heneker, 2003) where rainfall has been found to have significantly decreased over this period.

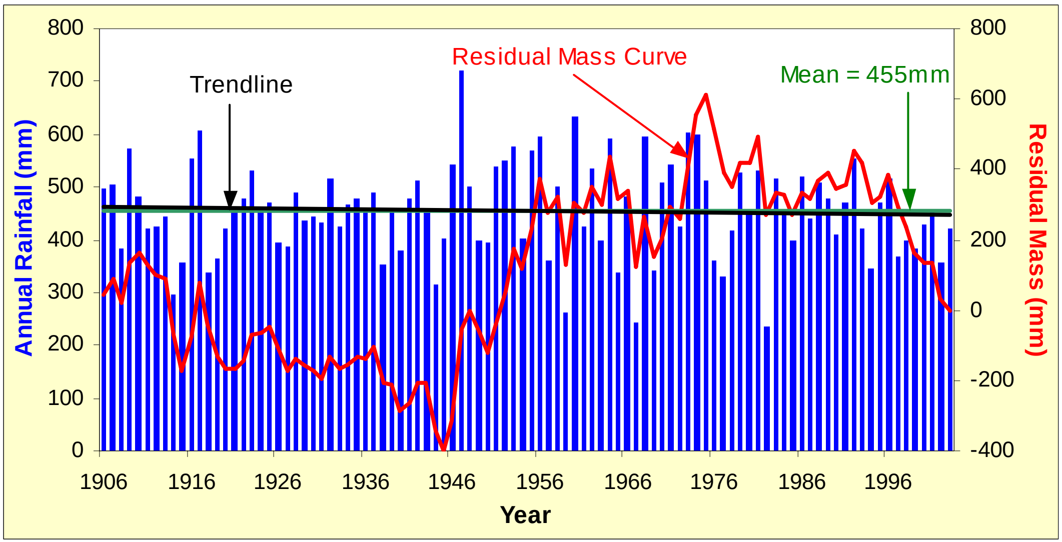


Figure 5 Annual Rainfall Totals and Variability at Keith (025507).

- The residual mass curves for these stations typically showed decreasing annual rainfall totals from the beginning of the data (in the case of Figure 5, from 1906) until the mid 1940s. From this time until the mid 1970s the data shows a generally increasing trend, followed by another decreasing trend until 2003.
- There appears a higher degree of variability of the annual totals about the mean from the beginning of 1940s to the end of the 1970s. Above average rainfall years are the highest on record and the below average rainfall years the lowest on record. This variability is

also shown by large increases and decreases between successive years in the residual mass curve.

- Similar trends in the annual totals, variability and residual mass curves were observed at other long-term stations across the region. Some of these are presented and discussed below, with additional results in Appendix A.2.
- Stations with rainfall between 450 to 490 mm per year, located at Wirrega, Woseley and Kaniva, all showed similar trends in the residual mass curves to those at Keith in Figure 5. However, while the data from the Keith and Wirrega stations showed a stable mean annual rainfall over the periods of record (beginning around 1910), those records from Kaniva and particularly Woseley (Figure 6), show slight increases. In comparison with the other two stations, this may be a result of a slightly longer record (beginning in 1896) with 15 of the first 20 years (including 9 of the first 10) all below the long term average.

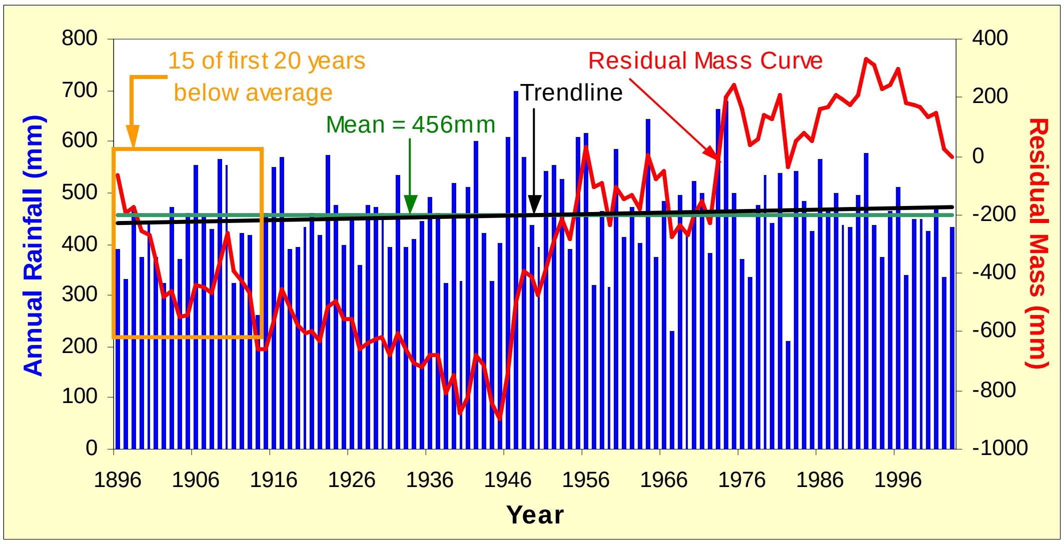


Figure 6 Annual Rainfall Totals and Variability at Woseley (025519).

- The trends seen in the annual rainfall data for the lower rainfall stations above, were also consistent with those observed at stations with annual rainfall of between 500 and 550 mm per year, located at Frances, Padthaway and Goroke. Padthaway showed a slightly decreasing trend in annual totals (data from 1935) and Goroke a slightly increasing trend (data from 1901) as shown in Figure 7.
- The region encompassing Kingston, Lucindale, Naracoorte and Edenhope receives an average of between 560 and 610 mm of rainfall each year. The data from most stations in this area show trends consistent with those drier, more northern stations above. The data from Keilira Station (30 km north-east of Kingston on Fairview Drain) is one of the few stations that doesn't show a decreasing trend prior to the 1940s, but instead shows a generally increasing trend until the mid 1970s. This is shown in Figure 8.
- Moving southwards from Callendale to Kalangadoo and Lake Leake, average annual rainfall increases from 650 mm to over 850 mm. This higher rainfall area covers the beginning of the Bakers Range Watercourse. The trends are again consistent with those above, although the decreasing trends at Callendale and Kalangadoo are slightly more pronounced than at other stations. Data begins in 1923 and 1915 for these stations respectively. Figure 9 shows these trends at Kalangadoo and also highlights the higher variability between the 1940s and 1970s.

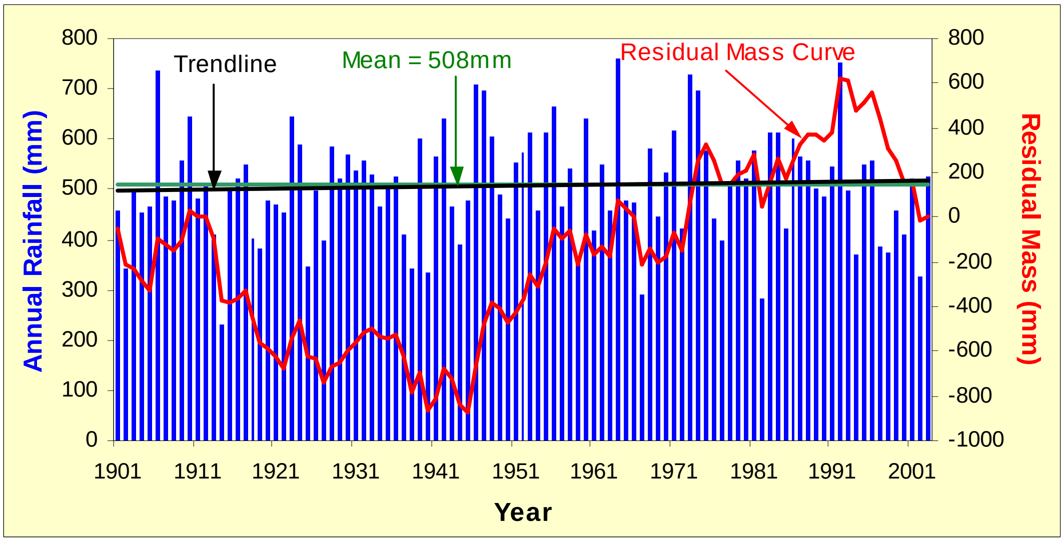


Figure 7 Annual Rainfall Totals and Variability at Goroke (079018).

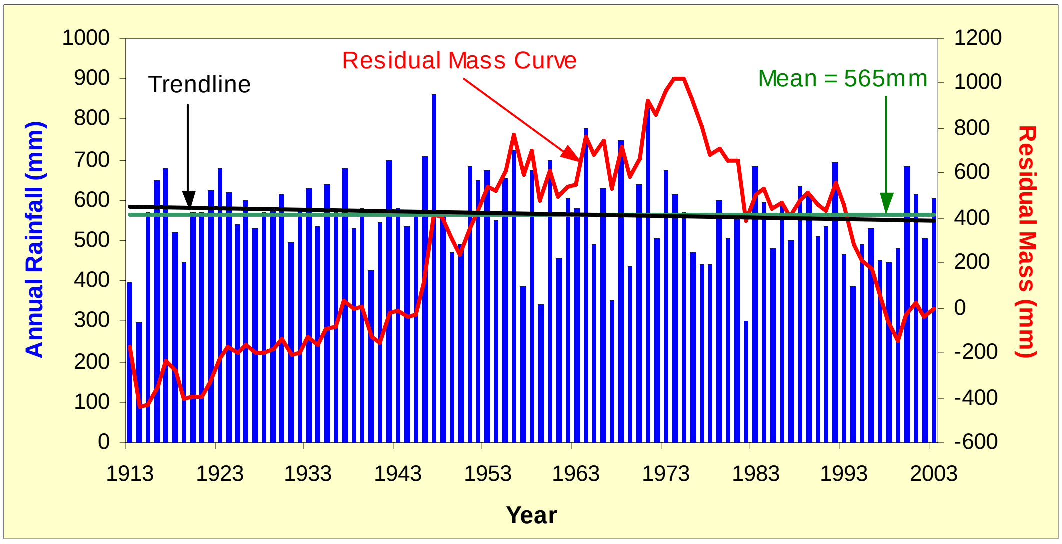


Figure 8 Annual Rainfall Totals and Variability at Kingston - Keilira (026010).

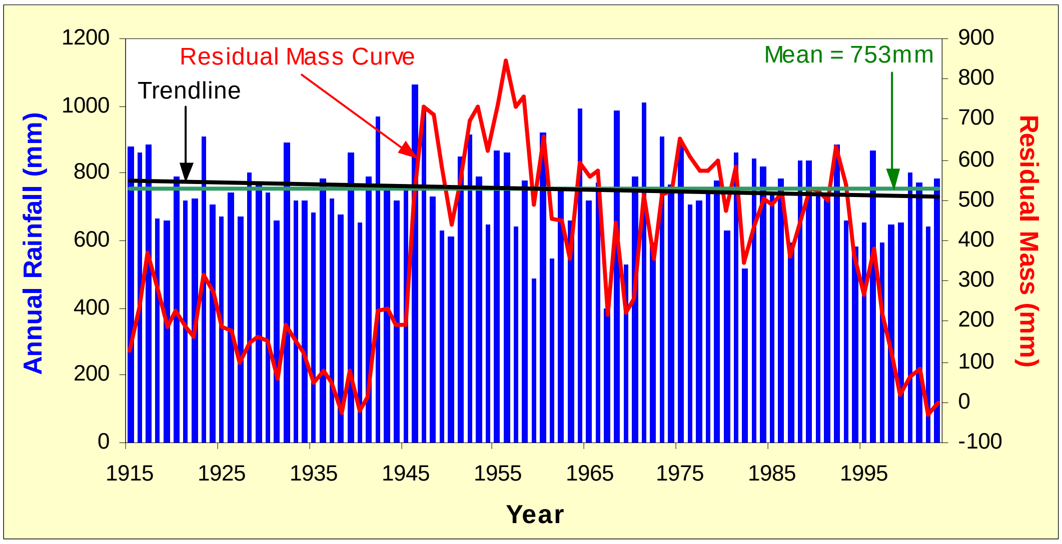


Figure 9 Annual Rainfall Totals and Variability at Kalangadoo (026009).

Shorter-Term Stations

- At most of the shorter-term representative stations, significant decreasing trends in annual rainfall totals were observable. An example presented in Figure 10 uses data from station 025525 at Bordertown.
- The residual mass curves for these shorter-term stations show the similar increasing trends in annual totals until the mid 1970s and then the subsequent decreasing trends as seen at the longer term stations. Because of the shorter lengths of record at these stations, the lower rainfall recorded in recent years dominate and hence result in an overall downward trend. Similar trends were observed at other shorter-term stations across the region, a selection of which are presented in Appendix A.2.

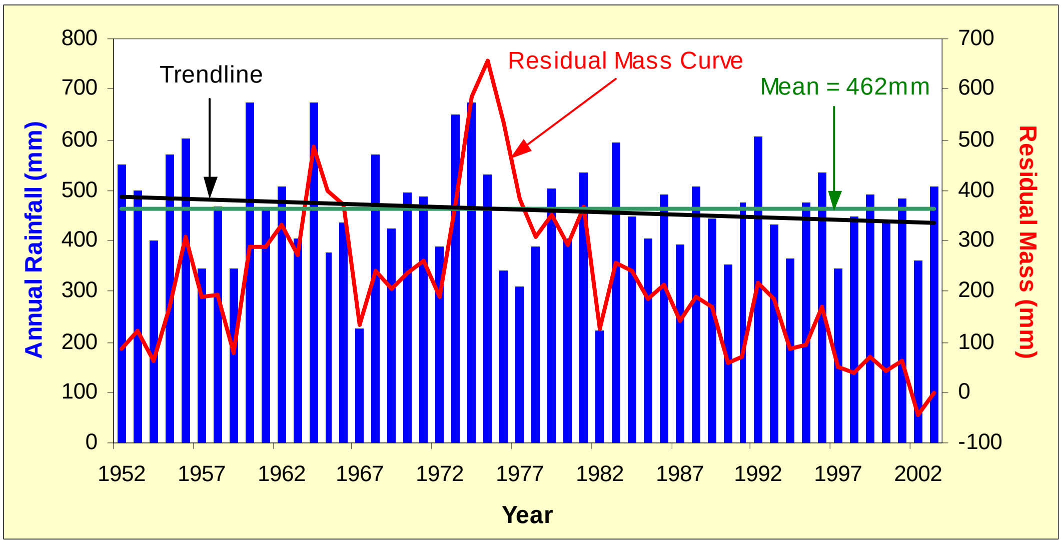


Figure 10 Annual Rainfall Totals and Variability at Bordertown (025525).

A comparison between the results from long-term and short-term stations highlight differences in the conclusions that can be made based on statistical analysis, when differing periods of data are available or used. For example, if only the long-term data was examined, it may have been determined that there was no significant trend in annual rainfall across the region. Alternatively, the sole use of short-term data may conclude that rainfall has been significantly decreasing and possibly attributable to some other phenomena such as climate change, as opposed to natural rainfall variability.

For the station at Keith (025507), the mean rainfall for the period from 1906 to 2003 was 455 mm/year as shown in Figure 5. From 1906 to 1975 the mean value was 464 mm/year, including a value of 489 mm/year between 1946 and 1976. From 1976 to 2003 the mean rainfall dropped to 434 mm/year. These values are significantly different, showing periods of both higher and lower than average rainfall, yet over the entire period no “trend” is evident.

If the recent decreasing trends in annual rainfall are not part of natural rainfall variability, then using long-term historical averages and data sets may result in estimates of rainfall, and hence surface water availability, that are not realistic today. Because of this, it would be prudent to place more emphasis on modelling results using rainfall for the last 30 years, avoiding potential bias from historically higher rainfall periods. However, examination of the long-term records do not provide sufficient evidence to suggest that the recent record is not anything other than natural variability.

2.2.2 Monthly Rainfall

The mean monthly data for a selection of stations across the Upper South East region is shown in Figure 11. For these and the remaining representative stations, between 75 and 80 percent of the rainfall occurs between April and October (80 to 85 percent occur between April and November). In comparing the magnitudes of the mean monthly rainfall from November to March, it is interesting to note the variation of recorded rainfall across the stations are not as great as the variation seen during the remainder of the year, even though the annual rainfall totals are significantly different. This indicates that the higher rainfall months (April to October) are primarily responsible for the majority of the difference in annual rainfall between sites and summer rainfall is consistently even across the catchment. Appendix A.2 presents the mean monthly totals for the remaining representative stations.

Analysis of the monthly standard deviations show that variability in the annual rainfall is much higher in the November to March period than for the remainder of the year. In addition, reliability of winter rainfall tends to increase with increasing mean monthly rainfall.

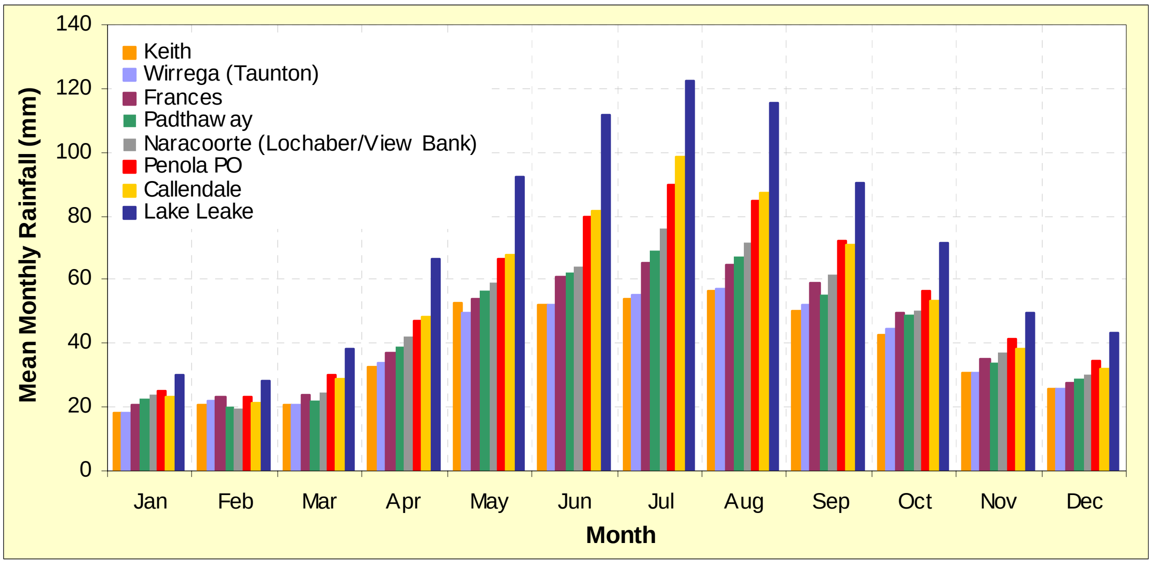


Figure 11 Mean Monthly Rainfall Totals at Selected Stations.

Analysis of the data showed that there were no long-term trends visible in the individual monthly totals. No long-term increasing or decreasing rainfall trends in individual months were apparent at any of the representative stations. Residual mass curves were plotted for each month, together with the annual curves. These were used to analyse the monthly rainfall data to detect any trends. Figure 12 presents these monthly residual mass curves for selected months at Keith (025507). Various attributes of this annual curve are partially reflected in each of the months shown, including:

- General decreasing trend in annual rainfall from around 1910 until 1945 visible in April and October monthly rainfall;
- Increasing and then decreasing trend from 1945 evident in May monthly rainfall;
- Similar patterns between annual rainfall and June monthly rainfall from 1922 to 1933; and
- Significant increases in annual rainfall between 1972 and 1975 is also significant in October monthly rainfall.

As for annual rainfall, the results differ from studies conducted in the Mount Lofty Ranges (Cresswell, 1991; Savadamuthu, 2002; Savadamuthu, 2003; Heneker, 2003) where June rainfall was found to have significantly decreased over the last 50 years, influencing observed decreasing trends in annual rainfall more than any other month.

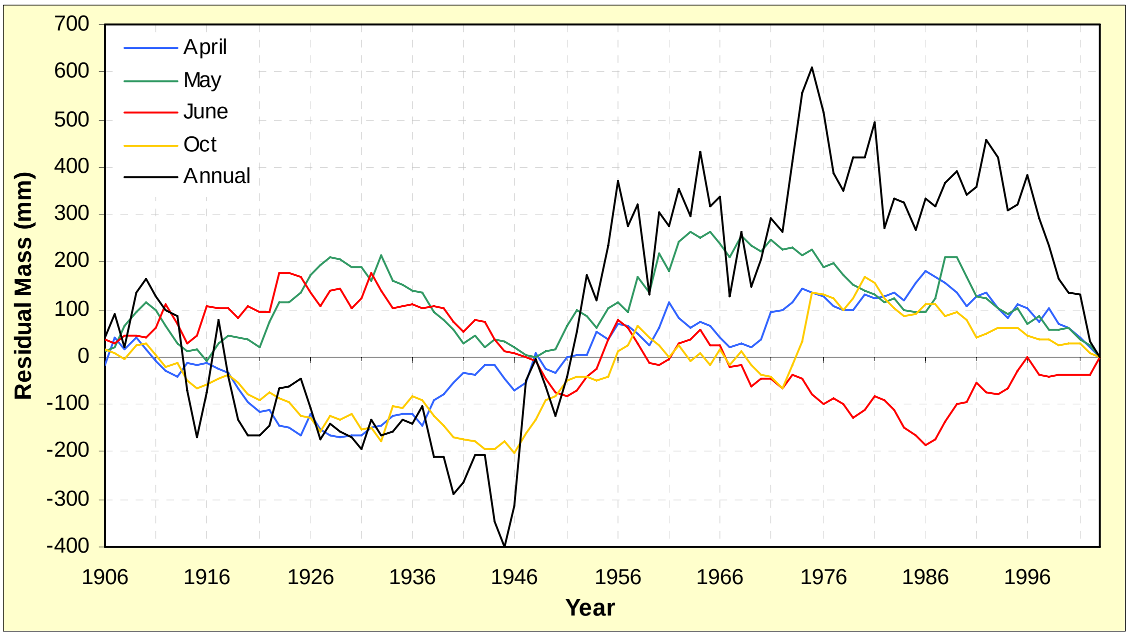


Figure 12 Monthly Residual Mass Curves at Keith (025507).

The magnitude of rainfall above or below the mean during a particular year is the result of the combination of above and below average monthly rainfall totals. While no individual months were found to solely influence the annual totals, the impact on total annual rainfall by rainfall during particular combinations of months or *seasons* was evident. Residual mass curves for different *seasons* were then compared with the annual curve, the results for Keith (025507) shown in Figure 13. Three general *seasons* were defined, namely, winter (June to August), summer (December to March) and a transitional season defined as the months between summer and winter (April to May, September to November).

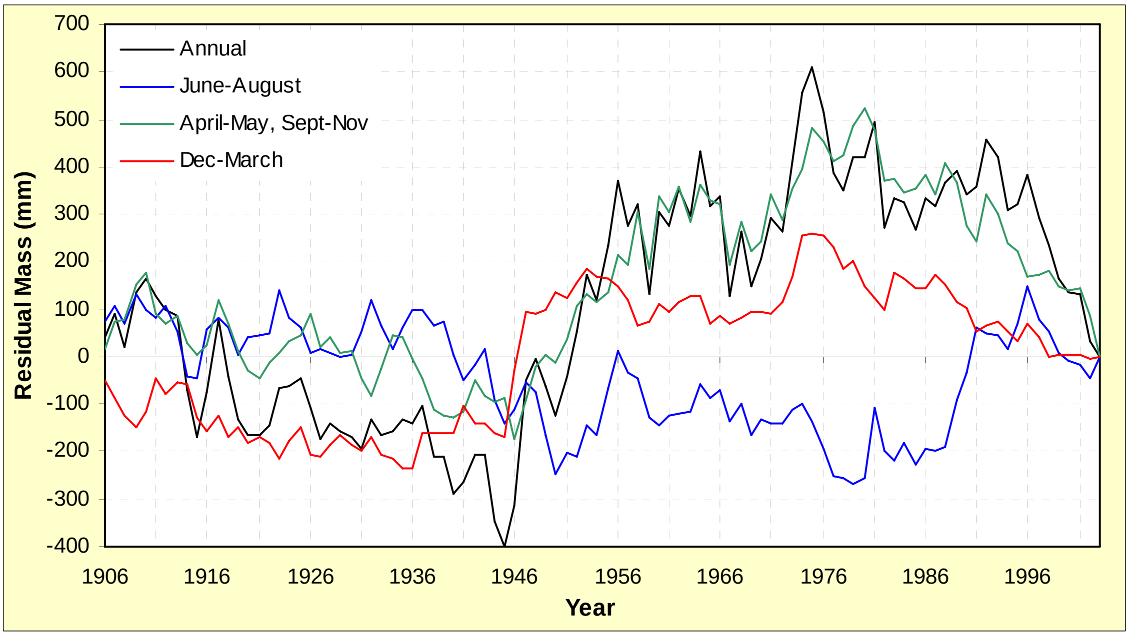


Figure 13 Seasonal Residual Mass Curves at Keith (025507).

General observations that were made from the analysis of this station included:

- patterns observed in the residual mass curve for the transitional season appear similar to the annual curve for most of the record. This suggests that rainfall during these transitional months has a primary influence on annual rainfall totals;
- there appears an overall long-term reduction in winter rainfall. From the mid 1940s until the mid 1970s generally increasing annual rainfall occurred despite these decreases; and
- annual rainfall totals that are much greater than average (for example, greater than 100 mm above the mean) tend to be significantly influenced by rainfall during the summer months, such as occurred during 1946 to 1947 and 1973 to 1974.

In Figure 13, the close relationship in terms of the magnitude of above or below average rainfall between the annual and transitional season residual mass curves is reasonably clear from 1946 until 2003. However, the summing of successive residuals to form residual mass curves means that the positions of these curves or sections of these curves at any point are dependent on the history of residuals. Because of this, while a section of a seasonal curve may mimic the annual curve, this similarity may not be as obvious as the curves may not physically overlap. One example of this was observed with the data from Padthaway (026017).

Figure 14 shows selected monthly residual mass curves at Padthaway (026017). As with the monthly curves from Keith (025507) in Figure 12, various attributes of this annual curve are partially reflected in each of the months shown. One example is the sudden increases in the annual curve caused by the above average rainfall years of 1946 to 1947 and 1983 to 1984 are also seen in the March curve. Similarly, the October curve reflects the above average rainfall years of 1974 to 1975. Figure 15 then shows the seasonal residual mass curves. While the transitional season curve closely mimics much of the annual curve between 1959 and 1972 and the winter curve for the years from 1939 to 1944 and 1996 to 1999, this may not be immediately evident. Generally decreasing trends in winter rainfall are evident over most of the record.

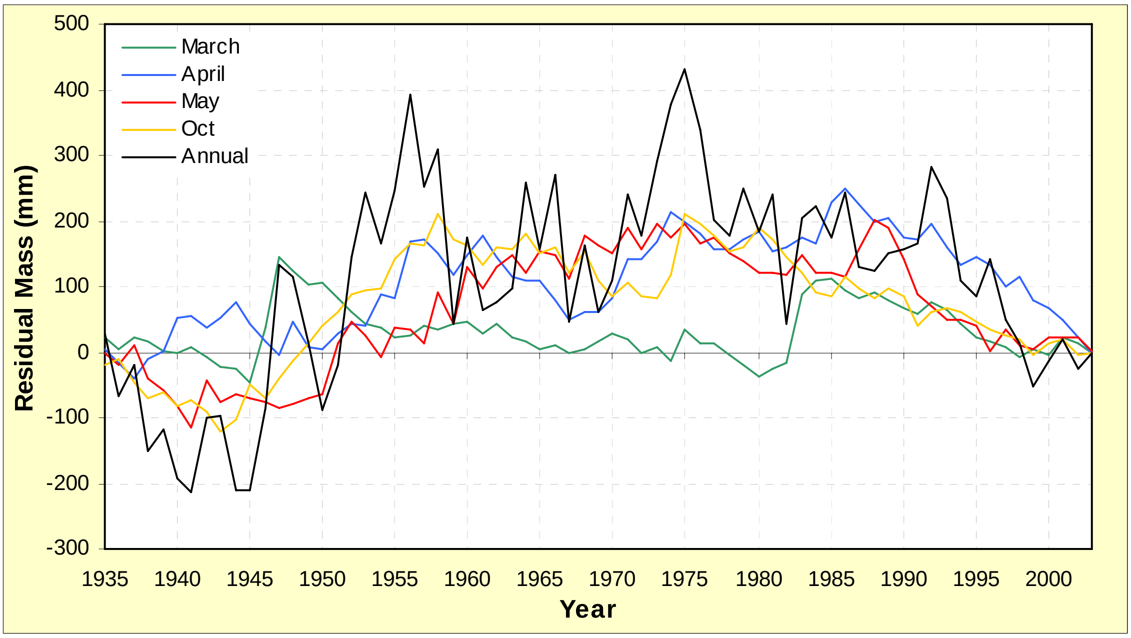


Figure 14 Monthly Residual Mass Curves at Padthaway (026017).

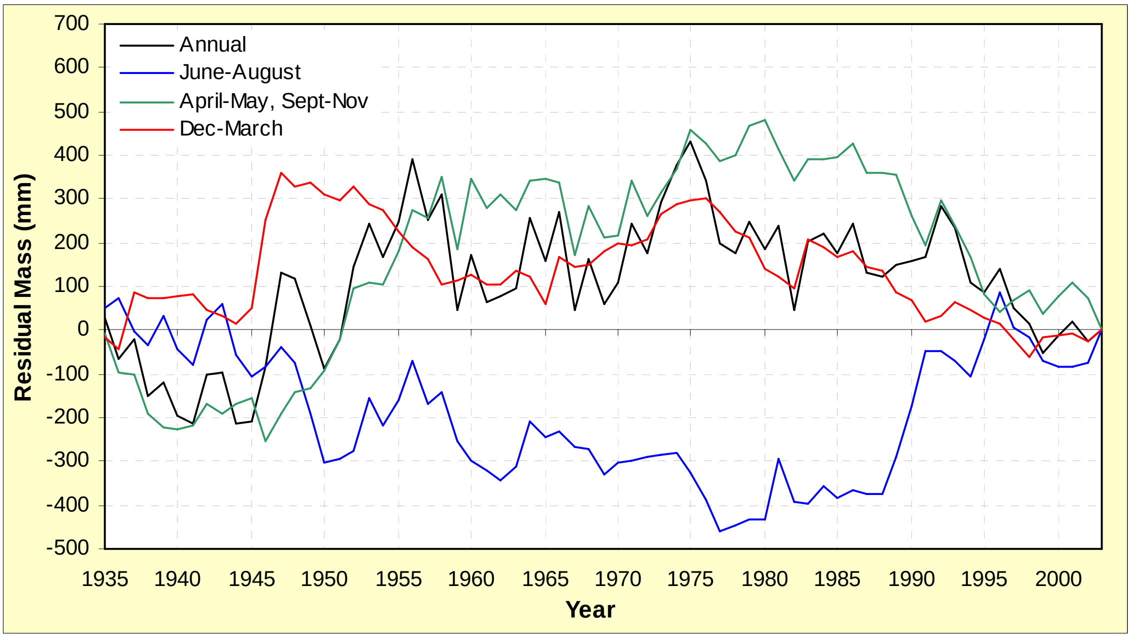


Figure 15 Seasonal Residual Mass Curves at Padthaway (026017).

Comparisons of the residuals themselves sometimes provides a clearer illustration of this relationship. Figure 16 compares the annual residuals with those from winter and the transitional season at Padthaway (026017). The close relationship between above and below average seasonal and annual rainfall over a number of periods is immediately evident. The results of this for the data from Padthaway (026017) indicated that:

- the residuals from the transitional season are very similar to the annual over successive years from 1935 to 1938, 1958 to 1962, 1968 to 1972 and 1999 to 2002; and
- the winter and annual residuals are very similar over successive years from 1939 to 1944, 1953 to 1958 and 1997 to 1999.

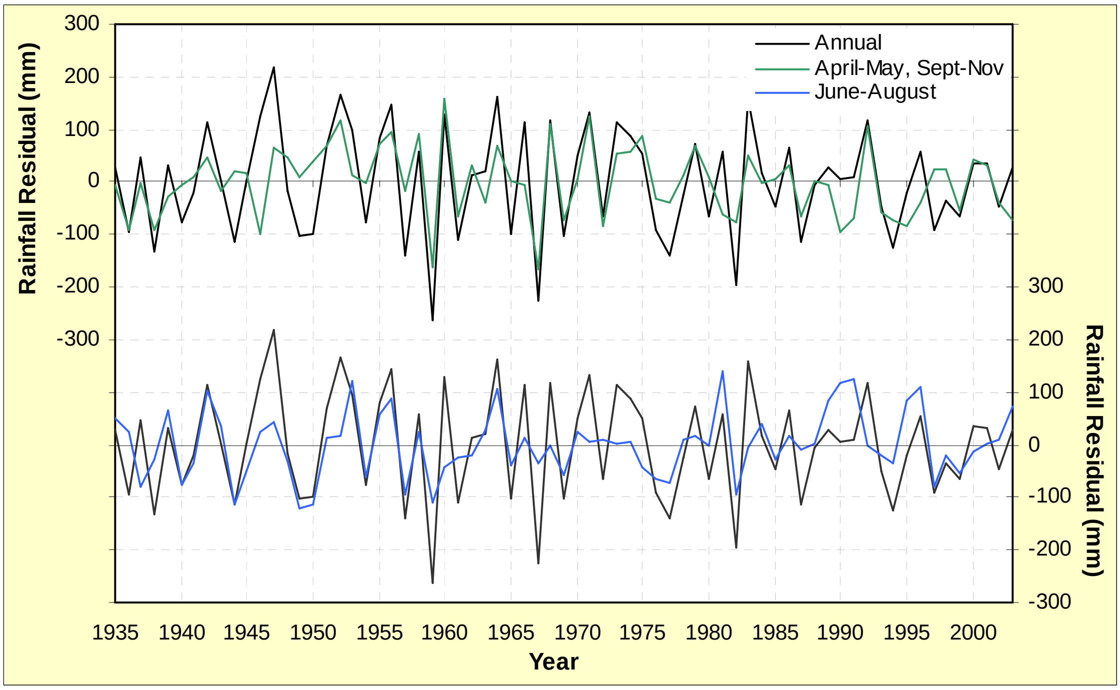


Figure 16 Comparison of Annual and Seasonal Residuals at Padthaway (026017).

The data from the other representative stations revealed similar results in terms of both monthly and seasonal residual mass curves. This grouping of months for the seasonal analysis was also found to be appropriate for data from other stations. Examining a station from the more southern, higher rainfall area, Figure 17 shows the monthly residual mass curves for Callendale (026003). Figure 18 then shows the seasonal residual mass curves. As for the lower rainfall stations, the transitional season mimics the overall pattern of the annual curve. The summer season again influences the annual curve in some significantly above average years such as 1946 and 1947. Although it is not as obvious, the winter season also mimics the annual curve, particularly from 1952 to 1961. The relationship between both the winter and transitional season residuals with the annual residuals is shown in Figure 19, again highlighting the importance of the transitional season.

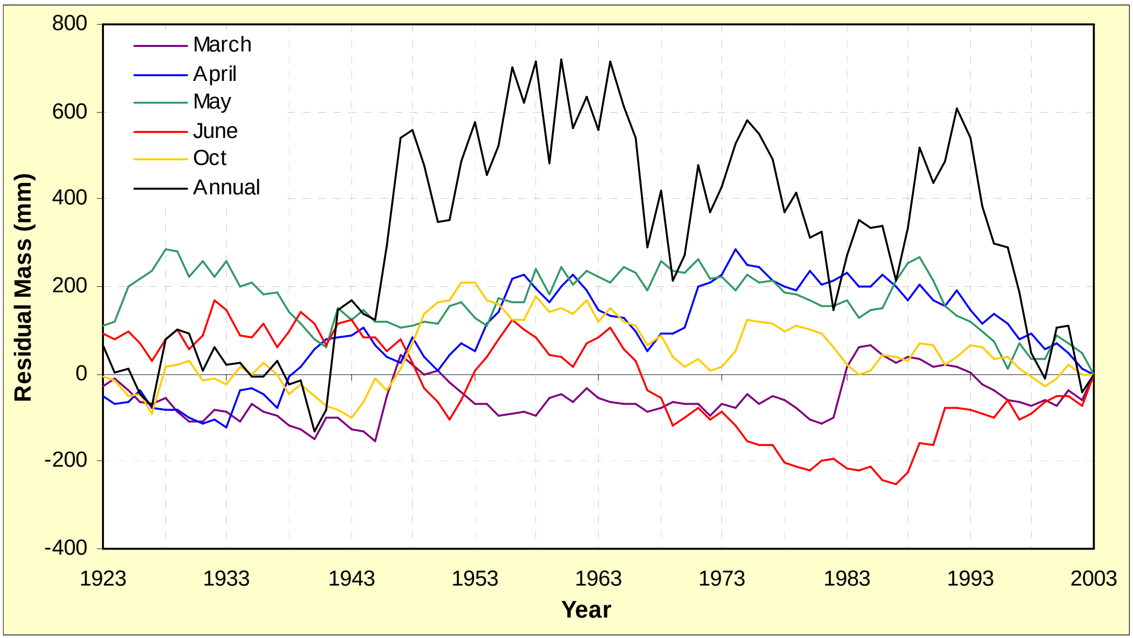


Figure 17 Monthly Residual Mass Curves at Callendale (026003).

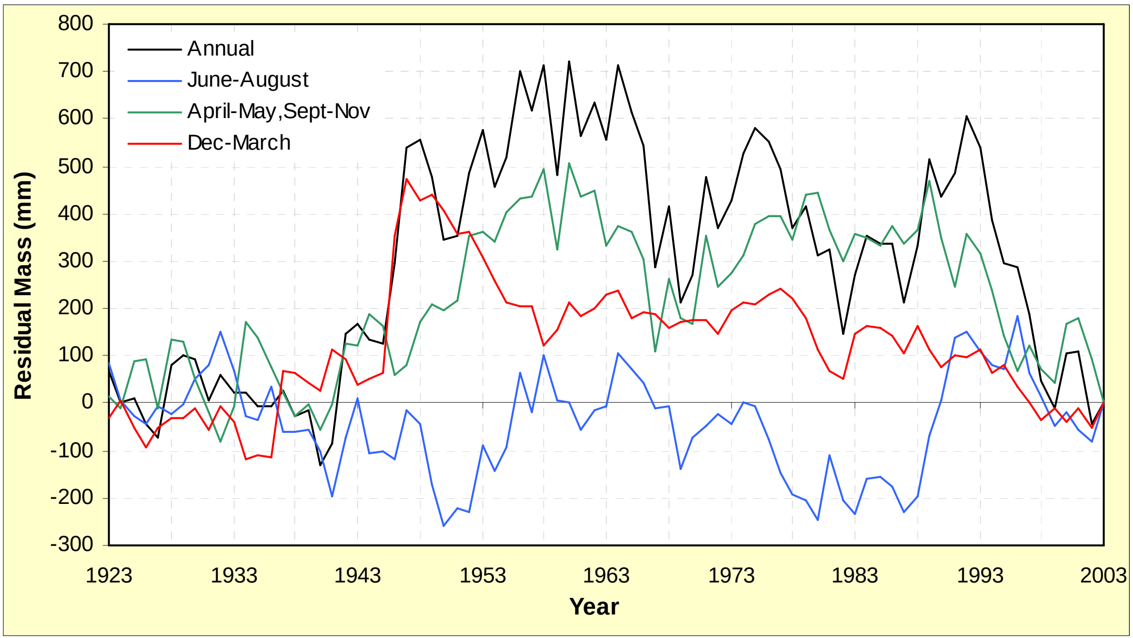


Figure 18 Seasonal Residual Mass Curves at Callendale (026003).

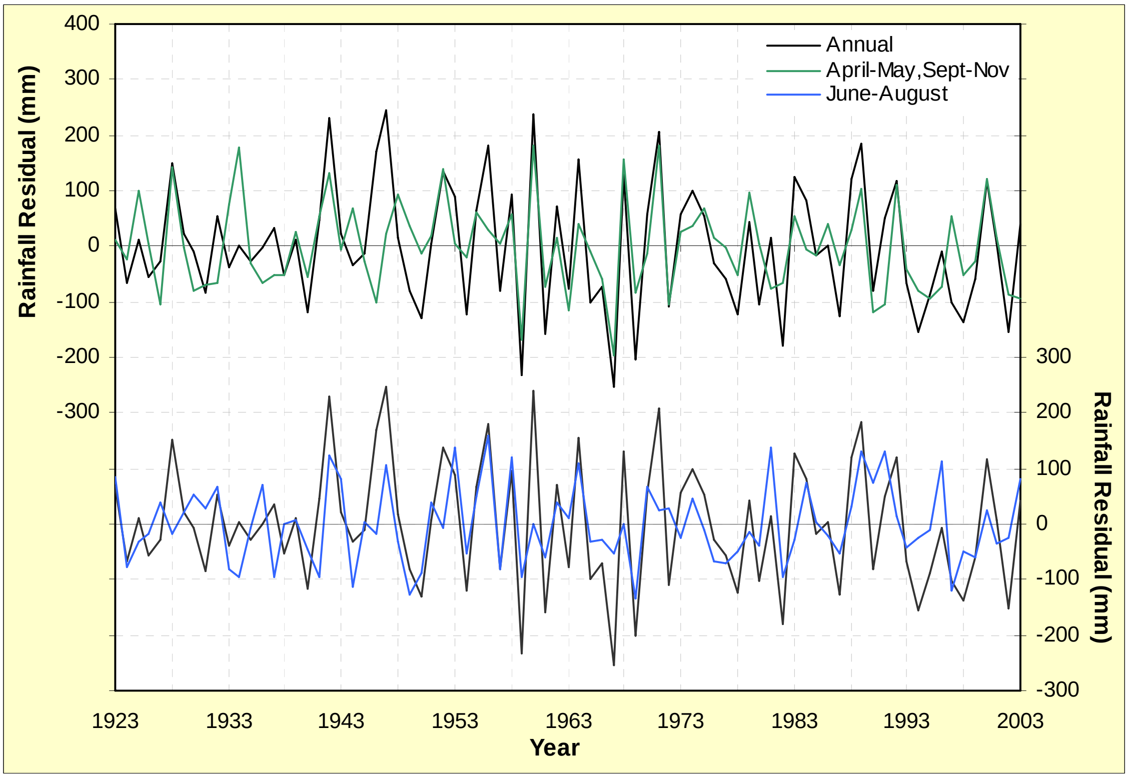


Figure 19 Comparison of Annual and Seasonal Residuals at Callendale (026003).

The importance of the transitional season should not be overlooked. Much of the autumn and early winter runoff infiltrates into the soil and saturates the catchment. This early season saturation is an important requirement for producing runoff later in the year. Therefore, fluctuations in the timing and volume of rainfall during April and May can delay the onset of higher winter runoff and reduce the total volume. The length of the winter runoff season is directly affected by rainfall during September to November. Less rainfall during this period and total runoff will be less and the season shortened.

The correlation between the seasonal and annual totals was also analysed. A selection of these results are present in Table 3.

Table 3 Correlation Between Seasonal and Annual Rainfall Totals.

Station	Correlation			Annual Rainfall (mm)
	Winter	Transitional	Summer	
Keith (025507)	0.64	0.72	0.40	456
Kaniva (078078)	0.62	0.68	0.40	452
Padthaway (026017)	0.59	0.68	0.38	526
Frances (026007)	0.68	0.72	0.31	522
Naracoorte (026015-026104)	0.62	0.69	0.40	558
Callendale (026003)	0.59	0.65	0.30	653
Penola (026025)	0.66	0.64	0.31	652
Kalangadoo (026009)	0.64	0.64	0.30	754
Lake Leake (026014)	0.70	0.71	0.21	860

The correlation between the annual and transitional season totals was generally higher than that between the annual and winter totals, with a higher difference at the drier, northern stations than at the southern, wetter stations. The correlation between the summer and annual totals also tended to drop with increasing rainfall. It was only at a small number of stations that the correlation between the annual and winter rainfall was greater than between the annual and transitional season.

The correlation analysis above also reaffirms the importance of the transitional season on the annual totals, particularly in drier regions. This significance is in part because in the drier areas the rainfall during the winter months constitutes a smaller proportion of the total annual rainfall than in the wetter areas. This was highlighted in Figure 11, where the major differences between the annual rainfall totals at stations across the region was the amount of winter rainfall.

Analysis of seasonal residual mass curves and residuals at other stations across the region showed similar results, a selection of which are presented in Appendix A.2. The conclusion drawn from this data is that the annual rainfall totals in the drier areas are generally affected and influenced more by rainfall during the transitional season than those in wetter areas.

2.2.3 Decadal Rainfall Analysis

The study of climate variability and climate change has increased over the last 20 years and has included the analysis of variables such as rainfall at a decadal time scale. This is in part because natural climate variability at decadal time scales has the potential to interact with and interfere in an unambiguous detection of climate change (Latif *et al*., 1999).

A decadal rainfall analysis of the data at each long-term station revealed significant trends. Figure 20 shows this analysis for the station at Keith (025507). The "mean decade rainfall" is the average rainfall over non-overlapping ten year periods. Average rainfall significantly above the long-term mean can be seen in the ten year periods 1946 to 1955 and 1966 to 1975. The ten year periods from 1936 to 1945, 1976 to 1985 and 1996 to 2003 show average rainfall significantly below the long-term mean.

Average rainfall over "standard" decades (for example, 1900 to 1909, 1910 to 1919) was initially examined but the ten year moving average clearly highlights the high (peaks) and low (troughs) rainfall periods as not being consistent with standard decades. This was the case at a majority of stations.

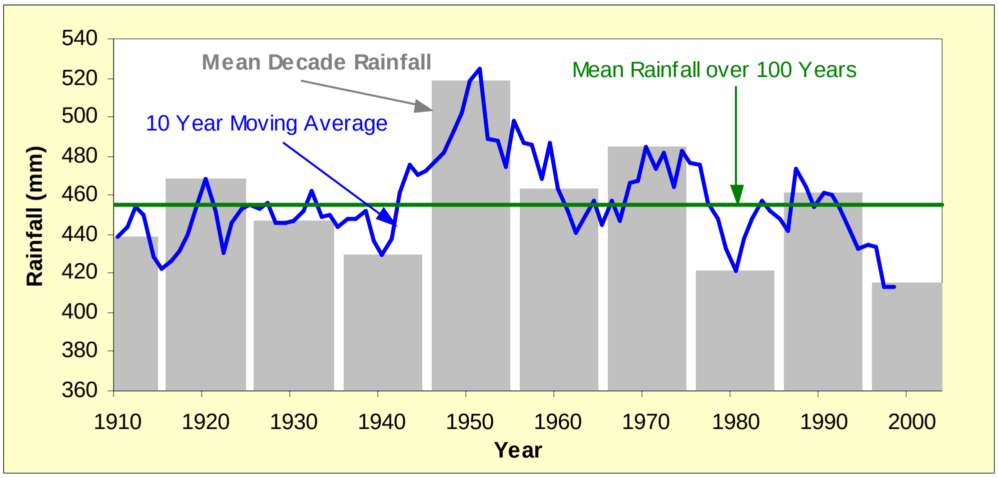


Figure 20 Decadal Rainfall Pattern at Keith (025507).

It is worth noting that the height of successive above average rainfall peaks in both the ten year moving average and the mean decade rainfall have decreased. This has resulted in the above average peak from 1986 to 1995 being close to the long-term mean. In contrast, those decades with rainfall significantly below average are all approximately the same magnitude. Although conclusions could be drawn with regards to long-term changes in the rainfall regime or even human induced climate change, without longer rainfall series it cannot be ascertained whether this may just be an example of long term rainfall variability. However, it does highlight the need to prepare strategies to manage the water resources of the region for extended periods of below average rainfall.

Similar trends were found at other stations across the region. Figure 21 shows the results for Naracoorte (026023-026099) and Figure 22 for Penola (026025). The results from additional selected stations are presented in Appendix A.2.

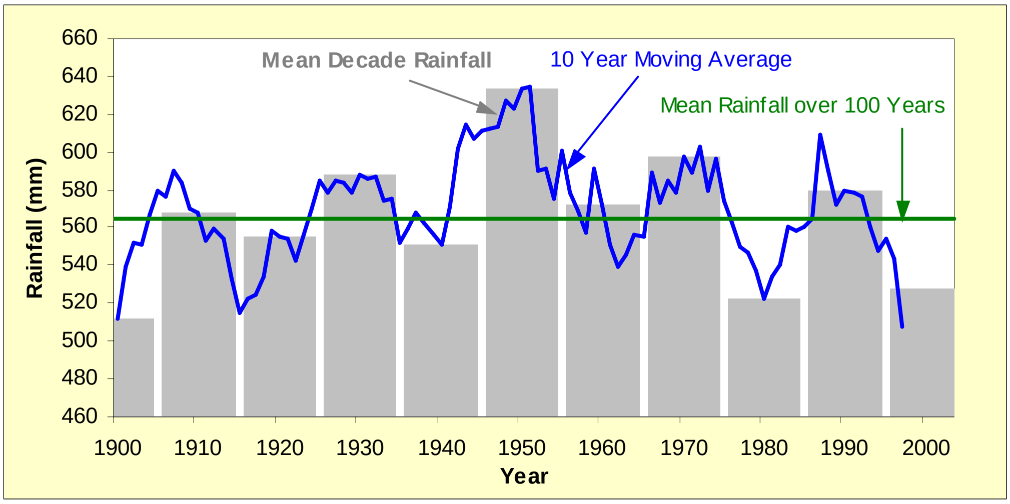


Figure 21 Decadal Rainfall Pattern at Naracoorte (026023-026099).

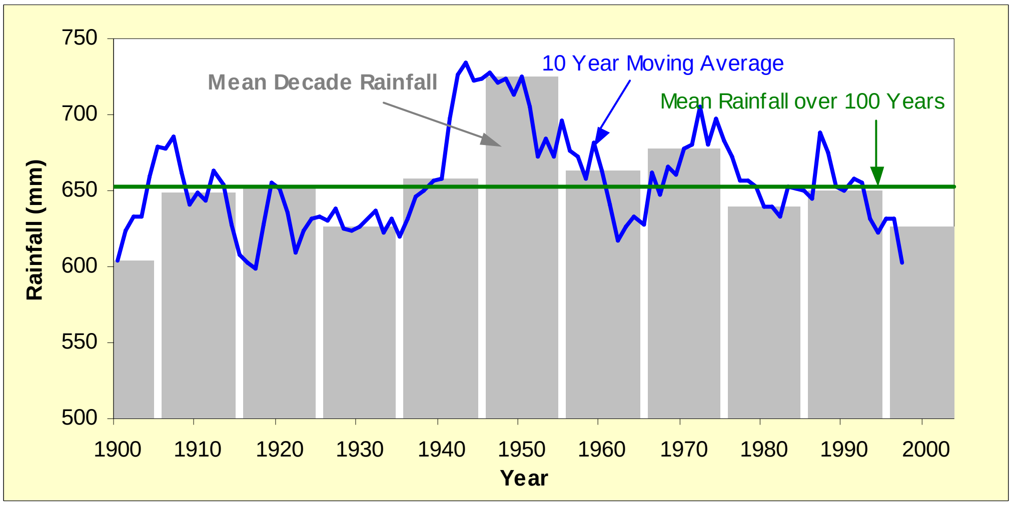


Figure 22 Decadal Rainfall Pattern at Penola (026025).

The results of the decadal analysis presented here are similar to those found in recent studies in the Mount Lofty Ranges (Savadamuthu, 2002; Savadamuthu, 2003; Heneker, 2003). One difference that is worth noting is that during the ten year period from 1916 to 1925, the mean decade rainfall in the Mount Lofty Ranges was often over 100 mm above the average, indicating that many years in this period had annual rainfall significantly above average. For most stations, this period had the highest mean decade rainfall in the record. For rainfall stations in the Upper South East region this was not the case and the mean decade rainfall was at most around 20 mm above the average.

3. EVAPORATION

Evaporation is the transfer of moisture into the atmosphere, whether from a free water surface such as a dam or reservoir, a soil surface or by the process of transpiration from plants. Accurate estimates are essential for hydrological water-balance calculations because evaporation influences the amount of rainfall that is intercepted by vegetation and absorbed by the soil before surface runoff and aquifer recharge will occur. It also significantly reduces the volume of water stored in wetlands and swamps, particularly during summer.

3.1 Data Availability and Processing

The availability of daily evaporation data is limited, particularly in comparison to rainfall data. In a number of previous investigations (for example, Savadamuthu, 2002; Teoh, 2003) a value of daily evaporation for each month has been obtained from the mean monthly rainfall for that month. However, it has been suggested (Lindsey and Farnsworth, 1997) that a limitation of the use of mean monthly values for evaporation is the large day-to-day variance in evaporation that often occurs during spring and autumn. Seasons may also begin early in some years and late in others or significant variations from mean monthly values may occur at any time during the year; for example, evaporation may be suppressed by lower temperatures and high humidity during a rainy period in the middle of summer, or extremely hot and dry periods may cause the evaporation to be very high during some years. Such factors may cause serious errors in the estimates of evaporation and hence the resulting water balance. During calibration of catchment models during previous studies (Heneker, 2004), significant improvements have been found in the representation of the observed streamflow data by using daily data, justifying this approach. Therefore, it is intended to use daily evaporation data to calibrate the model for the Upper South East Catchment.

There are two sources of evaporation data that may be used for catchment modelling, namely, measured pan evaporation or evaporation calculated using empirical equations. The method chosen usually depends on the type of surface from which evaporation is occurring because the factors affecting evaporation differ between a wetland or waterbody surface compared to a soil or plant surface. It has been shown that data from both sources can be used interchangeably (Heneker, 2002) with the use of an evaporation adjustment coefficient. The catchments to be modelled in this study include both open water and soil/vegetative surfaces but one method is generally chosen and adjustment coefficients applied to the data set to represent average evaporation from each type of surface.

Pan evaporation is based on evaporation from an open water surface and provides an index of the integrated effects on evaporation from solar radiation, air temperature, air humidity and wind. It generally provides a good representation of evaporation from wetlands and swamps but is collected at only a small number of locations across the South East region.

Empirical equations used to calculate evaporation incorporate estimates of the main factors that affect evaporation (solar radiation, air temperature, air humidity and wind). Although there are many such empirical equations available, the Priestley-Taylor method (Priestley and Taylor, 1972), which has been used for numerous catchment modelling studies in Australia (for example Sumner *et al*., 1997; Heneker, 2002; Heneker, 2003), has been used here. A description is presented in Appendix B.2. The Priestley-Taylor method uses solar radiation data but because this is not widely monitored in Australia, it often has to be estimated, spatially interpolated or extrapolated using relationships between solar radiation and sunshine hours and temperature. In this case, a method using sunshine hours and maximum and minimum temperature was used. However, as with the availability of the pan evaporation, the data required to calculate evaporation is collected only sporadically across the South East region.

The limited pan evaporation, sunshine hours and temperature data across the region of a good quality and reasonable length has made necessary the extrapolation of data from those available stations to other areas. While historically there were more stations recording sunshine and temperature data within the South East, there have never been many stations in the Upper South East and most of these, that were once recording, have now either closed or are not currently recording both variables. Table 4 lists the stations operated by the Bureau of Meteorology that provide useful pan evaporation, sunshine hours and temperature data. The pan evaporation data was examined and the potential evaporation calculated at each station.

Table 4 Climate Stations used to Generate Evaporation Datasets for Modelling.

Station Number	Location	Data Type	Period of Record	Percentage of Missing Data
026021	Mount Gambier	Pan Evaporation	1967-2004	<0.1
026021	Mount Gambier	Temperature	1943-2004	<0.1
026021	Mount Gambier	Sunshine Hours	1967-2004	<0.1
026082	Struan	Pan Evaporation	1975-1999	1.4
026089	Padthaway	Pan Evaporation	1978-2000	1.4
026100	Padthaway South	Pan Evaporation	2000-2004	-

3.1.1 Data Infilling and Adjustment

Processing of the pan evaporation data that included the infilling of missing data, disaggregation of accumulated data and adjustments for homogeneity or infrastructure changes was undertaken by Murdoch (2004). Adjustments for homogeneity may be required due to changes in instrument exposure at a station such as may result from the growth of obstructive vegetation or construction of a building that changes wind patterns. Of particular importance for evaporation is the type of instrument used to record the data. Sunken Tanks and subsequently Class A Pans have primarily been used by the Bureau of Meteorology to record evaporation data. Kernich (1984) indicated that there is a 10 to 12% reduction in evaporation when changing from a Sunken Tank to a Class A Pan. Details and the processing undertaken for each station is presented in Appendix B.1.

Processing of sunshine hours and temperature data was conducted using similar methods to the pan evaporation data. Missing temperature records were infilled using a linear relationship with a nearby site, while missing sunshine hours records were estimated from a fitted third order polynomial (Chiew and McMahon, 1991) between sunshine hours data and cloud cover data at the same location. The sunshine hours data was also examined to ensure homogeneity. Examples of the regression relationships and correlations are presented in Appendix B.1.

3.2 Data Analysis

Analysis of the recorded pan evaporation data for Mount Gambier (026021) and Padthaway (026089-026100) and the calculated potential evaporation data for Mount Gambier (026021) was undertaken at annual and monthly time scales. A discussion and examples of the results obtained are presented in this section, with the complete results contained in Appendix B.3.

3.2.1 Annual Evaporation

Using data from the station at Mount Gambier (026021), the annual totals and long-term trends for pan evaporation are shown in Figure 23 and for potential evaporation in Figure 24. The mean annual pan evaporation and the standard deviation of the mean annual pan evaporation are 1318 mm and 101 mm respectively. This compares with 922 mm and 24 mm for the potential evaporation data.

The differences in the mean values at the same recording station corresponds to the differences generally seen between evaporation from an open water body compared to evaporation from the soil surface. In comparison to vegetative and soil surfaces, some of the variability and higher values of pan evaporation can be attributed to:

- increased reflection of solar radiation from the water surface;
- the storage of heat within the pan that may cause significant evaporation during the night and heat transfer through the sides of the pan may also occur; and
- differences in turbulence, temperature and humidity of the air immediately above the pan.

The average ratio of the potential to the pan evaporation is 0.7, with 90% of ratios in the range 0.64 to 0.77. This further supports the interchangeable use of these datasets with appropriate adjustment factors when only one type of evaporation data is available.

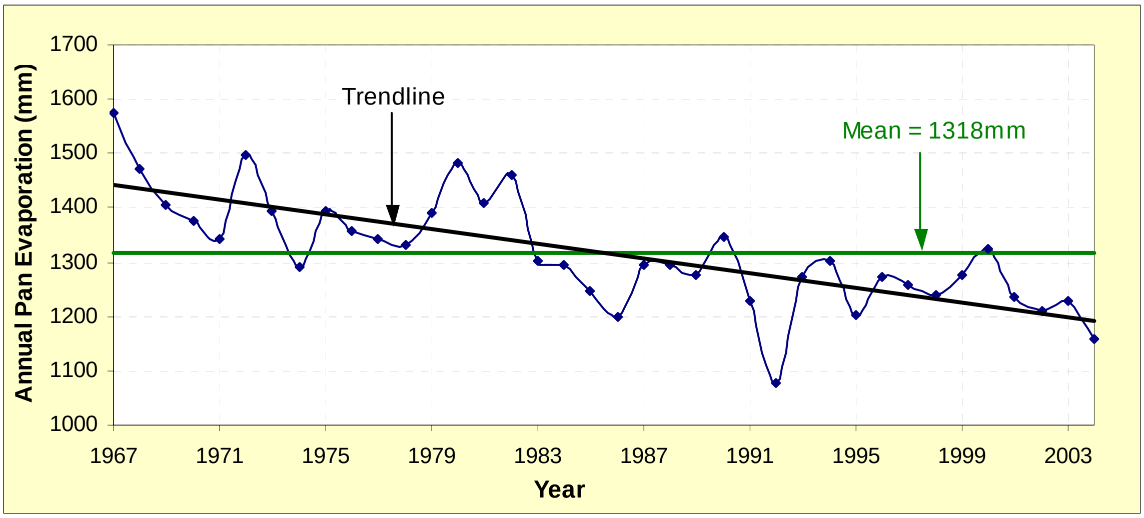


Figure 23 Annual Pan Evaporation and Long-Term Trends at Mount Gambier (026021).

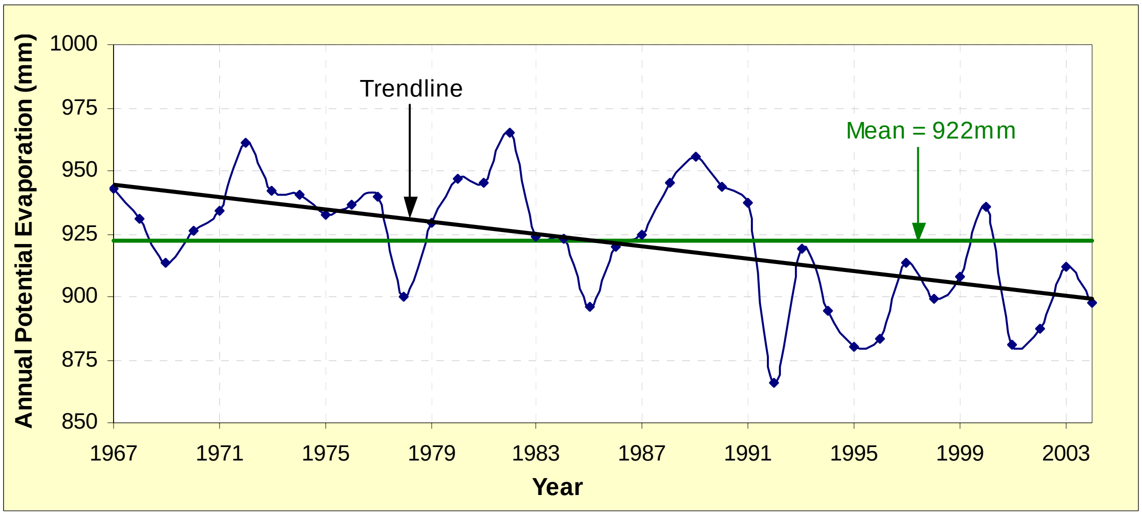


Figure 24 Annual Potential Evaporation and Long-Term Trends at Mount Gambier (026021).

Significant decreasing trends in annual totals are observable in both datasets. However, the size of the decrease appears greater in the pan evaporation data. Prior to 1983, the annual pan evaporation totals are generally above the mean and after 1983 they are generally below the mean. Calculating the mean pan evaporation before and after 1983 gives 1407 mm and 1252 mm respectively, equating to an 11% difference. This is presented in Figure 25. In comparison, the mean potential evaporation over these two periods was 937 mm and 911 mm, a decrease of only 3%. Figure 26 then shows the ten-year moving average for the pan evaporation data. The data point located at 1987 on this graph is the average of annual totals from 1983 to 1992. Therefore, it can be seen that the average annual pan evaporation within 10 year periods since 1983 has been generally consistent.

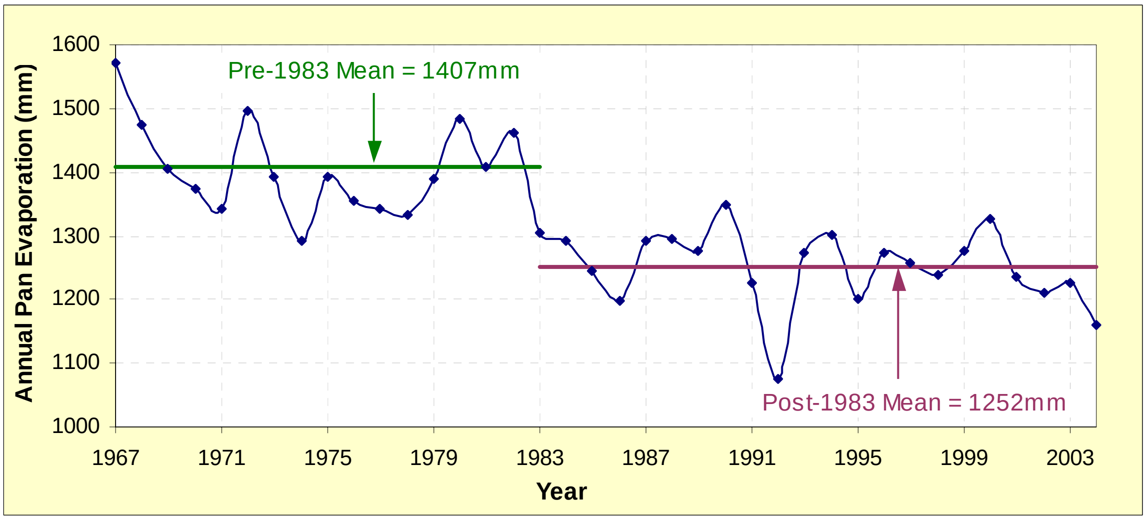


Figure 25 Change in Mean Annual Pan Evaporation at Mount Gambier (026021).

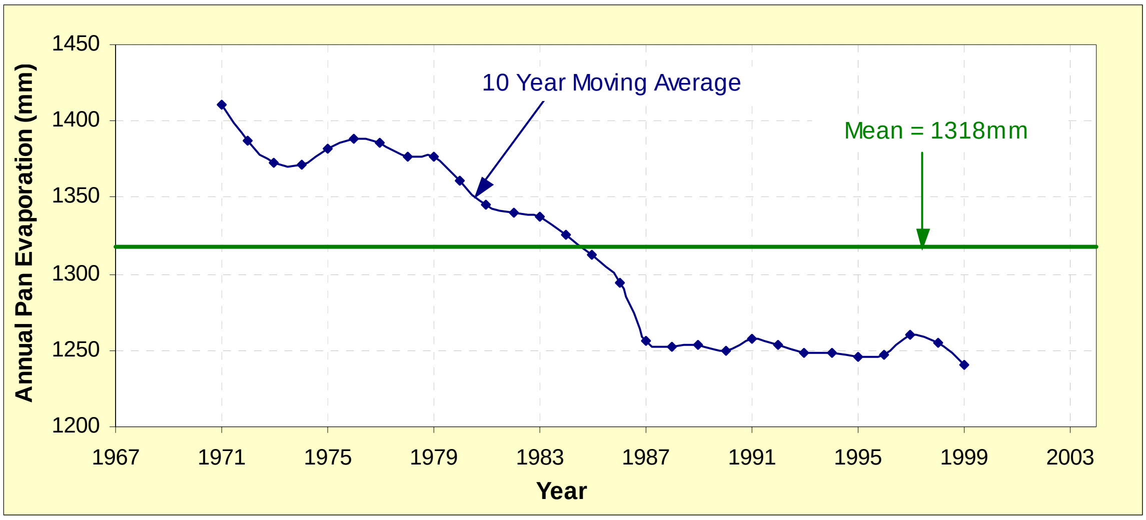


Figure 26 Ten-Year Moving Average of Pan Evaporation at Mount Gambier (026021).

3.2.2 Monthly Evaporation

The mean monthly pan and potential evaporation data from Mount Gambier (026021) is shown in Figure 27.

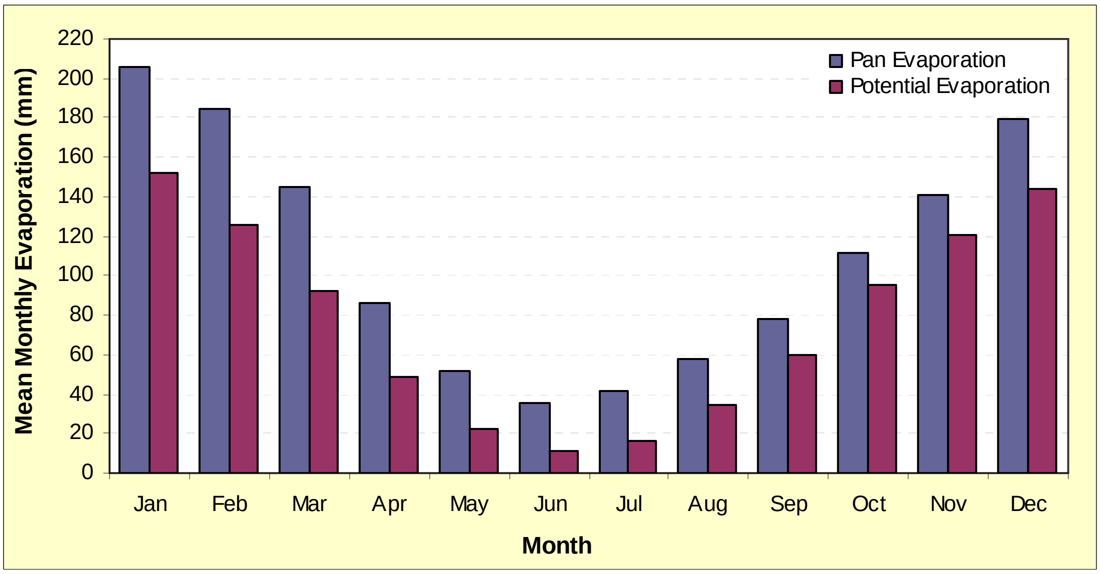


Figure 27 Mean Monthly Evaporation at Mount Gambier (026021).

Monthly pan and potential evaporation data was examined for evidence of trends. Figure 28 shows the annual residual mass curve, together with selected monthly curves that reflect the observed trends in the annual data. The annual residual mass curve reflects the results presented in Section 3.2.1 where evaporation was generally above average prior to 1983 and below average since 1983. This long-term above average then below average pattern is typical of an overall decreasing trend in the data.

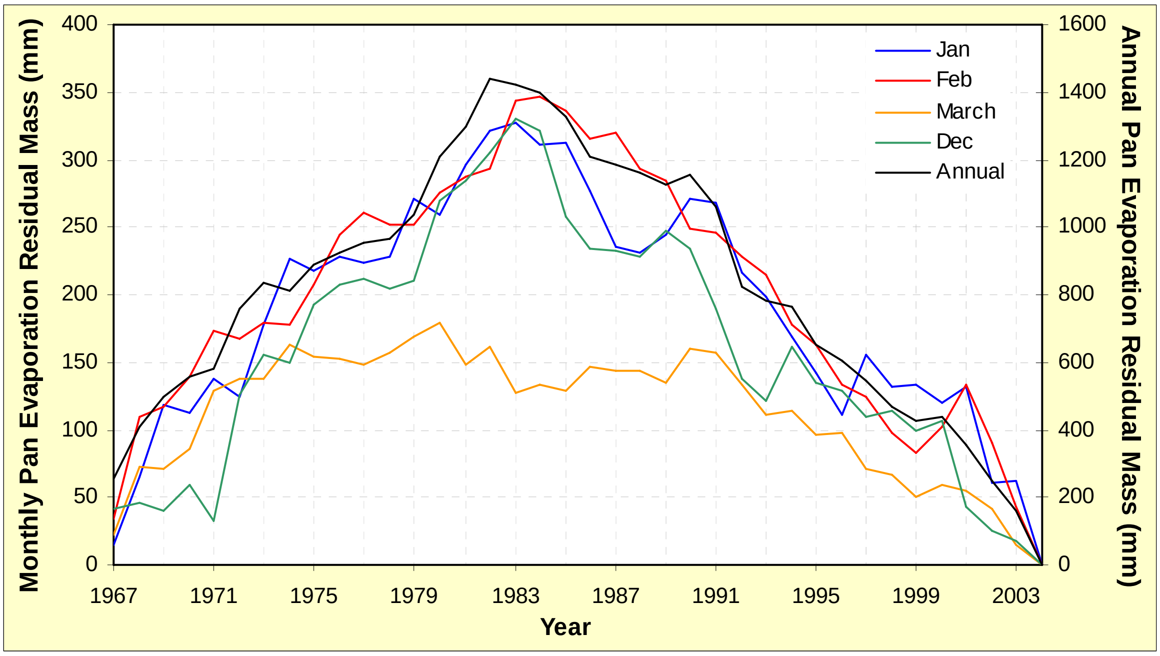


Figure 28 Residual Mass Curves for Pan Evaporation at Mount Gambier (026021).

From the monthly residual mass curves it was evident that the summer months (December to March) have had significant impact on the annual trends. A similar result was found for the potential evaporation data as for the pan evaporation above.

An analysis of the pan and potential evaporation monthly totals showed decreasing trends in more than half of the months with almost no trend in the remaining. The most prominent downward trends occurred during summer months. Figure 29 shows this trend for the February pan data from Mount Gambier (026021). Analysis of the sunshine hours data also showed a significant downward trend in many months. Decreases in sunshine hours represents a decrease in solar radiation reaching the ground. Therefore, from the results found in this study, it appears that over the last 35 years, solar radiation reaching ground has been decreasing during the summer months, resulting in lower values of evaporation.

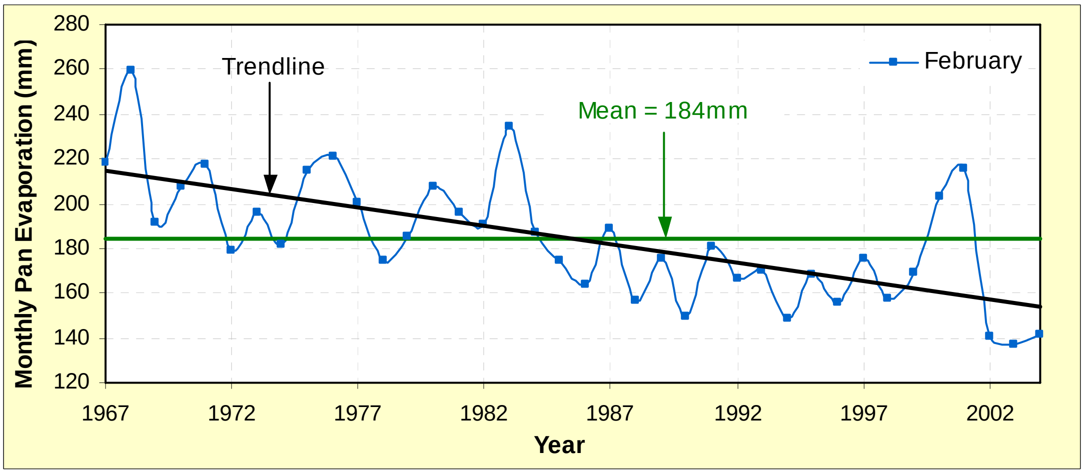


Figure 29 Long-Term Trends in February Pan Evaporation Totals at Mount Gambier (026021).

3.2.3 Evaporation and Rainfall Relationship

Variation between evaporation stations within a region is generally considered lower than for rainfall. However, it would be desirable to have a number of stations located across the catchment to adequately represent the spatially variability. This is the case even if evaporation adjustment factors are used to compensate for the distances between stations and catchments. Because of the very limited number of stations available in the South East region, a different approach to account for this spatial variability and to produce meaningful adjustment factors needed to be established.

It has been shown that evaporation has a high correlation with rainfall (Jones *et al*., 1972; Hoy, 1977; Srikanthan and McMahon, 1985; Heneker, 2002). As annual rainfall increases from north to south it is expected that evaporation will decrease. The data from Struan was extended to 2004 (refer Appendix B.1) and the relationship between the three pan evaporation stations was evaluated. Figure 30 shows the annual pan evaporation totals at these stations. The consistent increase in evaporation with decreasing rainfall is evident.

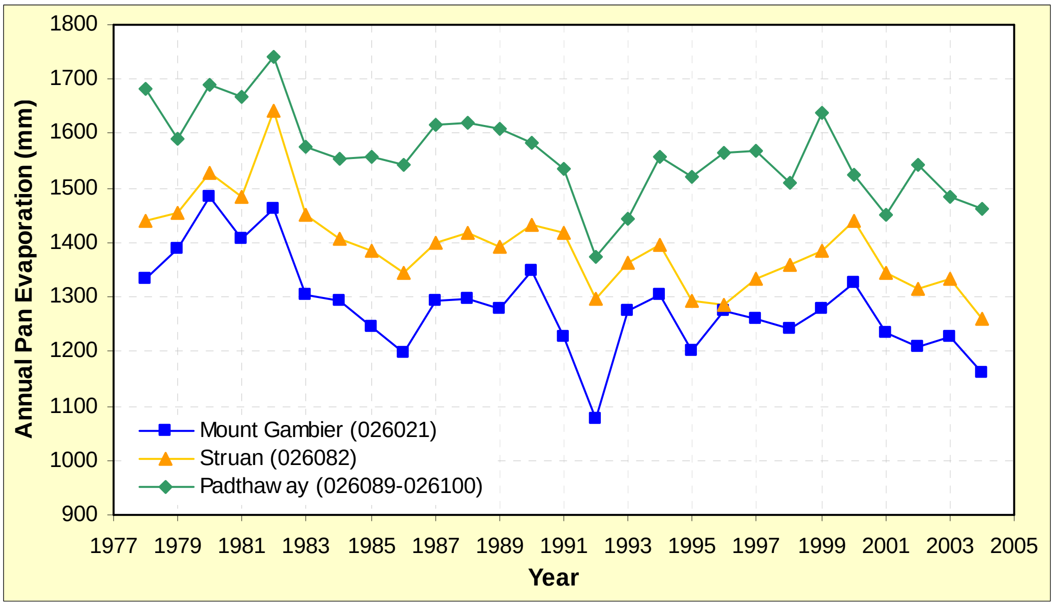


Figure 30 Relationship between Annual Pan Evaporation Stations in the South East.

The relationship between annual rainfall and pan evaporation for the three stations was then analysed. Annual rainfall and pan evaporation totals are shown in Figure 31 and mean annual values in Figure 32. A linear relationship between the mean annual values is also presented in Figure 32. Using this relationship a value of mean annual evaporation can be determined from the mean annual rainfall for a given sub-catchment. This in turn can be used to calculate the adjustment factor to be applied to either the Padthaway (026089-026100) or the Mount Gambier (026021) pan evaporation data. While it would be preferable to build a relationship between the annual totals and it is not ideal to build a relationship from only three data points, this trendline will allow a single adjustment factor for a given sub-catchment as opposed to a different factor for each year.

A relationship between the pan and potential evaporation was established in Section 3.2.1. The two relationships can be combined when only potential evaporation is to be used.

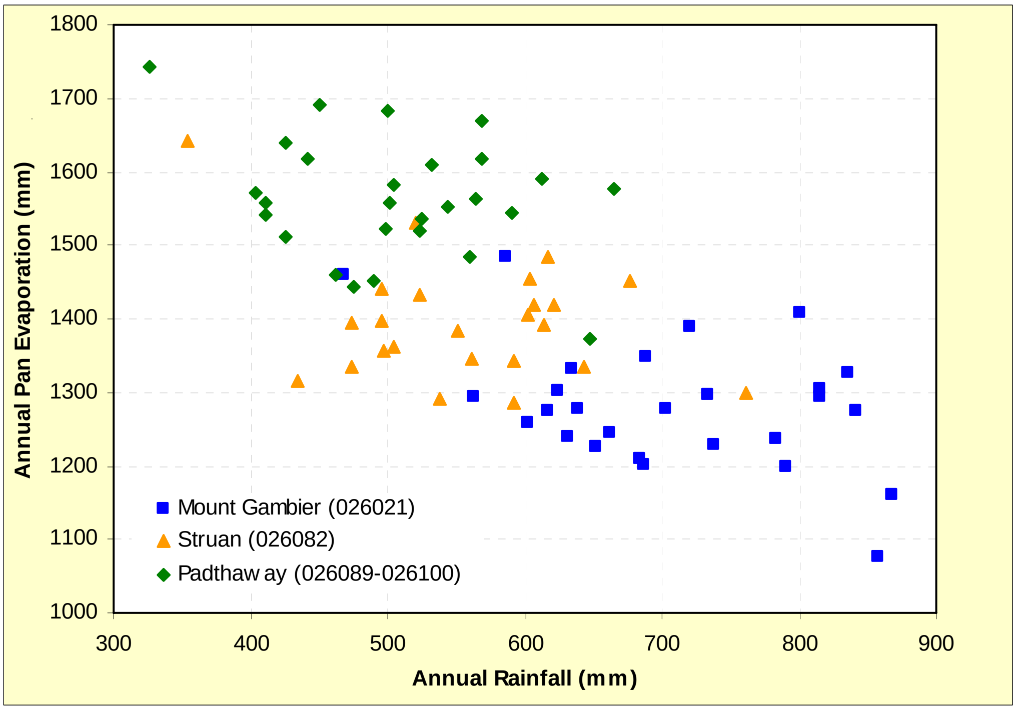


Figure 31 Relationship between Annual Rainfall and Pan Evaporation.

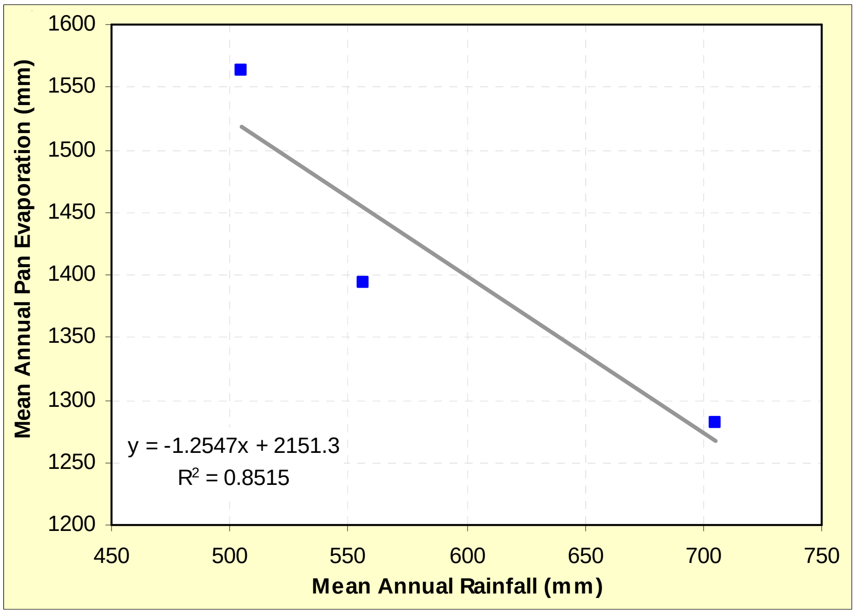


Figure 32 Relationship between Mean Annual Rainfall and Pan Evaporation.

4. SUMMARY AND CONCLUSIONS

This technical report contains an assessment of the meteorological information (rainfall and evaporation) across the Upper South East. It is a component of the data collection phase of the Drain and Watercourse Modelling Project and will form a fundamental basis for the development of a hydrological time-series model for the region.

4.1 Rainfall

Daily rainfall data from more than 100 stations was examined. The methodology used for the selection of stations for hydrological modelling considered operational status, length of record, quantity of missing and aggregated data and for closed stations, the potential for record extension using a nearby station. From this it was found that:

- long-term (>80 years) records are available at 17 stations;
- medium length (>30 years) records are available at 15 additional representative stations;
- the stations available should provide a good representation of catchment rainfall; and
- the majority of the records selected had low quantities of missing data and required only small corrections due to data inconsistencies.

Analysis of the rainfall data at each station suitable for hydrological modelling was undertaken at annual, monthly and decadal time scales. From this it was found that:

<u>Annual</u>

- Average annual rainfall increases from approximately 480 mm/year at Keith in north to 850 mm/year at the southern end of the Bakers Range Drain near Kalangadoo in the south;
- As the average annual totals increase, so does the variability;
- At the long term representative stations no overall discernable trend (records beginning late 1800s) or only very slightly increasing or decreasing trends (records beginning 1920s and 1930s) in annual totals were evident;
- Residual mass curves for these stations generally showed decreasing totals from the beginning of the data until the mid 1940s, followed by increasing rainfall until the mid 1970s before again decreasing until the present;
- There appears a higher degree of variability of the annual totals about the mean from the beginning of 1940s to the end of the 1970s. Above average rainfall years are the highest on record and the below average rainfall years the lowest on record; and
- The medium length records generally showed decreasing trends in annual totals (refer to discussion below).

<u>Monthly</u>

- Between 75 and 80 percent of annual rainfall occurs between April and October (80 to 85 percent between April and November);
- The higher rainfall months (April to October) are primarily responsible for the majority of the differences in annual rainfall between stations;
- Variability is higher between November to March than for the remainder of the year and reliability of winter rainfall tends to increase with increasing mean monthly rainfall; and
- Monthly residual mass curves showed that no individual month was primarily responsible for trends in the annual curves. Instead, it appears that particular combinations of months or *seasons* impact more heavily on annual rainfall. A transitional season that

defines the periods between summer and winter (April to May and September to November) was found to have the highest influence on annual totals, particularly in drier areas.

Decadal

- The decade from 1946 to 1955 appears to be the wettest on record and significantly above average; and
- The decades from 1976 to 1985 and from 1996 until the present are the driest on record.

An important result from a comparison of results from the long-term and shorter-term stations was the differences in conclusions that can be made based on statistical analysis, when differing periods of data are available or used. For example, if only the long-term data was examined, it may have been determined that there was no significant trend in annual rainfall across the region. Alternatively, the sole use of short-term data may conclude that rainfall has been significantly decreasing and possibly attributable to some other phenomena such as climate change, as opposed to natural rainfall variability.

If the recent decreasing trends in annual rainfall are not part of natural rainfall variability, then using long-term historical averages and data sets may result in estimates of rainfall, and hence surface water availability, that are not realistic today. Because of this, it would be prudent to place more emphasis on modelling results using rainfall for the last 30 years, avoiding potential bias from historically higher rainfall periods.

4.2 Evaporation

Evaporation is a major component of the hydrological cycle and hence good estimates are required when evaluating catchment water balances. Pan evaporation and potential evaporation calculated from empirical equations are the two sources of evaporation data generally used in hydrological modelling. The availability of daily pan evaporation data across the South East region is limited with only two suitable stations available (that are still operating) at Mount Gambier and Padthaway. In addition, both sunshine hours and temperature data used to calculate potential evaporation are only recorded together at the station in Mount Gambier. These datasets are around 35 years in length and were examined at annual and monthly time scales. From this it was found that:

Annual

- Average annual pan evaporation varies from 1320 mm at Mount Gambier up to 1560 mm at Padthaway with an average potential evaporation at Mount Gambier of 920 mm;
- Differences in the mean values at the same recording station corresponds to the differences generally seen between evaporation from an open water body compared to evaporation from the soil surface. The average ratio of the potential to the pan evaporation is 0.7, with 90% of ratios in the range 0.64 to 0.77; and
- Significant decreasing trends in annual totals were observable with the pan evaporation data showing the largest decrease. For the station at Mount Gambier (026021), prior to 1983, the annual totals were generally above the mean and after 1983 they have been generally below the mean. Calculating the mean pan evaporation before and after 1983 gives 1407 mm and 1252 mm respectively, equating to an 11% difference.

Monthly

- The distribution of mean values over the year is the reverse of that for mean monthly rainfall data since evaporation is inversely correlated to rainfall;

- Decreasing trends in evaporation totals during the summer months (December to March) are evident and evaporation during these months appear to have the most significant impact on annual trends and totals; and
- Decreasing trends in sunshine hours, particularly during summer, represent a decrease in solar radiation reaching the ground and can aid in explaining decreasing evaporation. It appears that over the last 35 years, solar radiation reaching ground has been decreasing during the summer months, resulting in lower values of evaporation

Accurate estimates are essential for hydrological water-balance calculations because evaporation influences the amount of rainfall that is intercepted by vegetation and absorbed by the soil before surface runoff and aquifer recharge will occur. It also significantly reduces the volume of water stored in wetlands and swamps, particularly during summer. While it would be preferable to have a number of stations located across the region to adequately represent spatial evaporation variability, a different approach was required to enable this. A relationship was developed between mean annual rainfall and mean annual evaporation to provide a more scientific basis for the calculation of evaporation factors that allow data from one station to be transferred across the region. Despite this, it is strongly recommended that additional stations that measure either pan evaporation or sunshine hours and temperature are installed across the region.

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APPENDIX A RAINFALL ANALYSIS

A.1 Data Availability and Processing

Daily rainfall data in the south east of South Australia and in western Victoria is collected primarily by the Bureau of Meteorology. While there are over 100 daily rainfall stations distributed across the South Australian portion of the study area alone, many of these have been closed or do not contain data over the last 15 year period, for which there is available flow data to calibrate the model.

Table A1 presents all rainfall stations that were identified as having long-term records and were either currently operational or had only been recently closed. The available data from each of these rainfall stations was examined and the stations initially categorised as to the potential for use in model calibration. The methodology for this considered:

- current operational status of site;
- for closed sites, existence of a nearby site that could be used to continue the record;
- length and period of record; and
- quantity of missing and aggregated data.

Table A2 presents those rainfall stations identified as having data that was limited in its use for modelling. Most of these stations were closed more than 20 years ago and many haven't been operational for over 50 years. The primary use of the data from these stations would be to infill missing data, to disaggregate accumulated records or to extend the data from other stations.

Table A3 then presents those stations with potentially useful short-term records. Most of these stations have been opened within the last five to ten years and the data may be useful if localised rainfall information is required for those areas.

Section 2.1 identified those stations from Table A1 with good long-term records that could be used for hydrological modelling as well as for examining rainfall patterns and trends in the region. Additional sites were also identified for modelling. Each of these sites were also used to disaggregate accumulated data, infill missing data and undertake homogeneity analysis. In some cases, supplementary stations were required and the choice of these was based on their proximity to the identified stations, the length of record and the correlation between monthly and daily rainfall values.

The following sections examine the correlation between selected stations within specified sub-regions, the processes involved in disaggregating accumulated data and infilling missing data, and the processes and results from a homogeneity analysis.

Table A1 Operational or Recently Closed Rainfall Stations with Longer Records.

Site Number	Site Name	Analysis Period	Operational Status	%Accumulated	%Missing	Notes
024518	Meningie	1896-2003	Current	3.5	8.1	Missing part or all of year from 1924-1927, 1929-1934. North of USE area.
025500	Bordertown (Berangwee)	1944-2000	-	0.3	2.1	Closed mid 2000, missing half of 1944, 2000.
025501 / 025560	Bordertown / Bordertown Industrial Estate	1896-2003	Current	7.8	2.5	Site 025501 closed beginning of 2002, missing part or all of 1975-1979. Missing 1mth of data from 1996 and 2001. No overlapping period to compare with 025560. Distance between sites is 2.9km.
025504	Coonalpyn	1896-2003	Current	6.3	1.9	Missing 1yr from 6/1921, 2/1989 and 4mths from 10/1993. North of USE area.
025505	Bordertown (Karrawirra)	1920-2003	-	-	-	Missing 1990-1995, 1997-1999, most 1989, 1996, 2000 & 2003 ==> Not examined.
025507	Keith	1906-2003	Current	0.1	1.5	Pluviograph station since 1990. Missing part of 1906, 1925.
025514	Tintinara	1900-2003	Current	7.5	1.3	Missing parts of years 1986-1989. North of region.
025518	Wirrega (Taunton)	1910-2003	Current	1.3	0.7	-
025519	Wolseley Wise Farm Equipment	1896-2003	Current	5.0	3.3	Missing parts of years 1908-1911, 1975 and most of 1993-1994.
025525	Bordertown (Inglewood)	1952-2003	Current	0.1	1.6	Missing part of 1952.
025526	Tintinara (Colebatch Downs)	1949-2003	Current	0.7	10.0	Missing years 1956-1960, part of 1949 and 1month in 1952, 1961 and 1970. Missing 0.4% since 1961.

Table A1 continued…

Site Number	Site Name	Analysis Period	Operational Status	%Accumulated	%Missing	Notes
025538	Wirrega (Yarrawin)	1969-2001	-	0.1	0.0	Site closed at beginning of 2002.
025541	Keith (Mandurama)	1969-2003	Current	0.2	0.7	Missing 1mth in 1969, 2003.
025546	Tintinara (Richards)	1969-2003	Current	0.2	0.7	Missing 1mth in 1969, 1997.
025550 / 025561	Bordertown (Monard) / Wolseley (Honiton)	1973-2003	Current	0.8	0.0	Site 025550 closed mid 2002 with 1mth overlapping data. Sites 2.2km apart and no missing data from either site.
026000	Beachport	1896-2003	Current	0.6	6.3	Missing most of 1990 and 1mth from 2002. Useful if required to model Lake George.
026003	Callendale	1923-2003	Current	1.8	7.5	Large amounts of missing data has not previously been infilled or disaggregated due to no suitable station within closest 15. Used 026026, 026025, 026016 and 026002 to infill/disaggregate. Missing part or all of 1923, 1924, 1927, 1928, 1930, 1931, 1946 and 1-2mths from 1932, 1934, 1951, 1996, 1999, 2002.
026007	Frances	1896-2003	Current	2.3	0.1	Missing 1mth data from 1919.
026009	Kalangadoo	1915-2003	Current	9.0	0.7	Missing 7mths data from 1915.
026010	Kingston (Keilira Station)	1913-2003	Current	0.1	10.5	Missing large parts of 1913, 1965, 1998 and all or part of years 1929-1934, 1938-1942. Only site in local area and between 1943-2003 there is little missing data.
026012	Kingston SE	1896-2003	Current	7.1	0.4	Missing large part of 1998.
026014	Lake Leake (Yurnga)	1898-2003	Current	1.5	4.2	Missing all or part of years from 1914-1917 and 3 to 5 months from 1899, 1935.

Table A1 continued…

Site Number	Site Name	Analysis Period	Operational Status	%Accumulated	%Missing	Notes
026015 / 026104	Naracoorte (Lochaber) / Naracoorte (View Bank)	1923-2003	Current	0.5	1.1	026015 (1923 to 30/11/2001), 026104 (1/12/2001 to 2003) ==> No overlap but use as one record.
026016	Lucindale Post Office	1896-2003	Current	3.0	1.3	Missing parts of 1956 and 2003, and 1mth from 1951, 1957, 1986, 1993 and 2002.
026017	Padthaway (Marcollat)	1935-2003	Current	0.2	0.6	Missing part of 1935, 1 mth from 1946.
026018	Millicent	1896-2003	Current	10.9	0.2	Missing 1mth of 1917, 1919. SW of region.
026023 / 026099	Naracoorte / Naracoorte Aerodrome	1896-2003	Current	0.3	0.4	026023 (1896 to 30/6/2001), 026099 (21/7/1999 to 2003) ==> Use 026099 once 026023 record finishes. Daily values in overlapping period: 026099=1.029*026023. Ave. diff. between values is 0.027 mm.
026025	Penola Post Office	1896-2003	Current	7.0	0.1	Missing 1mth from 1919, 1996.
026026	Robe	1896-2003	Current	1.1	0.0	No missing data. West of USE area.
026035	Noolook Well (Noolook Forest Reserve)	1954-2000	-	1.8	5.8	Missing most of 1954. Closed end of 2002 but missing 2001 and most of 2002 ==> only examined to 2000.
026037	Bordertown (Yacca Vale)	1959-2003	Current	0.1	1.0	Missing part of 1959, 1mth from 1998.
026049	Policemans Point	1968-2003	Current	0.7	12.8	Pluviograph station since 1972. Missing most of 1968, 1977-1979 and 1988, and up to 3mths from 1976, 1987, 1991 and 1994.
026053	Avenue (Sheraco)	1969-2000	-	0.8	15.8	Site closed mid 2001. Missing all or part of 1969, 1982, 1984-1988, 2001. Missing 1mth from 1998, 2000.
026054	Kingston (Mount Scott)	1969-2003	Current	0.1	0.7	Missing small part of 1969, 2002.

Table A1 continued…

Site Number	Site Name	Analysis Period	Operational Status	%Accumulated	%Missing	Notes
026057	Furner (Kookootonga)	1969-1999	-	0.5	0.2	Closed at beginning of 2000. Missing 2mths from 1969.
026058	Bordertown (Beeama Section 48)	1969-2003	Current	0.3	0.7	Missing 2mths from 1969, 1mth from 1998.
026062	Naraccorte (Bettws-Y-Coed)	1969-2003	Current	0.3	0.0	No missing data.
026065	Salt Creek (Pitlochry Outstation 1)	1968-2003	Current	3.5	10.1	Missing large portions of 1968, 1969, 1975 and 1976, and up to 3mths from 1973, 1974, 1977, 1978, 1986 and 1999.
026069	Lucindale (Greenvale)	1969-2003	Current	0.1	0.5	Missing 3mths from 1969.
026071	Greenways Post Office	1970-2003	Current	0.1	11.1	Missing all 1998-1999, most of 1970, 1997, & up to 2mths from 1993-1995, 2000, 2002.
026075	Wrattonbully (Joeville)	1967-2003	Current	0.1	0.0	No missing and little accumulated data.
026076	Tarpeena (Pleasant Park)	1973-1999	-	1.9	1.6	Site closed at beginning of 2000.
026078	Avenue (Downer)	1973-2003	Current	0.7	1.1	Missing 1mth from 1986, 3mths from 1987.
026079	Naracoorte (Koppamurra)	1972-2003	-	0.7	19.2	Closed mid 2003. Missing all of 1993-1996 and most of 1972 and 1992. Missing up to 3mths from 1997-1999 and 2003.
026082	Struan	1974-2003	Current	*****	*****	Pluviograph station since 1974.
026083	Salt Creek (Pitlochry Homestead)	1975-2003	Current	1.3	1.1	Missing 1mth from 1993, 1995, 1998, 1999.
026084	Salt Creek (Kendal Station)	1974-1999	-	0.3	3.4	Site closed at beginning of 2000. Missing majority of 1974 and 3mths from 1998. May be useful for northern drain catchments - is the only site within the area.
026087	Penola (Bendleby)	1979-1999	-	0.8	3.5	Site closed at beginning of 2000. Missing majority of 1979 and 1mth from 1998.

Table A1 continued…

Site Number	Site Name	Analysis Period	Operational Status	%Accumulated	%Missing	Notes
026088	Willalooka (Yardookra)	1979-2003	Current	2.4	19.4	Missing all data from 1994-1995, most of 1979, 1993, 1996, and 3mths from 1998.
026089	Padthaway	1977-2001	-	-	-	Apparent errors in Hydsys accumulated data ==> Not examined.
026091	Coonawarra	1985-2003	Current	0.4	4.7	Missing large portion of 1985 and up to 1mth from 1994, 2000.
026094	Robe (Woolmit)	1980-2002	-	0.9	0.4	Closed at beginning of 2003. Missing 1mth from 1982.
078025	Lillimur Estate	1896-2000	-	0.1	6.5	Closed at beginning of 2000. Missing most or all of 1958, 1959 and 2-3mths from 1912, 1913, 1957, 1960, 1999.
078031	Nhill	1896-2003	Current	0.1	2.4	Missing most of 1949 and up to 1mth from 1961, 1994, 1995. East of USE area.
078040	Nhill (Woorak)	1896-2003	Current	< 0.1	2.0	Missing most of 1930, a large amount from 1896 and up to 3mths from 1924, 1929, 1931,1983, 1954, 2003. East of USE area.
078043	Yanac North	1896-2003	Current	0.1	1.5	Missing part to all of 1896, 1897, and 1mth from 1999. East of USE area.
078078	Kaniva	1896-2003	Current	0.6	1.5	Missing 5mths from 1913 and 1mth from 1912, 1919, 1920, 1993.
079008	Clear Lake (Marlbro)	1904-2003	Current	0.1	0.2	Missing 1mth from 1925, 1960. East of USE area.
079011	Edenhope Post Office	1896-2003	Current	3.2	5.0	Missing part of 1955-1957, 1999, 2000, and 1-3mths from 1900, 1902, 1941, 1942, 1946, 1948, 1977, 1979, 1997, 1998.

Table A1 continued…

Site Number	Site Name	Analysis Period	Operational Status	%Accumulated	%Missing	Notes
079017	Goroke Post Office	1906-2003	Current	3.5	5.0	Missing 2-12mths over years within period 1919-1928. Missing 5mths from 1912 and 1-2mths from 1906, 1907, 1940, 1999, 2001-2003.
079018	Goroke (Kangawall)	1901-2003	Current	0.2	3.4	Missing part to all of 1999-2003, and 1mth from 1915.
079021	Harrow Post Office	1909-2003	Current	2.0	2.7	Missing 6-9 months from 1912, 1914, 1998, 1999 and 1-3mths from 1925, 1995, 1996. East of USE area.
079022	Harrow (Pine Hills)	1896-2003	Current	1.1	12.1	Missing most to all of 1899, 1980, 1982, 1991-2003. East of USE area.
079025	Karnak (Rosedale)	1896-2003	Current	< 0.1	4.0	Missing all of 1989, 2000-2002 and 1-2mths from 1980, 1994, 1999.
079071	Apsley Post Office	1954-2003	Current	5.2	13.9	Missing 1956-1960, most of 1995, 1999, and 1-3mths from 1955, 1975, 1996, 1997, 2001, 2003.
079083	Benayeo	1973-2003	Current	0.2	0.0	No missing & very little accumulated data.
090020	Casterton (Warrock)	1896-2003	Current	0.1	0.2	Missing 2mths from 1973.
090033	Dergholm (Hillgrove)	1900-2003	Current	0.8	1.4	Missing 1-2mths from 1901, 1905, 1912-1914, and all of 1966.
090034	Dergholm (Dorodong)	1944-2003	-	0.3	0.8	Closed end of 2003. Missing up to 2mths from 1977, 1996, 1999 and 2003. Could be used to model area around Dorodong Creek if required.

Table A2 Rainfall Stations with Records of Limited Use.

Site Number	Site Name	Data Availability	Notes
025510	Mundulla	01/1887 - 04/1962	Close to sites 025550, 025561.
025516	Keith (Narree Downs)	08/1949 - 05/1992	Close to site 025541. Not required.
025521	Dandaraga	07/1926 - 06/1941	North of USE area.
025522	Kongal	05/1884 - 07/1928	Time period not useful but may be used to translate site 025519.
025524	Bordertown (Kangaringa)	01/1950 - 08/1998	North-east of USE area.
025528	Bordertown (Kooroon)	01/1958 - 04/1964	North-east of USE area.
025531	Woods Well	02/1941 - 02/1970	North of USE area in Coorong.
025533	Cannawigara	02/1882 - 06/1893	Time period short and not useful.
025535	Nalang	12/1905 - 12/1966	Close to sites 025550, 025561.
025536	Bordertown	11/1967 - 01/1976	Close to sites 025501, 025560.
025537	Salt Creek (Sannon Downs)	11/1968 - 11/1970	DWLBC pluviograph nearby.
025544	Bordertown (Woolmit)	02/1969 - 06/1984	Sites 025518, 025525 and 025501 encircle site.
025545	Bordertown Section 75	02/1969 - 01/1980	North-east of USE area.
025549	Keith E&WS	05/1972 - 08/1989	Close to 025507.
025552	Coombe	01/1974 - 03/1984	North of USE area.
025553	Bordertown (Cuppa-Cup)	05/1989 - 07/1999	Close to sites 025501, 025560.
026001	Bonley	06/1923 - 12/1973	Close to site 026025.
026002	Bool Lagoon	08/1908 - 12/1955	May be possible to extend this site using 026003 to 1968, the time that site 026092 opened.
026004	Cape Jaffa (Jaffa Hills)	07/1934 - 07/1982	Outside USE boundary and location not required.
026006	Penola (Comaum Park)	01/1911 - 7/1989	May be used to translate 026091, 026075 or 026025 if required.
026011	Keppoch	01/1937 - 07/1954	May be used to translate site 026007.

Table A2 continued…

Site Number	Site Name	Data Availability	Notes
026013	Kybybolite Research Station	12/1906 - 05/1995	Good record but close to site 079093.
026019	Mount Burr Forest Reserve	03/1924 - 12/1994	South-west of USE area.
026022	Mount McIntyre	05/1898 - 12/1968	Close to site 026009.
026024	Naracoorte Cave Range	07/1887 - 12/1977	Close to site 026023.
026028	Frances (Waverley)	11/1934 - 05/1968	Close to site 026007.
026029	Kercoonda	03/1956 - 11/1965	May be used to translate site 026017.
026030	Kingston (Woolmit)	01/1901 - 12/1979	Outside USE boundary and location not required.
026032	Taratap	05/1914 - 10/1935	Time period not useful although period from 1915-1928 could be used to determine relationship with site 026010 and allow translation of this site.
026033	Cantara	01/1892 - 05/1927	Time period not useful.
026034	Comaum Forest Reserve	09/1954 - 09/1991	Close to site 026075 but could be used to extend this site if required.
026036	Penola State Forest Reserve	09/1954 - 06/1994	Could be used to translate sites 026025 or 026009 if required.
026038	Padthaway	04/1962 - 04/1979	Could be used as an extension for 026089 but this record has errors. May also be used to translate site 026017.
026040	Cromer	08/1898 - 12/1937	Time period not useful except to translate 026016 if modelling Drain K.
026042	Netley Park	01/1915 - 07/1924	Time period not useful.
026043	Tarloope	06/1913 – 02/1924	Time period not useful, except to translate site 026033 and/or 026075.
026045	Coonawarra	11/1966 - 01/1986	Close of 026091 and may be used to extend this site.
026046	Morambro Station	12/1886 - 12/1907	Time period short and not useful.

Table A2 continued…

Site Number	Site Name	Data Availability	Notes
026047	Glencoe Station	01/1882 - 05/1906	Time period short and not useful.
026051	Kingston (Centaninti)	11/1968 - 10/1979	May be used to determine relationship with site 026017 and allow translation of this site.
026052	Coorong (Cortina)	11/1968 - 06/1983	Close to site 026062.
026055	Frances (Karana Park)	01/1969 - 07/1979	May be used to translate site 026007.
026056	Naracoorte (Keppoch Park)	01/1969 - 04/1975	May be used to translate site 026015.
026059	Penold (Elad)	03/1969 - 02/2000	Close to site 026003.
026060	Glencoe	02/1969 - 02/1975	Close to site 026014 but may be used to translate this site if required.
026061	Penola (Narangga)	01/1969 - 06/1976	May be used to translate 026003 or 026014.
026063	Padthaway (Valley View Pastoral)	03/1969 - 08/1976	Short record not required.
026064	Tarpeena East	03/1969 - 07/1975	Short record not required. South-east of USE area.
026066	Willalooka Section	03/1969 - 11/1979	Close to site 026088.
026068	Killanoola	03/1969 - 06/1978	Short record but may be used to translate 026003.
026077	Penola (Windamere)	12/1972 - 06/1989	Close to site 026091.
026080	Millicent Section 28	05/1973 - 04/1976	Short record not useful. West of USE area.
026087	Penola (Bendleby)	05/1979 - 03/2000	Possible to extend this site using 026096 but close to site 026091.
026092	Bool Lagoon Game Reserve	06/1968 - 05/1998	May be possible to extend this site using 026075 to 2001, at which time site 026103 opened.
026093	Mount Burr Telecom	01/1967 - 05/1992	Close to site 026014.
026095	Cape Jaffa (Curley Hills)	06/1994 - current	Outside USE boundary and location not required. Other long term site 026012 more useful.
026098	Nangwarry DPI Depot	07/1994 - current	Close to site 026009. South-east of USE area.

Table A2 continued…

Site Number	Site Name	Data Availability	Notes
078001	Telopea Downs (Blue Hills)	06/2003 - current	Short record not useful. North of USE area.
078008	Diapur	04/1907 - 12/1981	Close to site 078078.
078023	Lawloit	09/1902 - 06/1974	Close to site 078078.
078024	Lecor View Point	05/1912 - 11/1954	Time period not useful. Close to sites 078078 and 025519.
078025	Lillimur Estate	08/1884 - 01/2000	Close to site 078078.
078026	Lillimur (Kildonan)	07/1914 - 11/1955	Time period not useful. Close to sites 078078 and 025519.
078034	Serviceton	06/1889 - 09/1971	Close to site 025519.
078047	Nateyip	03/1954 - 02/1965	Short time period not useful.
078052	Broughton	07/1902 - 08/1915	Time period not useful but could be used to translate site 078078 if required.
078060	Miram (Lawbit West)	01/1907 - 02/1931	Time period not useful.
078065	Tallageira	11/1904 - 03/1917	Time period not useful.
078071	Telopea Downs	01/1958 - 11/1972	No missing record but north of USE area.
078074	Yanipy	01/1969 - 12/1989	Close to site 078078.
078075	Serviceton North	02/1966 - 09/1998	Could be used to translate sites 078078 or 025518 if required. North of USE area.
078081	Blackheath	01/1887 - 11/1901	Time period not useful.
079001	Apsley	12/1883 - 12/1947	Could be used to translate sites 079011 or 026023 if required.
079005	Bringalbert (Apsley)	02/1936 - 02/1952	Could be used to translate 079018 if required.
079007	Charam	02/1903 - 12/1983	No missing record but close to long-term site 079011. Could be extended if required.

Table A2 continued…

Site Number	Site Name	Data Availability	Notes
079012	Elderslie	05/1925 - 10/1970	Close to site 026075 and could be used to extend this site back to 1925 if required.
079030	Minimay (Booroopki)	02/1884 - 02/1956	May be used to translate 026007 into Victorian catchment.
079058	Goroke (Rose Banks)	11/1903 - 12/1949	Time period not useful. East of USE area.
079065	Minimay (Neuarpur Station)	09/1889 - 02/1929	Time period not useful. Close to site 026007.
079094	Neuarpurr (Brippick)	02/1881 - 10/1892	Short time period not useful. Close to site 026007.
079095	Neuarpurr	09/1903 - 05/1924	Time period not useful. Close to site 026007.
079104	Harrow (Kadnook)	02/1991 - 08/1998	South-east of USE area.
090018	Casterton Post Office	08/1899 - 03/1957	Time period not useful. South-east of USE area.
090019	Casterton (Roseneath)	09/1891 - 06/1996	Close to 090033. Missing large amounts of data between 1973-1996.
090066	Poolaijelo	01/1903 - 10/1954	Time period not useful. Could be used to translate site 026025.
090091	Chetwynd	06/1889 - 07/1980	Not required. East of USE area.
090107	Casterton (Nangeela)	08/1884 - 09/1920	Time period not useful. South-east of USE area.
090109	Chetwynd (Woodacres)	09/1908 - 08/1917	Time period not useful.
090164	Poolaijelo (Glenara)	05/1974 - 09/1986	Close to site 026075.
090177	Poolaijelo (Dorothy Downs)	01/1990 - 01/2001	South-east of USE area.

Table A3   Rainfall Stations with Potentially Useful Short Term Records.

Site Number	Site Name	Data Availability	Notes
025557	Keith (Munkora)	07/2001 - current	Close to 025507. Potentially useful if this site is ever closed.
026096	Penola (Andabago)	08/1991 - current	Close to sites 026025 & 026091 but could be used if more localised information around drain B is required.
026097	Penola Caves Range	06/1992 - current	Close to site 026025 but could be used if more localised information is required around the Grey-Monbulla watercourse and/or drain.
026100	Padthaway South	05/2000 - current	Pluviograph site. Daily record has no missing data.
026103	Bool Lagoon (Locksley Farm)	01/2001 - current	May provide local information at Bool Lagoon.
026105	Robe Airfield	07/2003 - current	Site 026026 has complete record nearby and location is not required.
026107	Willalloka (Nioka)	07/2003 - current	Close to station 026088.
079107	Ozenkadnook (Bookoopki)	01/1998 - current	At upper end of Naracoorte Creek catchment.
090178	Langkoop (Springdale)	03/1990 - current	Just over border on Mosquito Creek and close to 026075.
A2390567	Fairview Drain @ The Pitts	06/1998 - current	Pluviograph site.
AW426646	Coorong AWS @ Salt Creek	06/2001 - current	Pluviograph site.

Correlation Analysis

The USE region was arbitrarily divided into a series of sub-regions with stations chosen within each area with generally longer records that were identified as potentially the most useful for infilling of missing data, homogeneity analysis and translation of data between sub-catchments. Figure A1 shows these regions and the rainfall stations that were used in this analysis. Correlation between monthly and daily rainfall totals was determined between the selected stations and these are presented in Tables A4 to A8. Good (reasonable) correlations between sites was assumed if the correlation value for monthly data was greater than 0.90 (0.85) and for daily data if it was greater than 0.70 (0.65). The results presented indicate generally high correlation between monthly rainfall values at each pair of stations. The correlations between daily rainfall values shown are also relatively high. Lower correlations on a daily basis are to be expected due to localised rainfall events.

Sub-Region One: This north-west area of the USE region extends southward from Salt Creek and Keith to the east-west aligned section of the Fairview and Blackford drains. It encompasses the northern outlet drains, Tilley Swamp Watercourse and drain, Henry Creek and part of the West Avenue watercourse and wetlands, Northern Bakers Range Watercourse and wetlands, and the northern part of the Marcollat Watercourse.

Table A4 Sub-Region One: Rainfall Correlations.

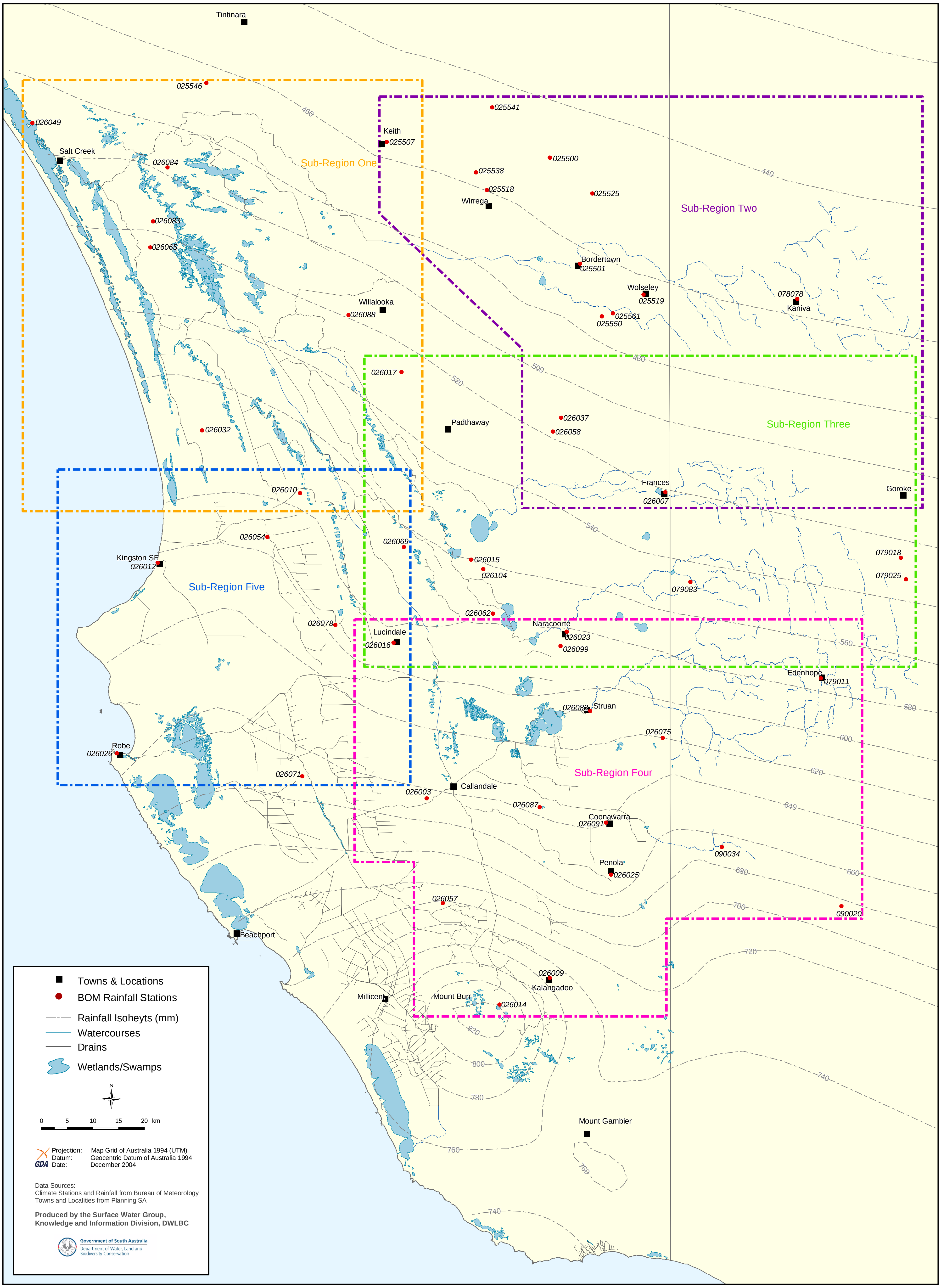
Monthly Rainfall									
	025507	*025546*	*026010*	*026017*	*026049*	*026065*	*026083*	*026084*	*026088*
025507	1								
025546	0.917	1							
026010	0.857	0.888	1						
026017	0.897	0.909	0.912	1					
026049	0.852	0.911	0.874	0.869	1				
026065	0.861	0.911	0.903	0.897	0.907	1			
026083	0.894	0.931	0.917	0.919	0.929	0.968	1		
026084	0.911	0.946	0.904	0.914	0.920	0.930	0.960	1	
026088	0.921	0.913	0.928	0.966	0.898	0.913	0.928	0.921	1
Daily Rainfall									
	025507	*025546*	*026010*	*026017*	*026049*	*026065*	*026083*	*026084*	*026088*
025507	1								
025546	0.807	1							
026010	0.630	0.645	1						
026017	0.668	0.745	0.630	1					
026049	0.722	0.767	0.654	0.712	1				
026065	0.695	0.704	0.643	0.715	0.750	1			
026083	0.764	0.774	0.667	0.764	0.798	0.827	1		
026084	0.760	0.780	0.609	0.720	0.736	0.710	0.805	1	
026088	0.765	0.707	0.630	0.836	0.691	0.684	0.728	0.730	1

Sub-Region Two: This north-east area of the USE region extends eastwards from Keith to Kaniva (Victoria) and southwards to Frances and Goroke. It encompasses the Tatiara and Nalang Creek catchments as well as part of the Morambro Creek catchment.

Table A5 Sub-Region Two: Rainfall Correlations.

Monthly Rainfall												
	025500	*025501*	*025507*	*025518*	*025519*	*025525*	*025538*	*025541*	*025550*	*026007*	*026037*	*078078*
025500	1											
025501	0.940	1										
025507	0.926	0.904	1									
025518	0.943	0.923	0.927	1								
025519	0.936	0.948	0.902	0.917	1							
025525	0.972	0.944	0.924	0.937	0.944	1						
025538	0.947	0.932	0.956	0.980	0.927	0.943	1					
025541	0.964	0.929	0.936	0.927	0.925	0.949	0.943	1				
025550	0.929	0.937	0.923	0.943	0.962	0.929	0.943	0.922	1			
026007	0.886	0.890	0.880	0.879	0.905	0.891	0.905	0.874	0.927	1		
026037	0.890	0.892	0.899	0.913	0.900	0.884	0.909	0.885	0.928	0.944	1	
078078	0.916	0.901	0.869	0.881	0.926	0.922	0.885	0.905	0.906	0.871	0.863	1
Daily Rainfall												
	025500	*025501*	*025507*	*025518*	*025519*	*025525*	*025538*	*025541*	*025550*	*026007*	*026037*	*078078*
025500	1											
025501	0.818	1										
025507	0.813	0.757	1									
025518	0.784	0.765	0.766	1								
025519	0.797	0.828	0.759	0.721	1							
025525	0.875	0.827	0.800	0.801	0.817	1						
025538	0.828	0.797	0.868	0.880	0.785	0.840	1					
025541	0.854	0.785	0.845	0.812	0.783	0.843	0.857	1				
025550	0.782	0.833	0.790	0.793	0.871	0.833	0.812	0.793	1			
026007	0.701	0.725	0.677	0.653	0.731	0.740	0.752	0.733	0.810	1		
026037	0.746	0.767	0.778	0.757	0.762	0.761	0.779	0.743	0.809	0.833	1	
078078	0.761	0.729	0.665	0.672	0.731	0.821	0.745	0.758	0.792	0.670	0.723	1

Figure A1 Rainfall Station Correlation Sub-Regions Across South Eastern South Australia and Western Victoria.



Sub-Region Three: This central area of the USE region extends from Padthaway and Lucindale in the west, to Goroke (Victoria) in the east. It encompasses the Morambro and Naracoorte Creek catchments, Drain E catchments and wetlands, most of the Marcollat watercourse, part of the Bakers Range watercourse, the eastern part of the Fairview Drain and the Tresant Drain.

Table A6 Sub-Region Three: Rainfall Correlations.

Monthly Rainfall

	026007	*026015*	*026016*	*026017*	*026023*	*026037*	*026058*	*026062*	*026069*	*079018*	*079025*	*079083*
026007	1											
026015	0.910	1										
026016	0.872	0.939	1									
026017	0.904	0.926	0.906	1								
026023	0.913	0.944	0.930	0.906	1							
026037	0.944	0.892	0.871	0.919	0.894	1						
026058	0.952	0.919	0.886	0.934	0.914	0.967	1					
026062	0.904	0.965	0.947	0.913	0.948	0.879	0.904	1				
026069	0.893	0.964	0.955	0.923	0.931	0.872	0.901	0.949	1			
079018	0.903	0.846	0.831	0.847	0.869	0.889	0.883	0.838	0.833	1		
079025	0.907	0.847	0.833	0.844	0.874	0.881	0.883	0.836	0.829	0.967	1	
079083	0.919	0.890	0.860	0.878	0.908	0.895	0.908	0.879	0.868	0.892	0.885	1

Daily Rainfall

	026007	*026015*	*026016*	*026017*	*026023*	*026037*	*026058*	*026062*	*026069*	*079018*	*079025*	*079083*
026007	1											
026015	0.740	1										
026016	0.682	0.833	1									
026017	0.642	0.709	0.663	1								
026023	0.765	0.821	0.790	0.644	1							
026037	0.833	0.785	0.745	0.809	0.769	1						
026058	0.828	0.794	0.748	0.822	0.795	0.870	1					
026062	0.759	0.877	0.845	0.766	0.865	0.754	0.762	1				
026069	0.742	0.884	0.847	0.793	0.834	0.753	0.762	0.846	1			
079018	0.646	0.685	0.577	0.612	0.619	0.741	0.716	0.657	0.641	1		
079025	0.726	0.701	0.642	0.607	0.691	0.736	0.703	0.657	0.645	0.794	1	
079083	0.703	0.667	0.642	0.645	0.702	0.666	0.658	0.650	0.624	0.668	0.665	1

Sub-Region Four: This south-east area of the USE region extends southwards from Lucindale, Naracoorte and Edenhope (Victoria) to Mount Burr and Kalangadoo. It encompasses the Mosquito and Glen Roy Creek catchments, most of Drain M and southerly adjoining drains and part of the Bakers Range Watercourse and drain north of Callendale.

Table A7 Sub-Region Four: Rainfall Correlations.

Monthly Rainfall

	026003	*026009*	*026014*	*026016*	*026023*	*026025*	*026057*	*026075*	*026087*	*079011*	*090020*	*090034*
026003	1											
026009	0.920	1										
026014	0.924	0.958	1									
026016	0.929	0.910	0.903	1								
026023	0.903	0.894	0.877	0.930	1							
026025	0.919	0.940	0.930	0.919	0.917	1						
026057	0.950	0.964	0.963	0.923	0.899	0.952	1					
026075	0.912	0.907	0.901	0.924	0.945	0.935	0.914	1				
026087	0.947	0.943	0.935	0.940	0.937	0.971	0.942	0.940	1			
079011	0.850	0.865	0.850	0.875	0.911	0.894	0.854	0.913	0.905	1		
090020	0.873	0.900	0.884	0.879	0.897	0.928	0.890	0.911	0.928	0.908	1	
090034	0.905	0.917	0.907	0.906	0.920	0.948	0.922	0.942	0.940	0.901	0.933	1

Daily Rainfall

	026003	*026009*	*026014*	*026016*	*026023*	*026025*	*026057*	*026075*	*026087*	*079011*	*090020*	*090034*
026003	1											
026009	0.666	1										
026014	0.711	0.850	1									
026016	0.709	0.739	0.734	1								
026023	0.645	0.720	0.691	0.790	1							
026025	0.695	0.819	0.770	0.783	0.760	1						
026057	0.749	0.782	0.793	0.711	0.695	0.771	1					
026075	0.728	0.715	0.738	0.776	0.842	0.783	0.694	1				
026087	0.814	0.840	0.799	0.823	0.827	0.890	0.774	0.820	1			
079011	0.551	0.641	0.621	0.668	0.731	0.682	0.552	0.699	0.644	1		
090020	0.624	0.713	0.670	0.641	0.664	0.696	0.643	0.762	0.769	0.661	1	
090034	0.638	0.711	0.716	0.712	0.728	0.779	0.687	0.800	0.780	0.676	0.780	1

Sub-Region Five: This south-west area of the USE region extends from the southern end of the West Avenue Watercourse to Robe in the south and Lucindale in the east. It includes Blackford Drain, Fairview Drain, part of the Bakers Range Watercourse, Avenue Watercourse and the Drain K region.

Table A8 Sub-Region Five: Rainfall Correlations.

Monthly Rainfall								
	026010	*026012*	*026016*	*026026*	*026054*	*026069*	*026071*	*026078*
026010	1							
026012	0.919	1						
026016	0.943	0.919	1					
026026	0.880	0.911	0.883	1				
026054	0.956	0.923	0.951	0.882	1			
026069	0.947	0.893	0.955	0.870	0.941	1		
026071	0.903	0.917	0.924	0.929	0.907	0.900	1	
026078	0.949	0.924	0.968	0.901	0.952	0.943	0.926	1
Daily Rainfall								
026010	1							
026012	0.696	1						
026016	0.737	0.755	1					
026026	0.641	0.753	0.709	1				
026054	0.770	0.745	0.833	0.722	1			
026069	0.744	0.695	0.847	0.693	0.809	1		
026071	0.667	0.742	0.794	0.825	0.760	0.738	1	
026078	0.682	0.713	0.832	0.701	0.781	0.781	0.740	1

Accumulated Data

Accumulated data occurs when a value has not been recorded on a particular day(s) but the cumulative total has been recorded on a subsequent day. These records may be disaggregated over the total number of missing days. SKM (2000) disaggregated the rainfall data at the stations used for this study for the period up to 1998 using the method described in Porter and Ladson (1993). This method was also used to disaggregate the data within the period 1999-2003 and if required, will be used for the future disaggregation of rainfall data as it becomes available.

The method assumes that the influence of the rainfall at nearby stations to the station where accumulated data is to be disaggregated is inversely proportional to their distance from the station. Therefore, if station S has rainfall accumulated over m days, and complete data is available from n nearby rainfall stations, the rainfall (R) on day j (where $j = 1, \cdots, m$) at station S is given by:

$$R_{jS} = \frac{\sum_{j=1}^{m} R_{jS} \cdot \sum_{k=1}^{n} \{P_{jk} / d_k\}}{\sum_{k=1}^{n} \{1 / d_k\}} \qquad \text{(A.1)}$$

where:

$\sum_{j=1}^{m} P_{jS}$ = total rainfall accumulated over m days at station S;

d_k = distance between station S and station k (where $k = 1, \cdots, n$); and

P_{jk} = proportion of rainfall that fell on day j at station k.

Using a number of nearby gauges reduces the uncertainty from using data from a single station. For this study, the closest 15 rainfall stations to the station of interest were examined. In each case, data was available from at least one of these stations. If this had not been the case, additional stations could be considered or the data distributed uniformly over the period of accumulation. If the latter method is used and the data is used to calibrate a rainfall-runoff model, comparisons between the observed and modelled streamflow hydrograph resulting from that period of rainfall should be viewed with caution, particularly if the accumulated rainfall volume is large.

Missing Data

Data may be completely missing from a record due to a number of reasons including recording errors, the temporary closing of the station or station relocation. SKM (2000) infilled missing data at stations used for this study for the period up to 1998 using data from a nearby station. The nearby station was chosen as the one with the highest correlation between daily values that had data concurrent with the missing period. To infill the missing period, the daily rainfall value at the nearby station was then adjusted by the ratio of the concurrent mean annual rainfalls of the two stations.

This method may also use more than one nearby station and is referred to as the *normal-ratio method* (McCuen, 1998). If station S has missing data and complete data is available from n nearby rainfall stations, the rainfall (R) at station S is given by (McCuen, 1998):

$$R_S = \sum_{k=1}^{n} \omega_k R_k \tag{A.2}$$

where:

$\omega_k \quad = \dfrac{A_S}{nA_k}$;

$A_S \quad =$ average annual rainfall at station S; and

$A_k \quad =$ average annual rainfall at station k (where $k = 1, \cdots, n$).

This method is preferred if differences between the average annual rainfall at the stations are larger than 10%. Differences greater than 10% are observable between stations in the Upper River Torrens catchment. This method was also used to infill data at stations with missing data during the period 1999-2003, using a single nearby station. If required, this method will also be used to infill additional rainfall data as it becomes available.

Data Consistency

To identify the occurrence, magnitude and nature of trends within long-time series records the double mass curve technique (Grayson *et al*., 1996) is often used. It is constructed by plotting the accumulated values of two time series against each other. A break in slope or a gradual change in curvature or slope will reveal a change in the constant proportionality between the two sets of data. This indicates the presence of a trend such as in measured rainfall due to, for example, changes in instrument exposure at a station resulting from the growth of obstructive vegetation. The method is often used to establish the presence of such changes within rainfall records and adjustments can subsequently be made to affected data sets to ensure consistency of record.

The consistency of each long-term rainfall record used for hydrological modelling was confirmed by constructing a double mass curve using an average of the monthly rainfall from eight regional stations. Using an average of a number of records reduces inconsistencies that may be present in any one record.

Although there are no definite guidelines surrounding the magnitude at which a change in slope between two sets of data becomes significant, a change in slope of 5% or more is generally considered to indicate inconsistencies in the data. There are also a number of methods for determining the slope that should be used to correct the inconsistent sections. One alternative is to use the average slope of the entire period of record. However, if there are sudden, very large changes in slope (for example greater than 50%), the overall statistics of the data may not reflect the actual rainfall pattern at that station. In such cases it is preferable to adjust these sections or periods, to the section that is considered to best represent the rainfall pattern at that site. This is often the section with the longest period of consistent data.

This method was used here and the procedure is best explained with an example. Figure A9 shows the double mass curve for Wirrega (025518) against the average of five regional stations.

The process used is then described as follows:

- Changes in slope of the data were determined and eight sections s1 to s5 were defined at this station;
- The average slope within each section was calculated as shown in Table A9;
- The sections with the most consistent and similar slope are usually defined as the "homogeneous" section of the data. In this case it was decided to use section s5 as the homogenous section and adjust the remainder.
- The differences between the homogeneous section slope to those in sections s1 to s4 were determined as shown in Table A9;
- The differences between the slope of section s5 with those of s1 and s2 are significant and require correction. Although the differences between section s5 and the remaining sections are minor, these were adjusted as well to ensure a homogenous slope. The correction factors were defined as the ratio of the homogeneous slope to the ratio in each section s1 to s4 and are shown in Table A9.
- The factors were then used to adjust the inconsistent sections s1 to s4 and produce a consistent set of data for the entire period of record.

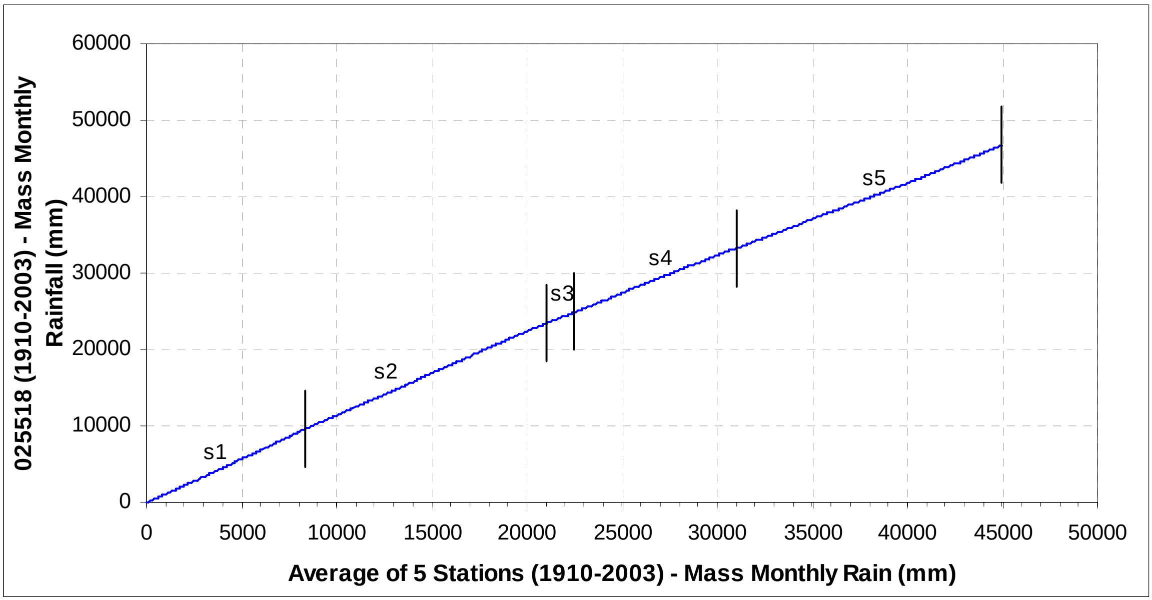


Figure A2 Double Mass Curve for Wirrega (025518) against an Average of Stations 025507, 025514, 025519, 026007 and 078078.

Table A9 Double Mass Analysis for Wirrega (025518).

Section	Section Slope	Difference in Slope to Homogeneous Section (%)[1]	Factor	Section Start	Section End
s1	1.154	19.403	0.837	01/1910	10/1927
s2	1.091	12.892	0.886	11/1927	09/1953
s3	0.969	0.301	0.997	10/1953	06/1956
s4	0.981	1.590	0.984	07/1956	02/1974
s5	0.966	-	1.000	03/1974	12/2003

[1] Homogenous section for station 025518 is the average slope of section s5.

The aforementioned procedure was carried out on data from each station. Table A10 presents the statistics from this analysis. The data for the stations examined here did not exhibit extremely large changes in slope for extended periods although there were a number of significant inconsistencies. However, the overall increase or reduction in rainfall was not generally significant.

Table A10 Double Mass Analysis for Long-Term Rainfall Stations.

Station	Period	No. Stations Used	Max. Slope Change (%)[1]	Change in Total Rainfall (mm)[2]	% Change	Average Annual Change (mm/yr)
025507	1906-2003	3	10.7	-1220	-3	-12
025518	1910-2003	5	11.0	-3276	-7	-35
025519	1896-2003	3	11.5	-2199	-4	-20
026003	1923-2003	8	11.6	623	1	8
026007	1896-2003	4	-10.9	67	<0.1	<1
026009	1915-2003	6	8.5	-24	<1	<1
026010	1913-2003	4	9.0	-1106	-2	-12
026012	1896-2003	4	-17.6	-2112	-3	-20
026014	1898-2003	4	-11.7	2451	3	23
026015/ 026104	1923-2003	6	2.5	not adjusted	-	-
026016	1896-2003	5	12.6	-1832	-3	-17
026017	1935-2003	8	5.8	not adjusted	-	-
026023/ 026099	1896-2003	3	14.5	-1511	-2	-14
026025	1896-2003	5	-8.0	751	1	7
078078	1896-2003	5	-10.0	598	1	6
079011	1896-2003	6	-18.6	14	<0.1	<1
079018	1901-2003	3	-11.1	-97	<1	1

[1]From homogenous section. This change in slope need not be over a large time period.

[2]Total over period examined.

Extension of Data Records

Many of the long-term daily rainfall stations have records beginning in 1896. The records from the remainder of these long-term stations were also extrapolated back to 1896 to create records of over 100 years across the region. This allows for the examination of extended wet and dry rainfall periods and the subsequent effect on runoff and water availability for wetlands and swamps. The extension was done by using proportional relationships with nearby sites at a monthly timescale. These stations and the average annual proportions are presented in Table A11.

Table A11 Extension of Rainfall Records.

Station	Existing Period	Station Used	Proportion	Monthly Correlation	Daily Correlation
025507	1906-2003	025519	0.741	0.902	0.759
025518	1910-2003	025519	0.749	0.917	0.721
026003	1923-2003	026016	0.783	0.929	0.709
026010	1913-2003	026016	0.751	0.943	0.737
026014	1898-2003	026018	0.962	0.955	0.866
026015 026104	1923-2003	026016	0.781	0.939	0.833
026017	1935-2003	026015	0.784	0.926	0.709
		026007	0.708	0.904	0.642
079018	1901-2003	079025	0.880	0.967	0.794

A.2 Data Analysis

Analysis of the rainfall data at each of the representative stations to be used in the hydrological model was undertaken at annual, monthly and decadal time scales.

Annual Rainfall

The results and discussion in Section 2.2.1 showed that there was generally no discernable trend or only a very slightly increasing or decreasing trends at the long-term representative stations with records greater than 80 years. In addition, these findings were reasonably consistent across the region. An additional selection of results from both long-term and short-term stations are presented here. Figures A3 to A10 present the annual rainfall totals and residual mass curves selected longer term stations and Figures A11 to A15 for shorter term stations. Each selection is ordered in terms of their position (north to south) across the region.

Long Term Stations

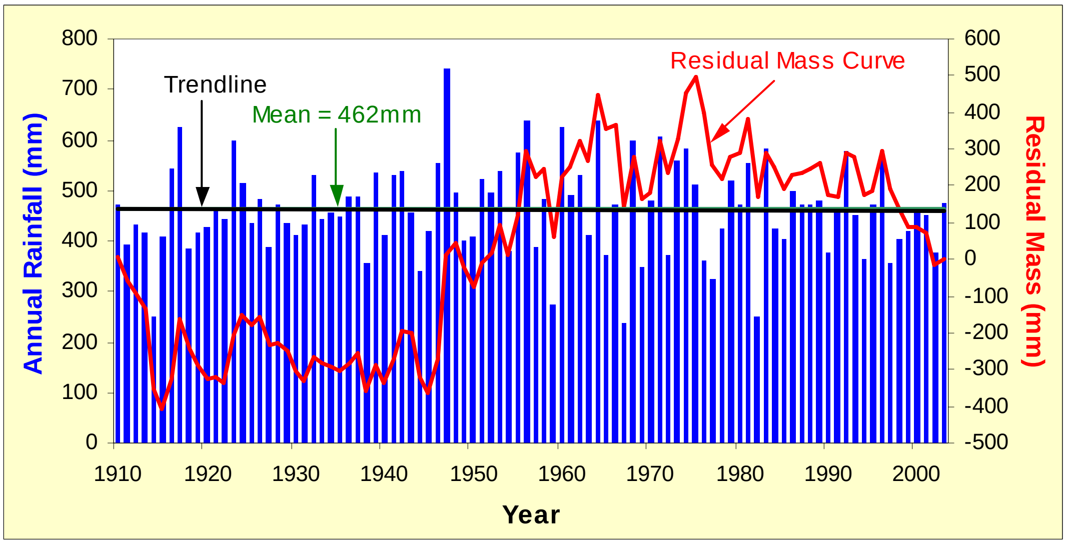


Figure A3 Annual Rainfall Totals and Variability at Wirrega (025518).

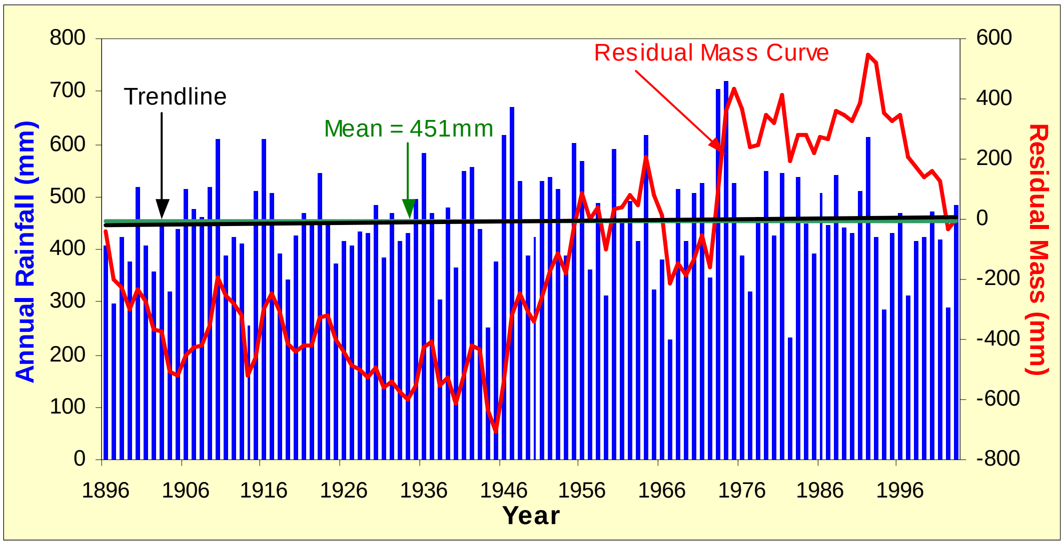


Figure A4 Annual Rainfall Totals and Variability at Kaniva (078078).

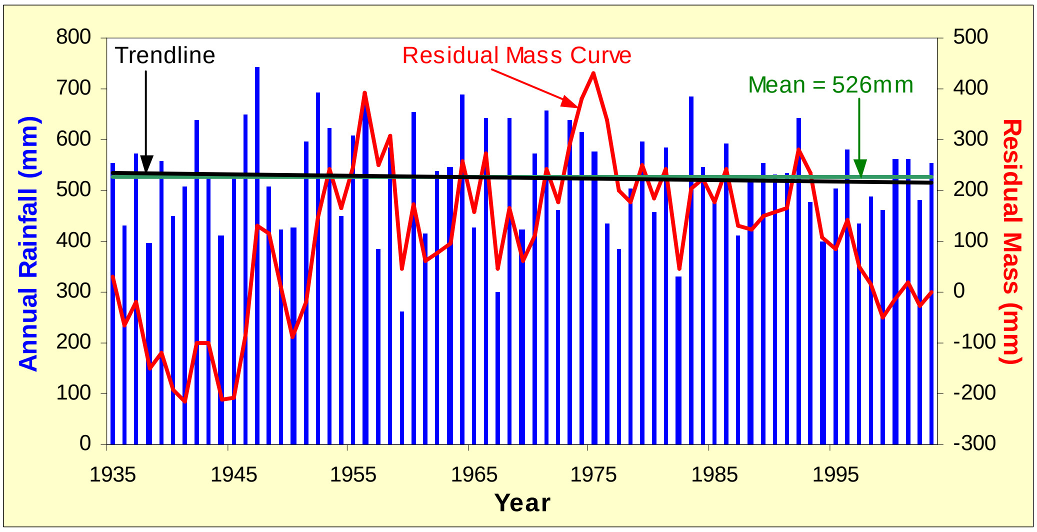


Figure A5 Annual Rainfall Totals and Variability at Padthaway (026017).

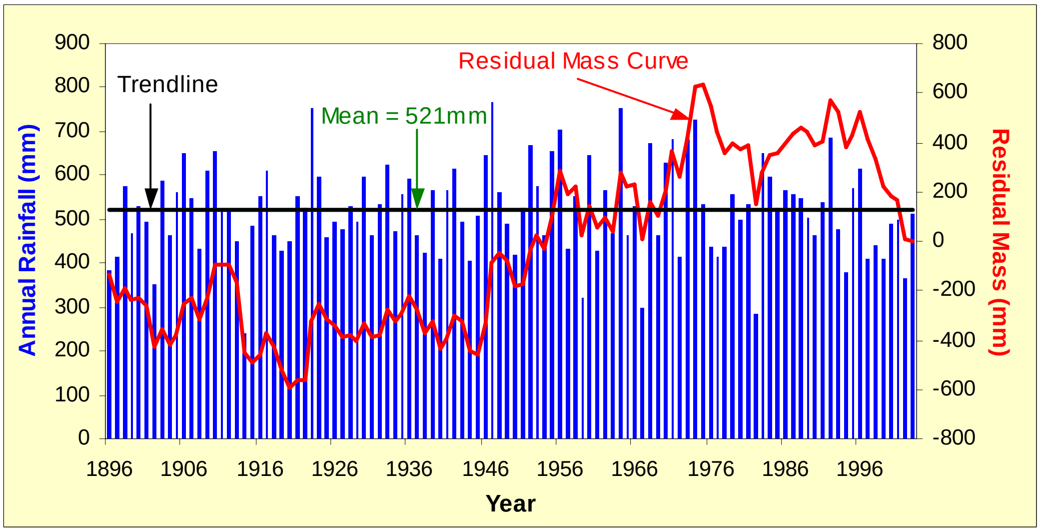


Figure A6 Annual Rainfall Totals and Variability at Frances (026007).

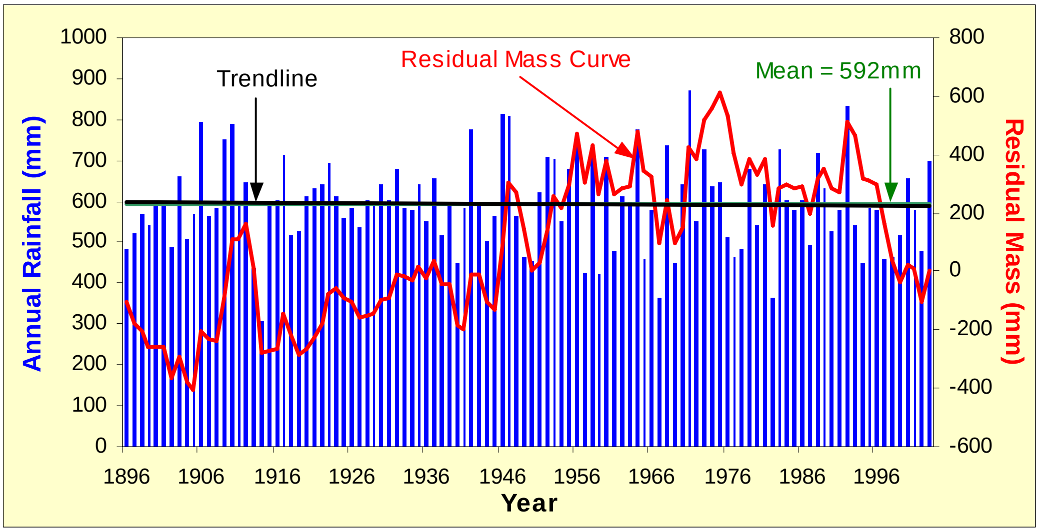


Figure A7 Annual Rainfall Totals and Variability at Lucindale (026016).

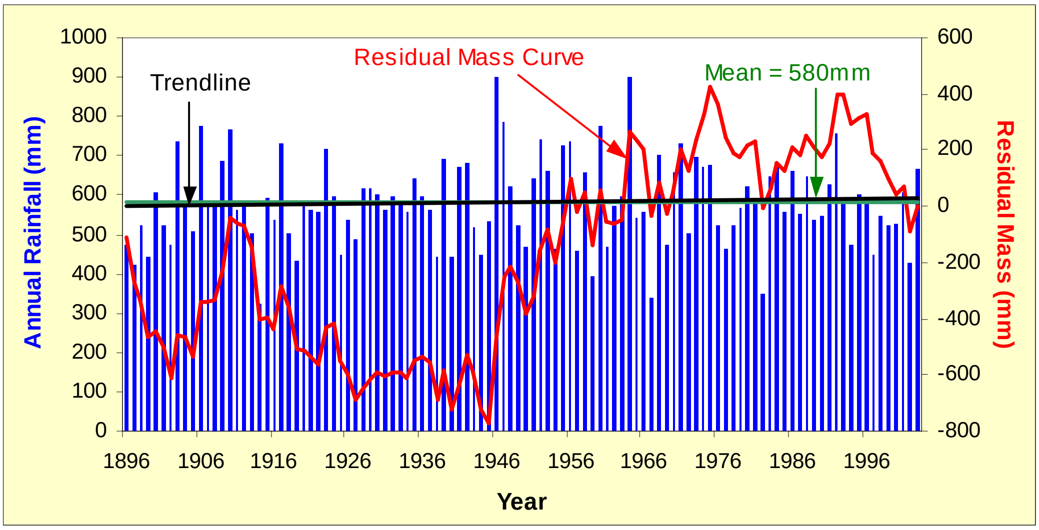


Figure A8 Annual Rainfall Totals and Variability at Edenhope (079011).

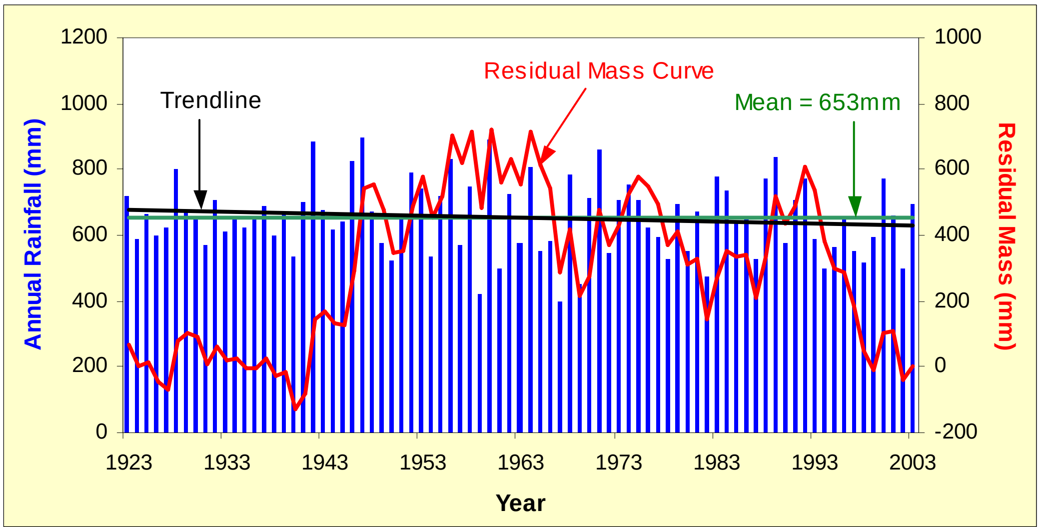


Figure A9 Annual Rainfall Totals and Variability at Callendale (026003).

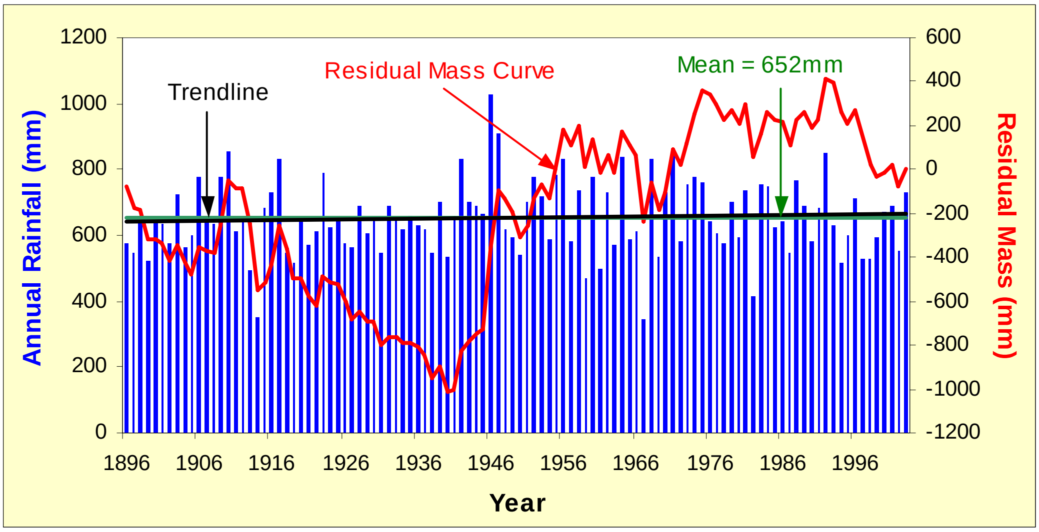


Figure A10 Annual Rainfall Totals and Variability at Penola (026025).

Short Term Stations

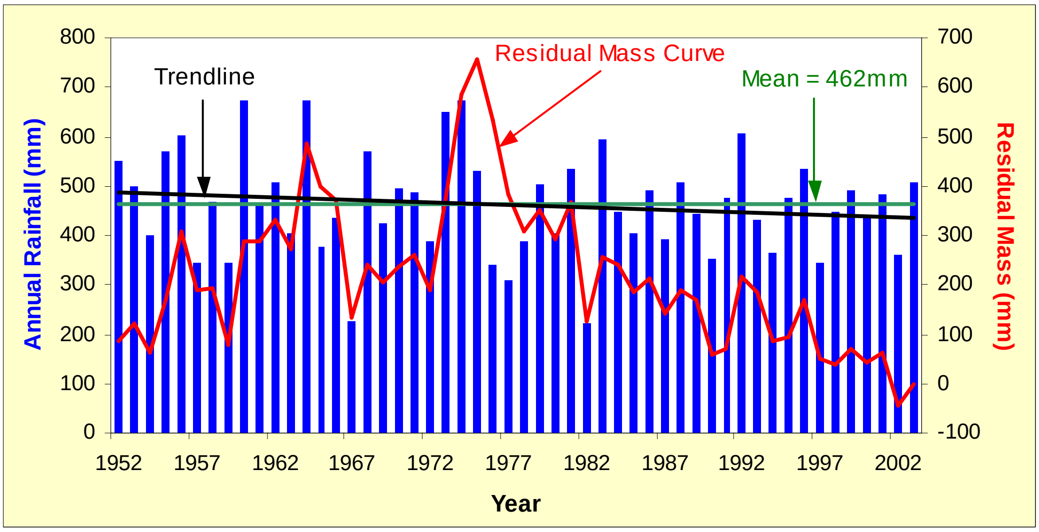


Figure A11 Annual Rainfall Totals and Variability at Bordertown - Inglewood (025525).

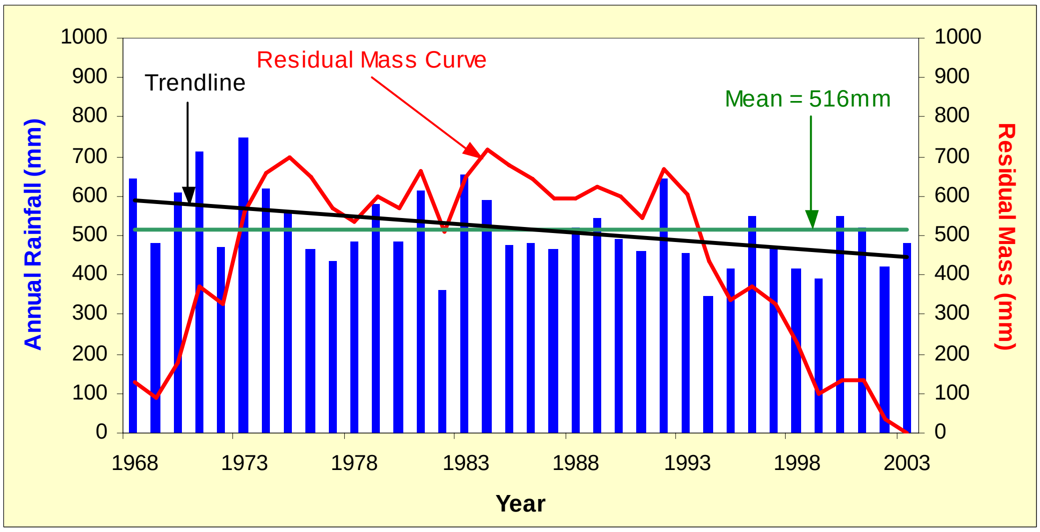


Figure A12 Annual Rainfall Totals and Variability at Salt Creek - Pitlochry 1 (026065).

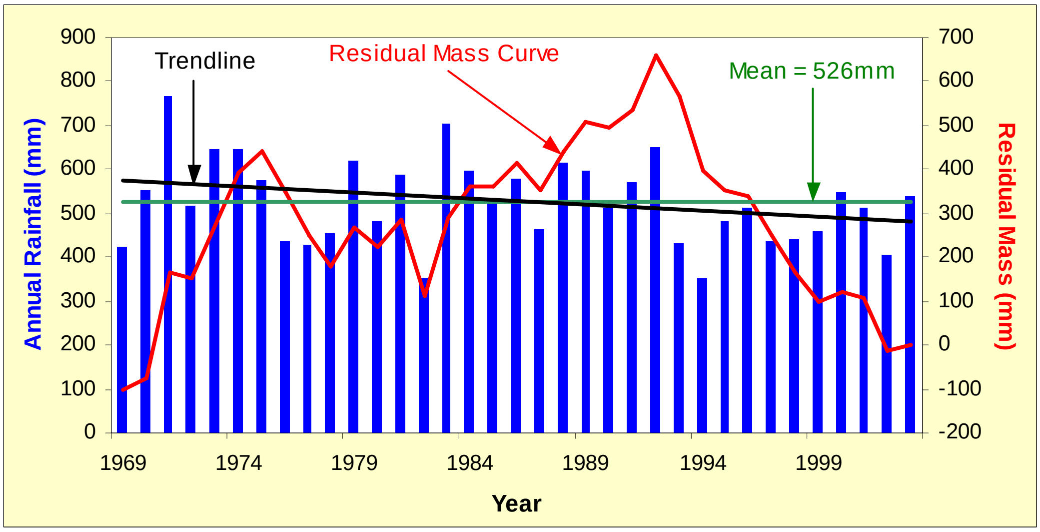


Figure A13 Annual Rainfall Totals and Variability at Lucindale - Greenvale (026069).

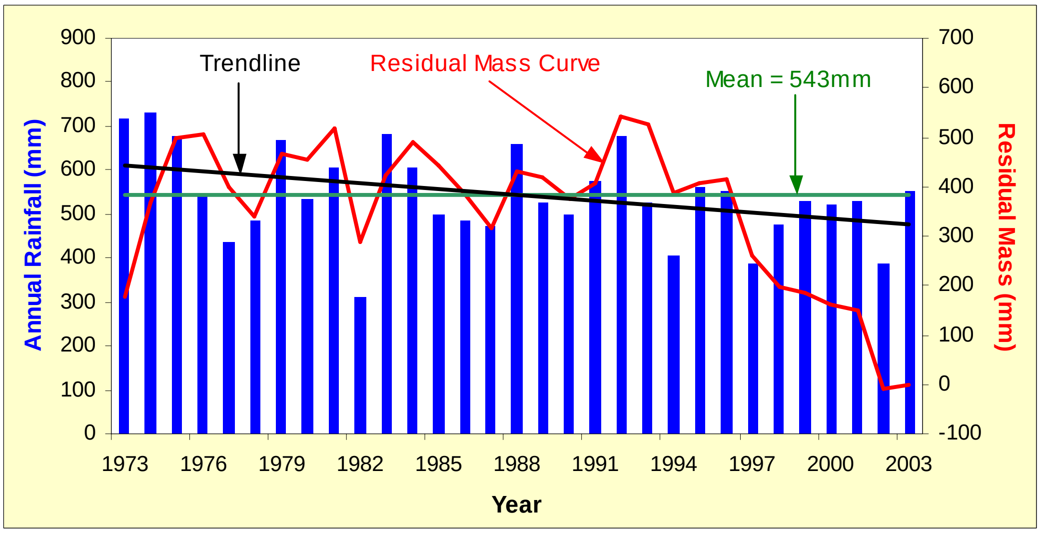


Figure A14 Annual Rainfall Totals and Variability at Benayeo (079083).

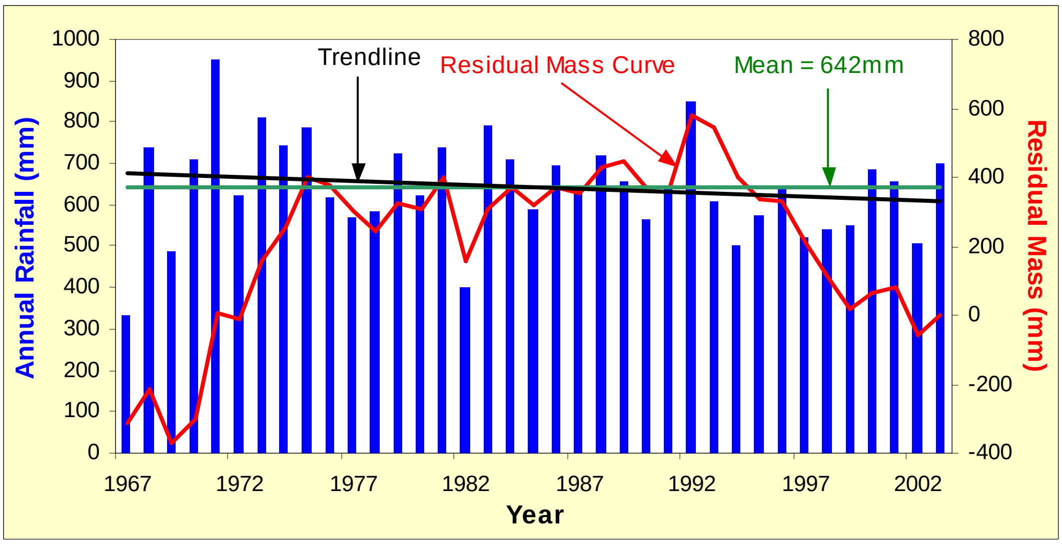


Figure A15 Annual Rainfall Totals and Variability at Wrattonbully (026075).

The mean, median, 10th percentile and 90th percentile of annual rainfall and the standard deviation of the mean annual rainfall for each representative station is shown in Table A12 below.

Table A12 Annual Statistics of Representative Rainfall Stations

Station	Mean (mm)	Median (mm)	Standard Deviation (mm)	10th Percentile (mm)	90th Percentile (mm)	No. Years
025507	456	452	88	349	570	98
025518	462	459	91	362	581	94
025519	456	453	93	333	570	108
025525	462	466	104	345	601	52
025546	489	469	81	402	593	35
025550 / 025561	480	470	95	363	612	31
026003	653	656	111	522	804	81
026007	522	524	102	412	655	108
026009	754	752	124	607	908	89
026010	566	571	109	439	683	91
026012	607	601	100	501	749	108
026014	860	840	142	698	1047	106
026015 / 026104	558	563	104	426	628	81
026016	593	587	107	460	728	108
026017	526	540	101	410	652	69
026023 / 026099	565	567	107	433	711	108
026025	652	640	112	532	787	108
026037	514	507	100	377	646	45
026054	615	600	100	500	714	35
026062	558	542	96	435	669	35
026065	517	485	95	417	642	36
026069	527	516	97	425	646	35
026075	643	645	123	505	789	37
026078	597	595	93	497	714	31
026083	533	531	77	451	629	29
026084	530	499	84	451	644	26
026088	507	527	74	406	579	25
026091	579	601	81	495	662	19
078078	452	444	97	321	573	108
079011	581	574	110	446	733	108
079018	508	503	106	375	640	103
079083	543	530	102	406	678	31

Monthly Rainfall

The mean monthly rainfall totals for selected long-term stations were presented in Section 2.2.2. Figure A16 presents the mean monthly values for the remaining stations. Figures A17 and A18 then show the mean monthly rainfall totals for the shorter term representative stations. As discussed in Section 2.2.2, between 75 and 80 percent of the rainfall occurs between April and October. In addition, the differences in the magnitude of mean monthly rainfall between stations from November to March is not as great as during the remainder of the year, even though the annual rainfall totals are significantly different.

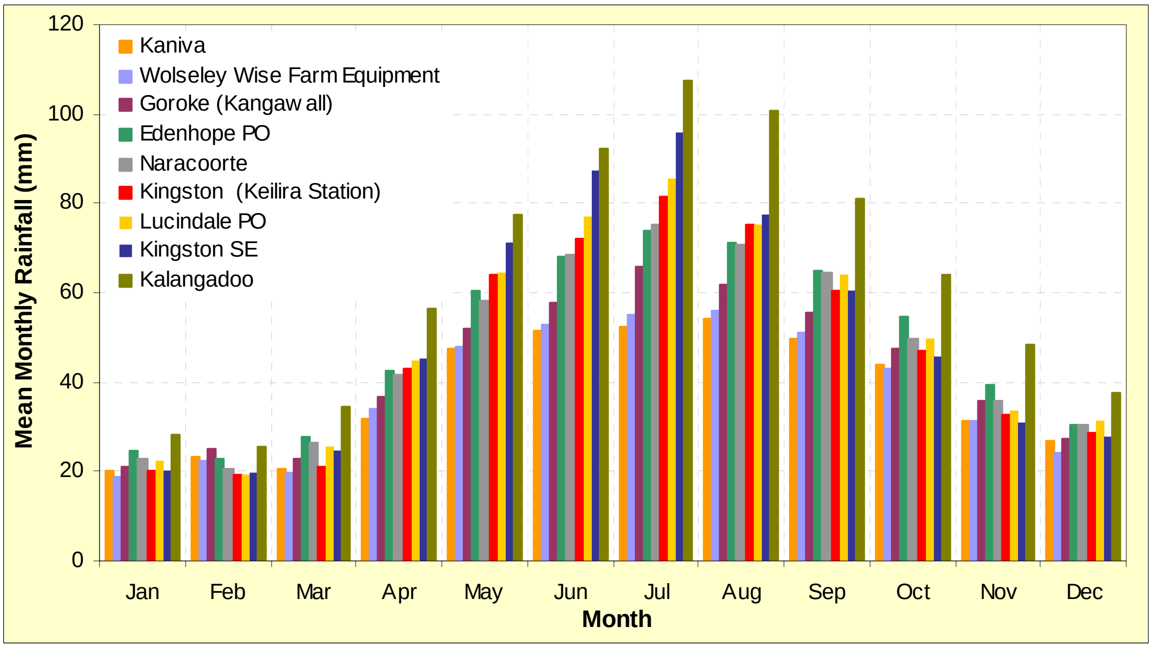


Figure A16 Mean Monthly Rainfall Totals at Remaining Long-Term Stations.

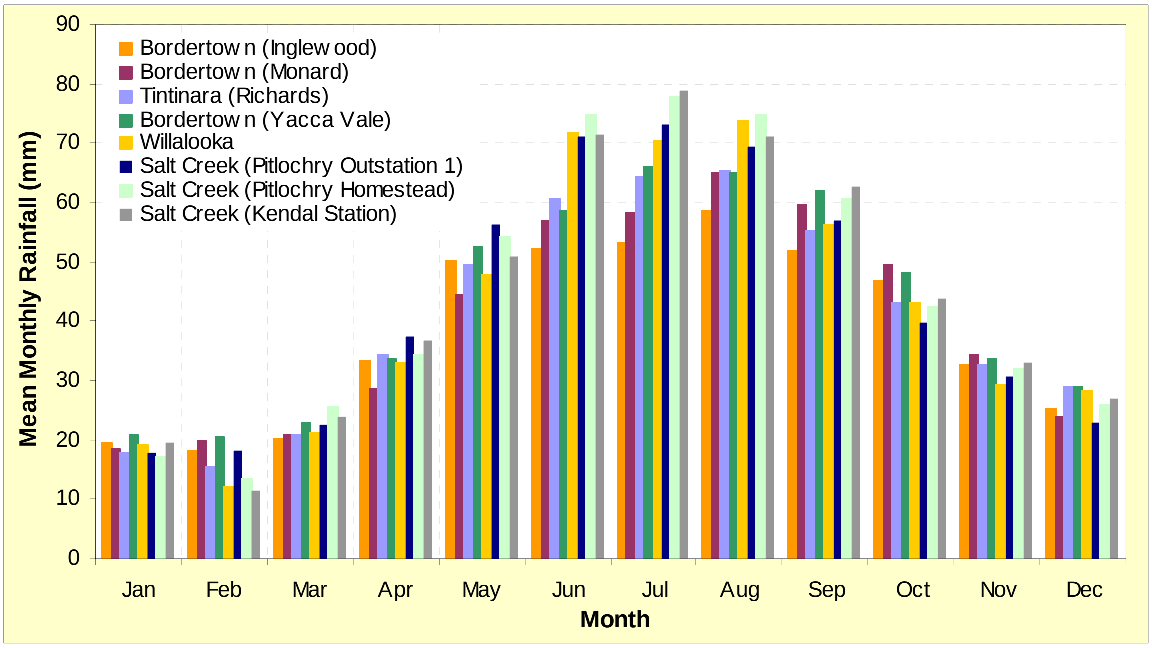


Figure A17 Mean Monthly Rainfall Totals at Short-Term Stations (North of Padthaway).

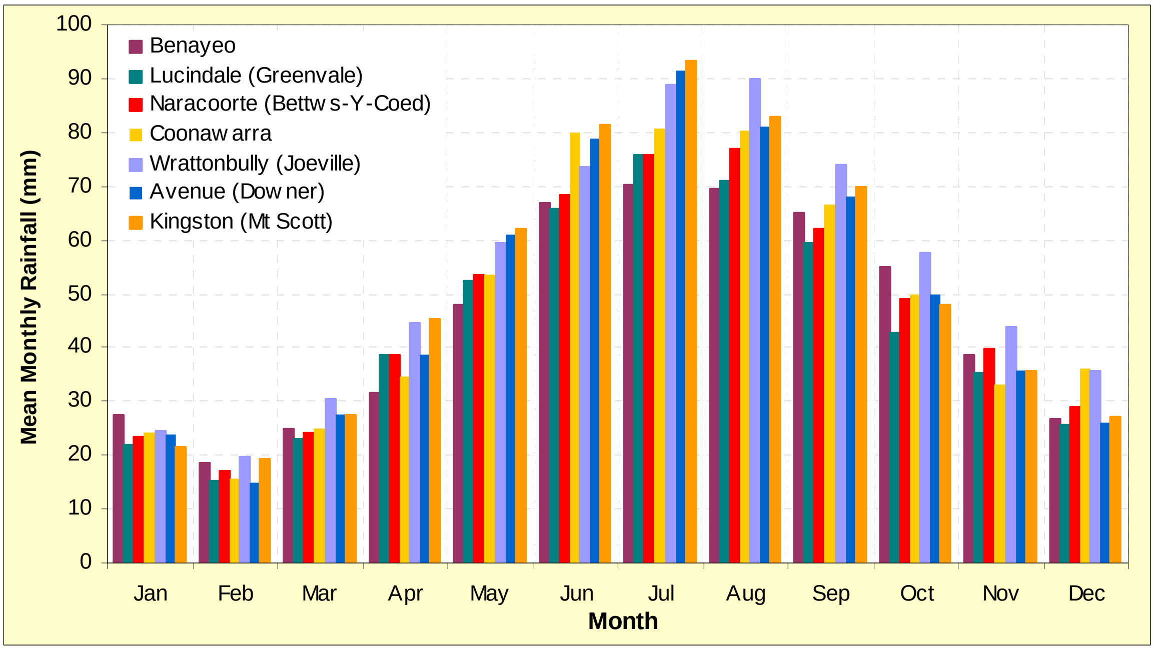


Figure A18 Mean Monthly Rainfall Totals at Short-Term Stations (South of Padthaway).

Residual mass curves were plotted for each month, together with the annual curves. The results and discussion in Section 2.2.2 showed that there were no overwhelming increasing or decreasing rainfall trends in individual months but that the impact on total annual rainfall was often influenced by particular combinations of months or seasons. Three general seasons were defined, namely, winter (June to August), summer (December to March) and a transitional season defined as the months between summer and winter (April to May, September to November). The observations described in Section 2.2.1 were fairly consistent across the region. An additional selection of results from the long-term representative stations are presented here. For each station, the residual mass curves for selected months, the seasonal residual mass curves (winter and transitional season) and a comparison of the seasonal residuals are presented. The stations are ordered in terms of their position (north to south) across the region.

Wirrega (025518)

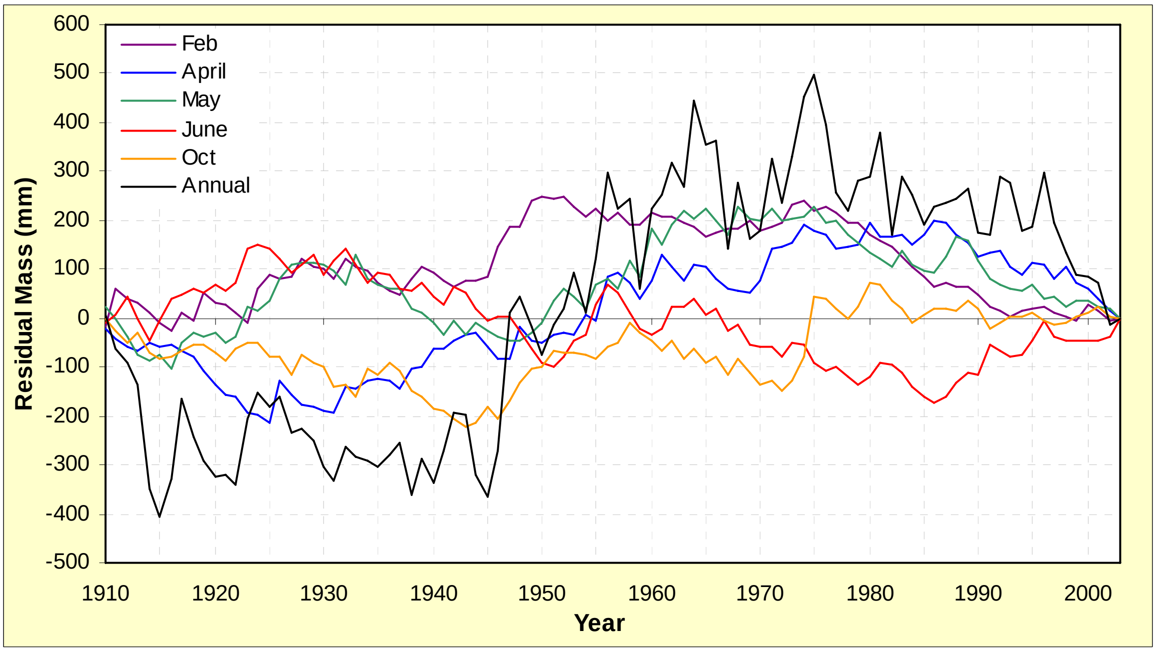


Figure A19 Monthly Residual Mass Curves at Wirrega (025518).

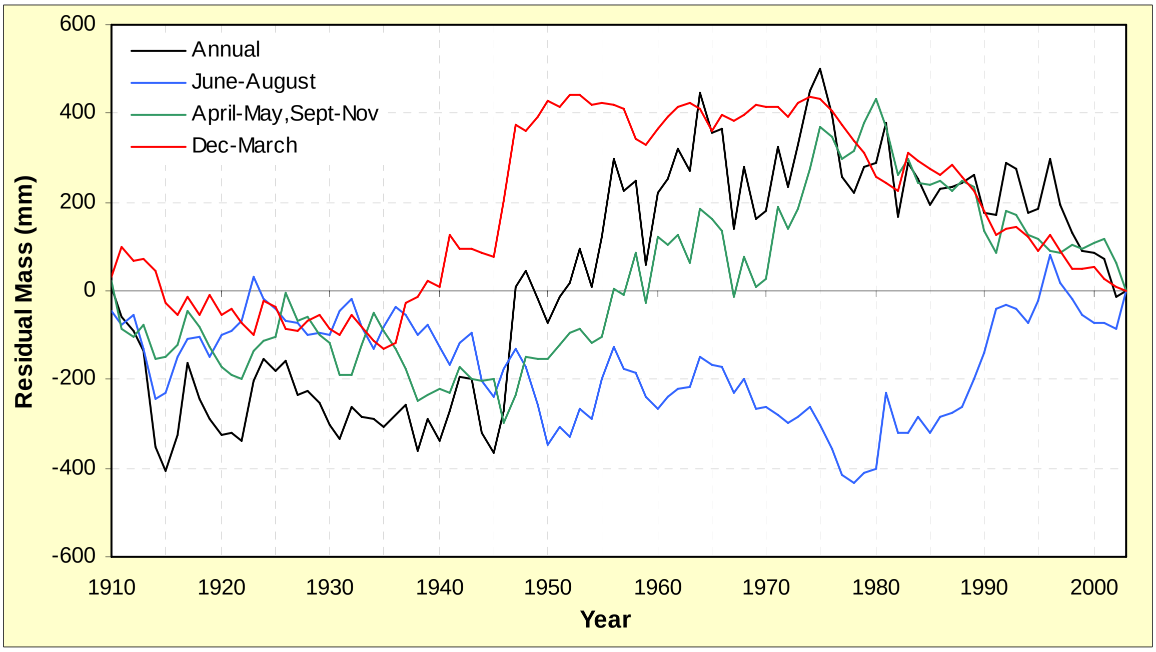


Figure A20 Seasonal Residual Mass Curves at Wirrega (025518).

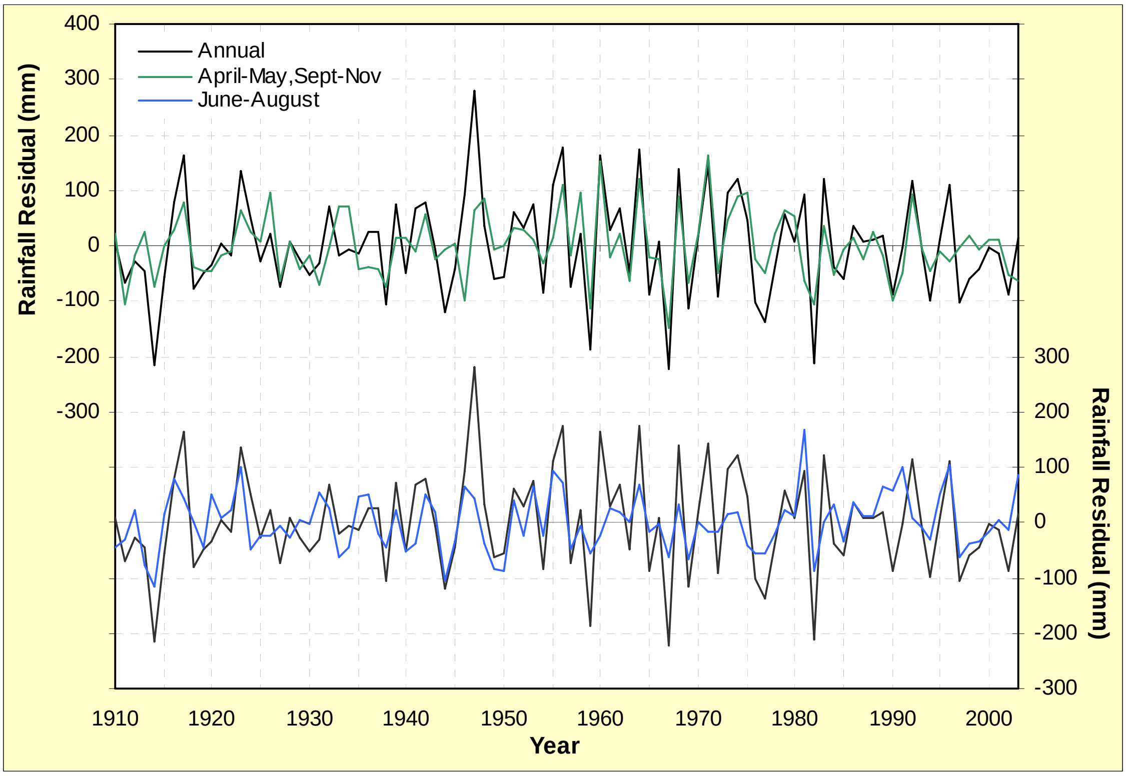


Figure A21 Comparison of Annual and Seasonal Residuals at Wirrega (025518).

Kaniva (078078)

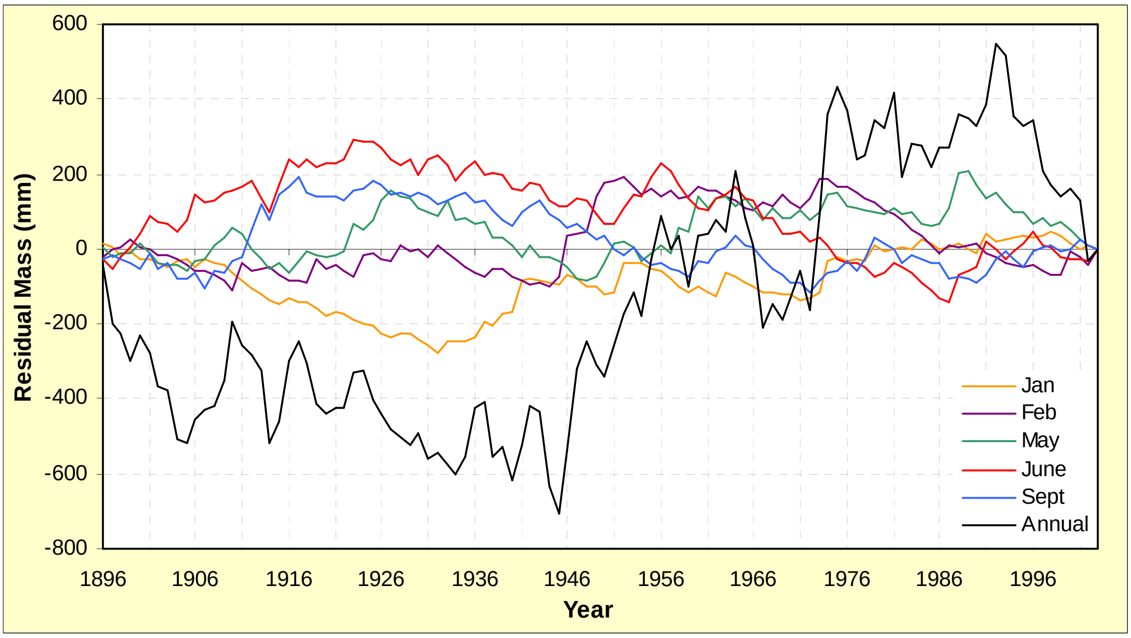


Figure A22 Monthly Residual Mass Curves at Kaniva (078078).

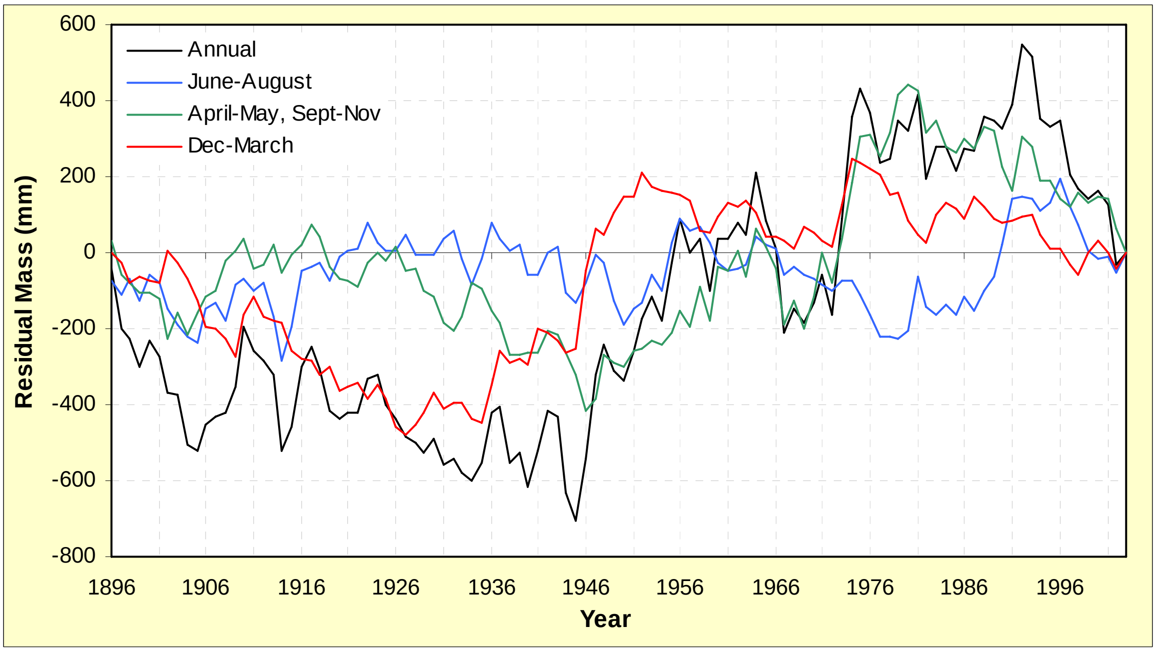


Figure A23 Seasonal Residual Mass Curves at Kaniva (078078).

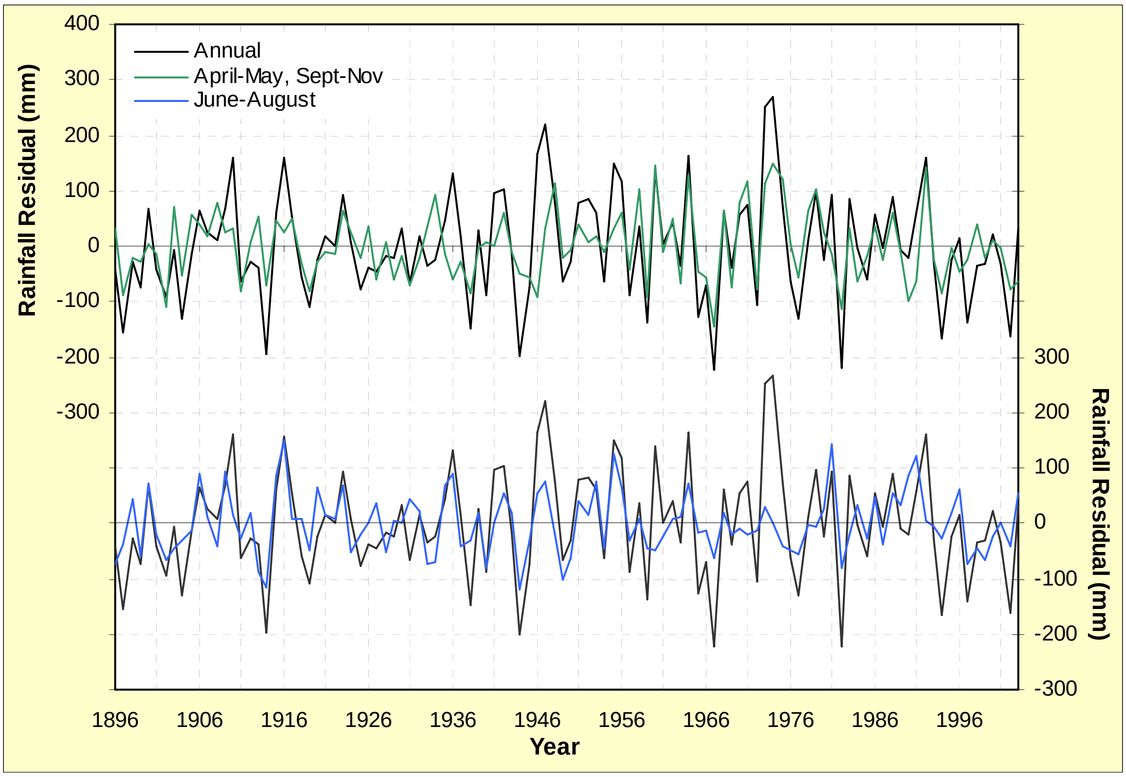


Figure A24 Comparison of Annual and Seasonal Residuals at Kaniva (078078).

Frances (026007)

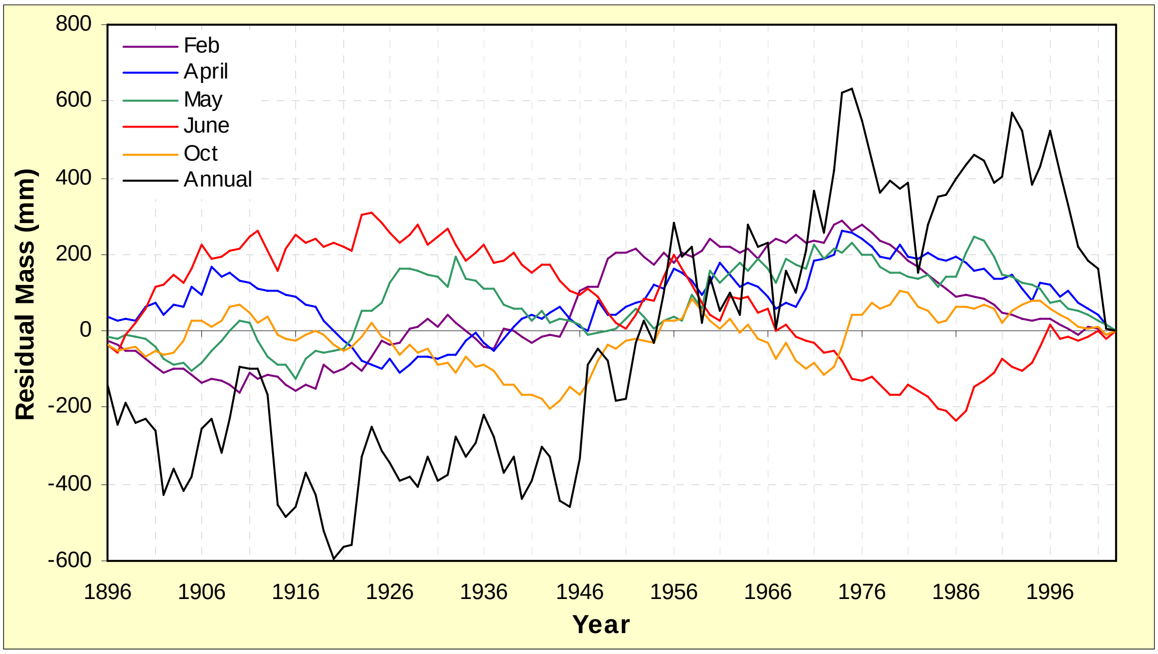


Figure A25   Monthly Residual Mass Curves at Frances (026007).

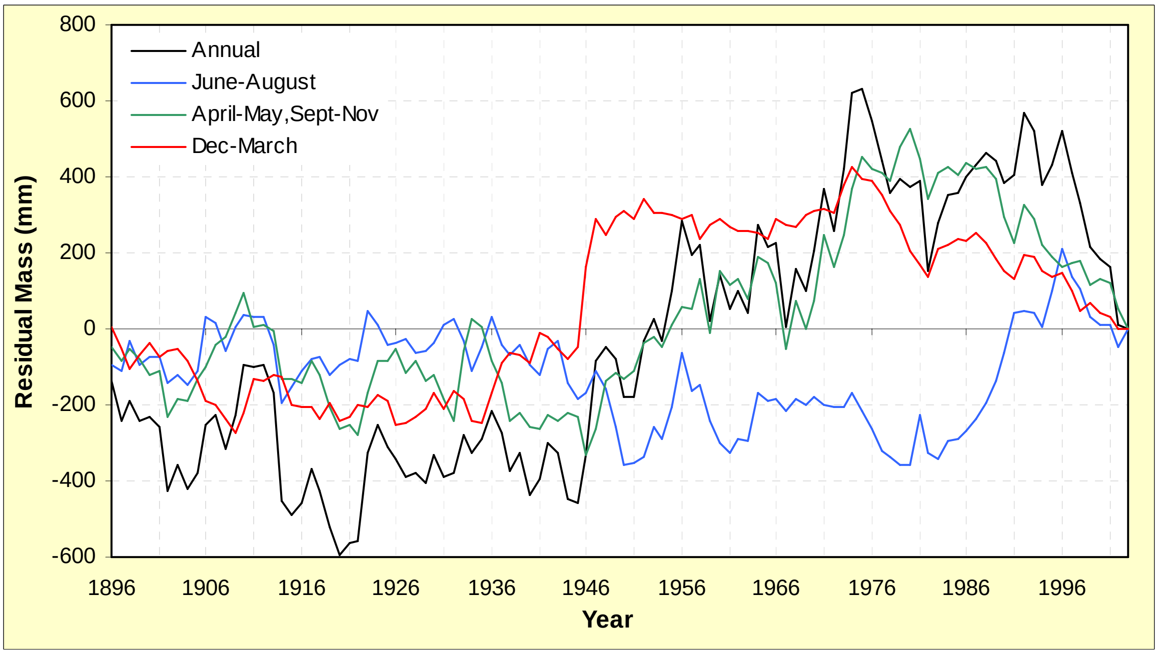


Figure A26   Seasonal Residual Mass Curves at Frances (026007).

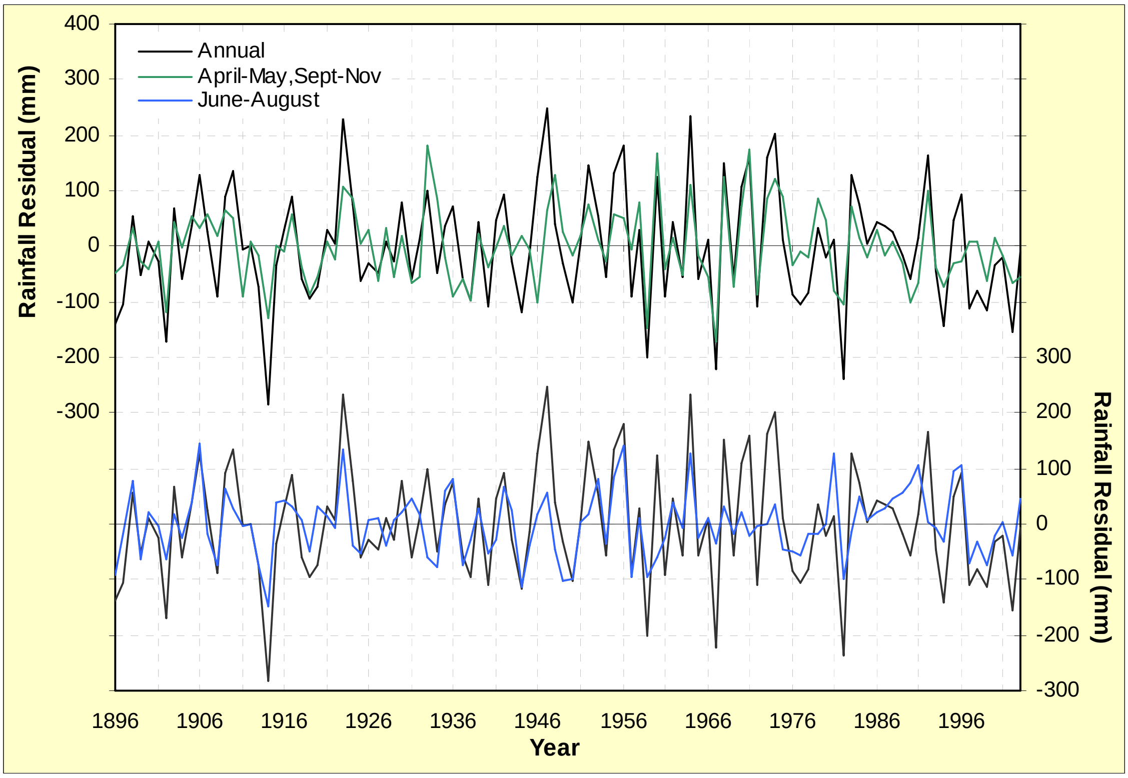


Figure A27 Comparison of Annual and Seasonal Residuals at Frances (026007).

Penola (026025)

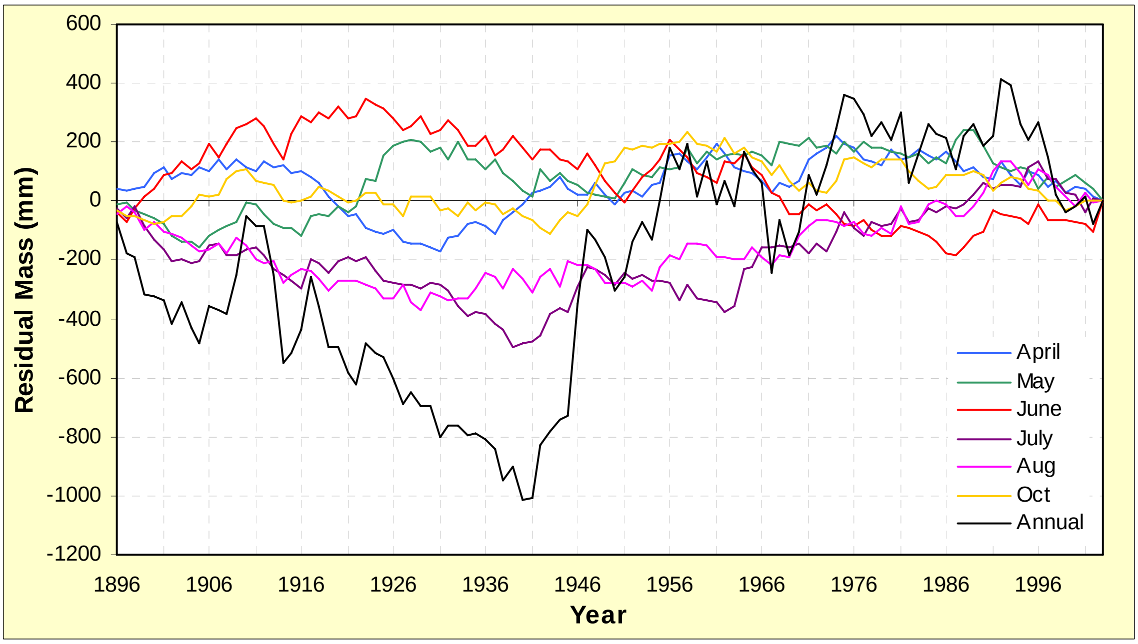


Figure A28 Monthly Residual Mass Curves at Penola (026025).

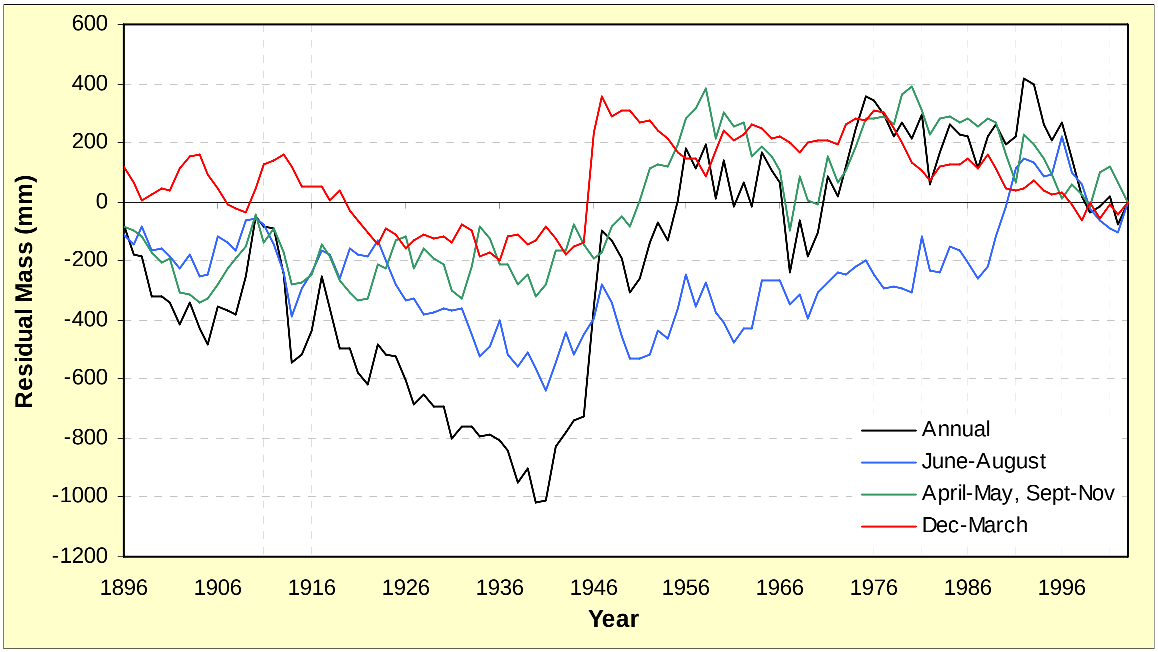


Figure A29 Seasonal Residual Mass Curves at Penola (026025).

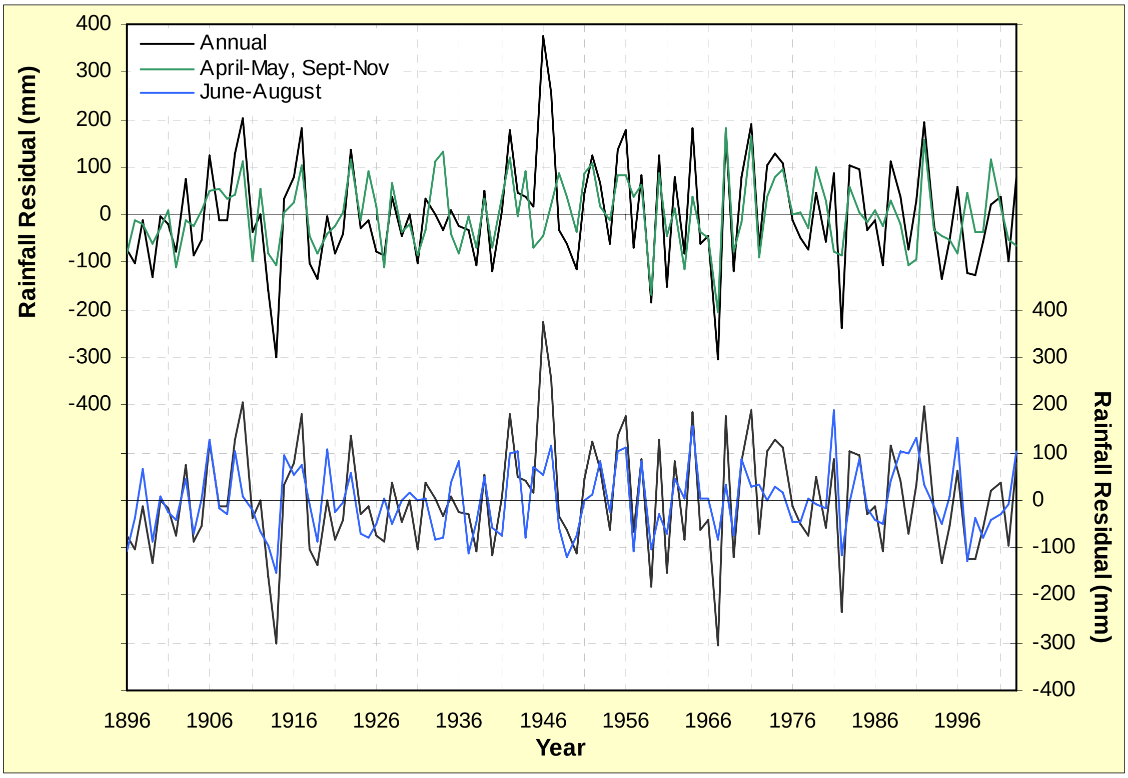


Figure A30 Comparison of Annual and Seasonal Residuals at Penola (026025).

Kalangadoo (026009)

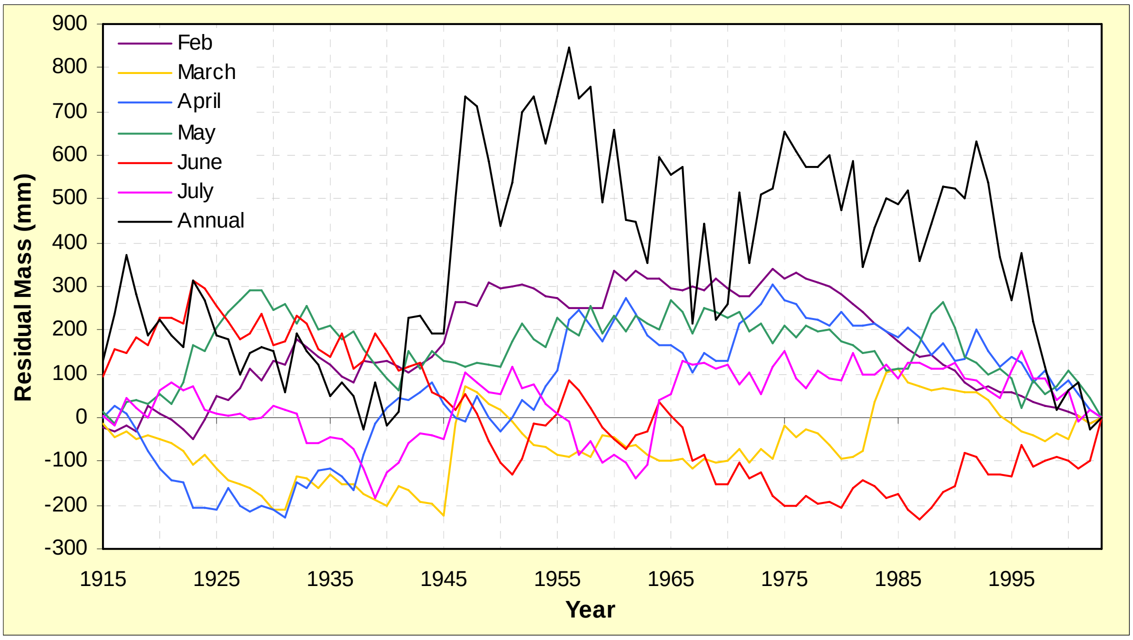


Figure A31 Monthly Residual Mass Curves at Kalangadoo (026009).

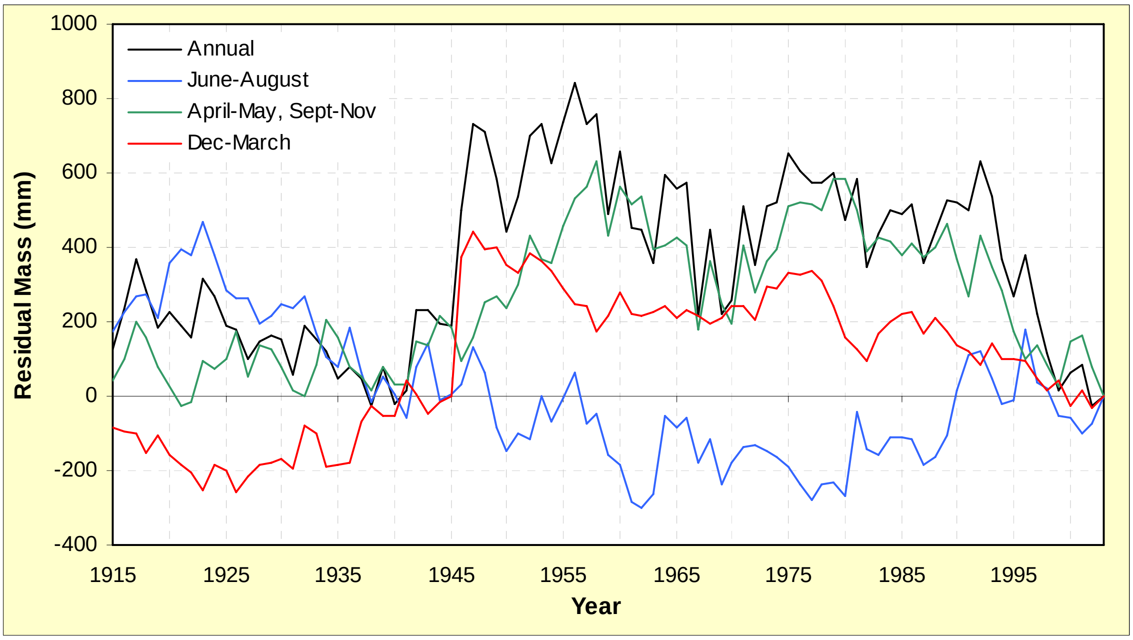


Figure A32 Seasonal Residual Mass Curves at Kalangadoo (026009).

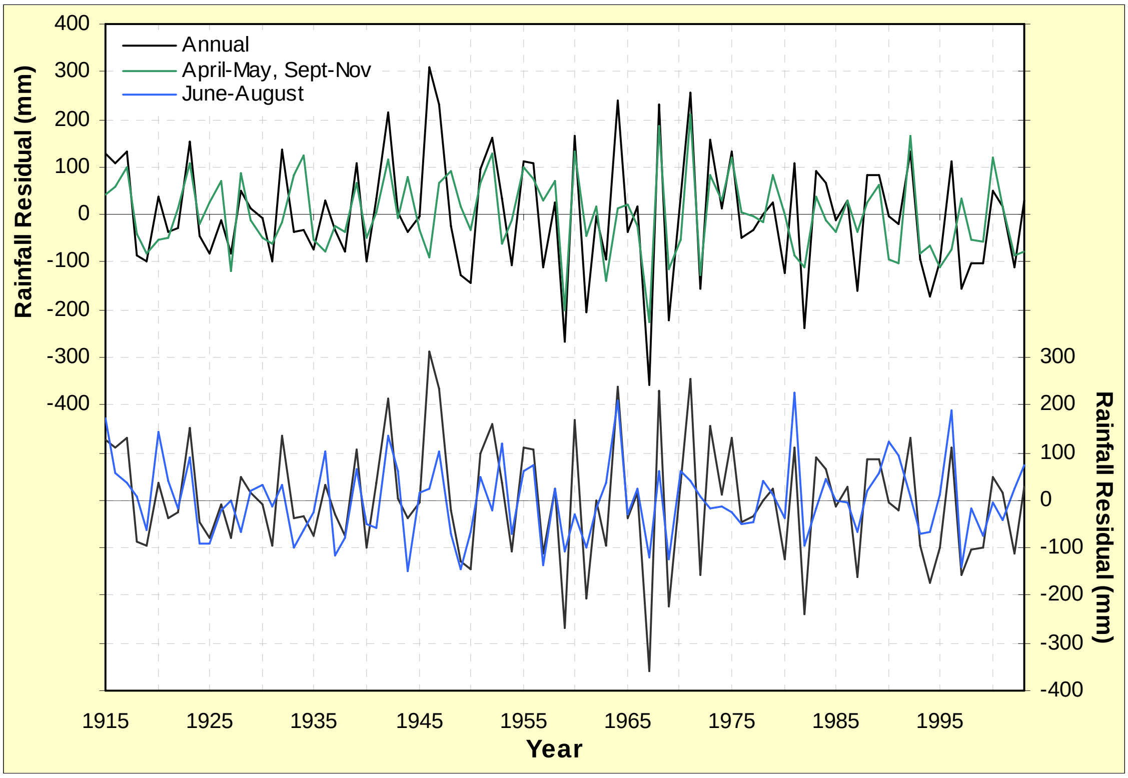


Figure A33 Comparison of Annual and Seasonal Residuals at Kalangadoo (026009).

Lake Leake (026014)

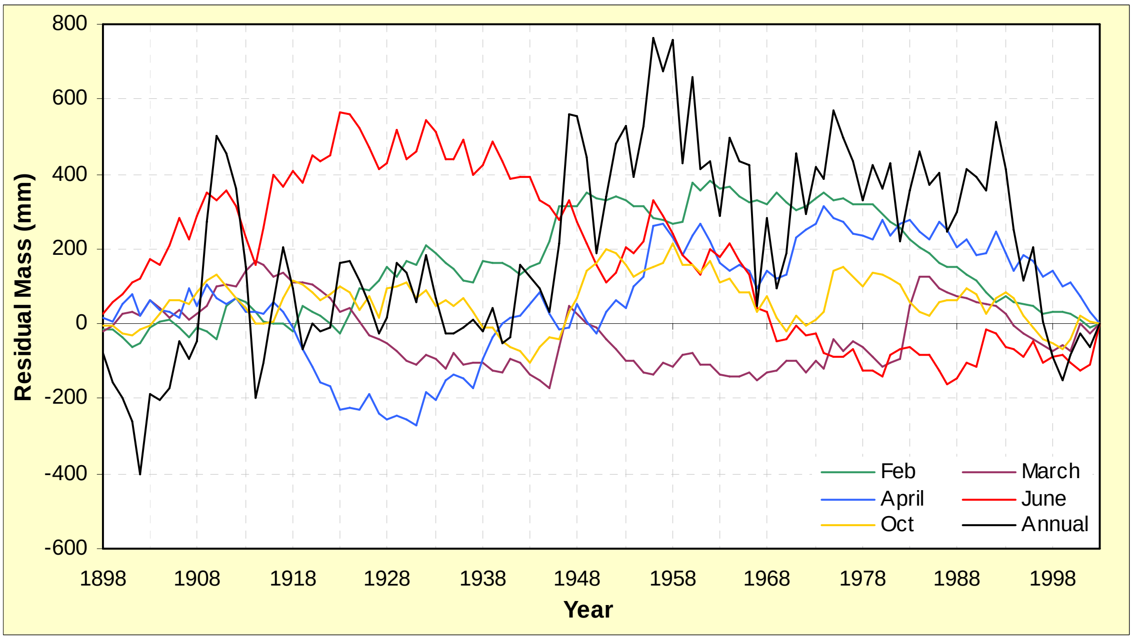


Figure A34 Monthly Residual Mass Curves at Lake Leake (026014).

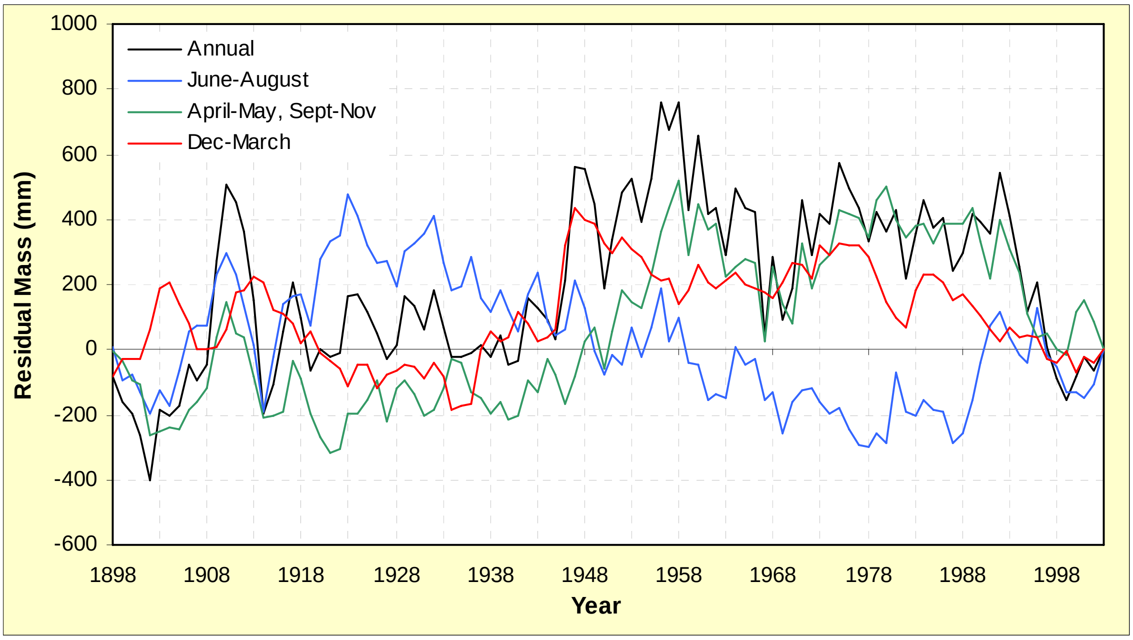


Figure A35 Seasonal Residual Mass Curves at Lake Leake (026014).

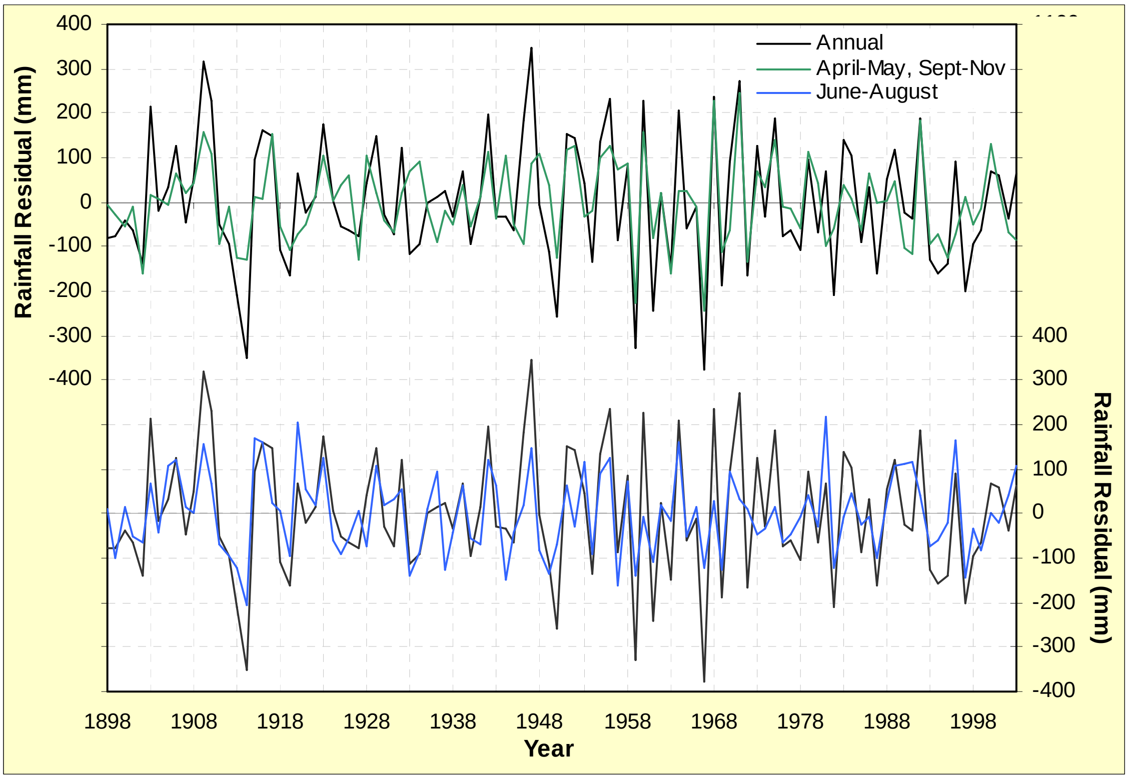


Figure A36 Comparison of Annual and Seasonal Residuals at Lake Leake (026014).

Decadal Rainfall Analysis

A decadal rainfall analysis of the data at each site used for catchment modelling revealed significant statistical trends as was discussed in Section 2.2. Figures A37 to A43 show this analysis for data from the long-term stations. In each case, average rainfall was significantly above the long-term mean in the ten year periods 1916 to 1925, 1946 to 1955, 1966 to 1975 and below the long-term mean in the periods 1936 to 1945, 1956 to 1965 and 1976 to 1985. The ten year moving average clearly highlights the high (peaks) and low (troughs) rainfall decades with successive above average rainfall peaks in both the ten year moving average and the mean decade rainfall decreasing over the last 100 years.

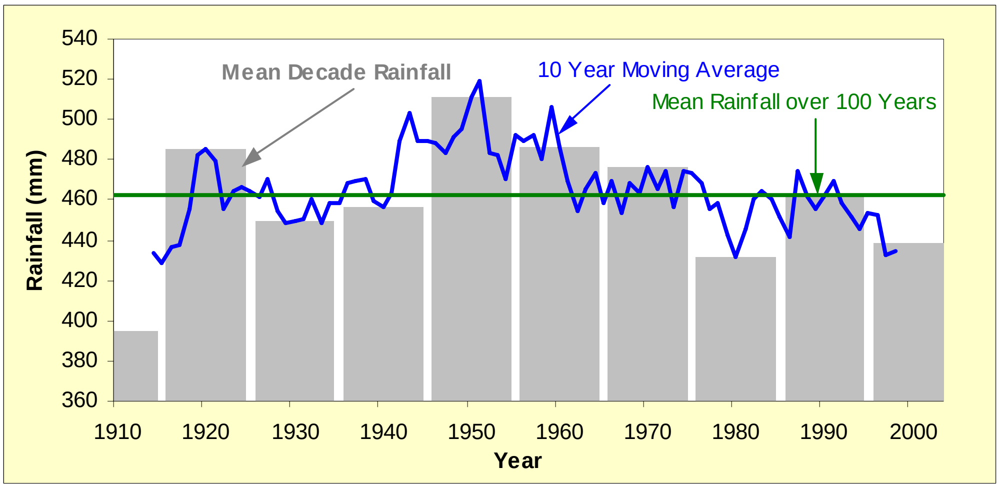


Figure A37 Decadal Rainfall Pattern at Wirrega (025518).

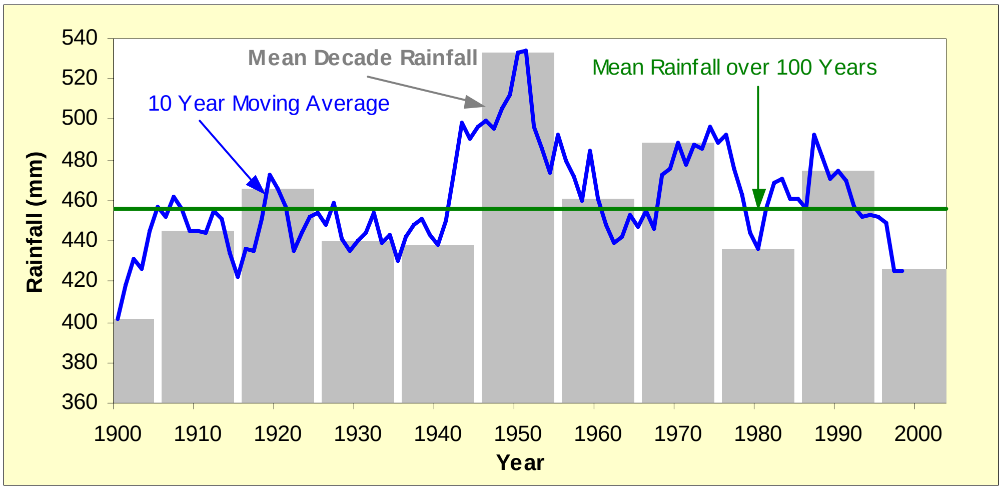


Figure A38 Decadal Rainfall Pattern at Wolseley (025519).

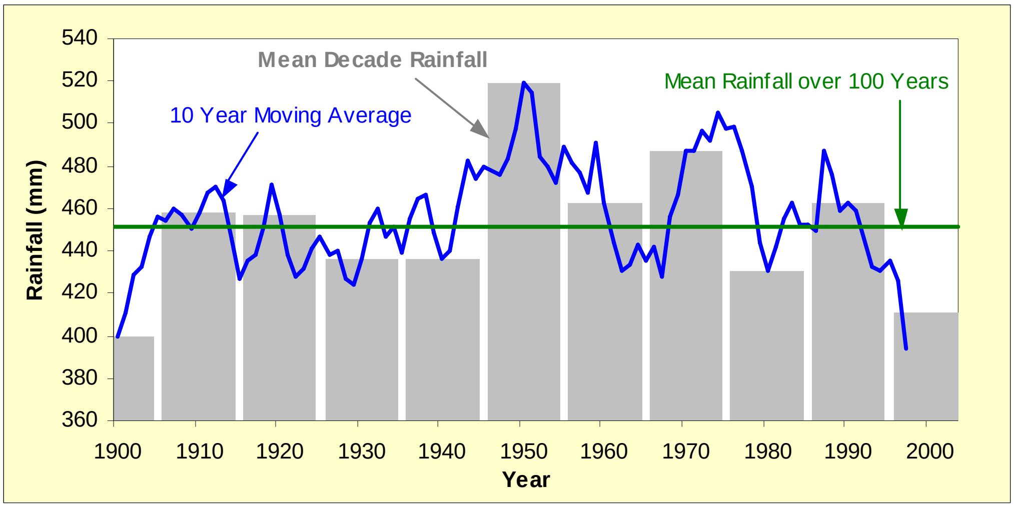


Figure A39 Decadal Rainfall Pattern at Kaniva (078078).

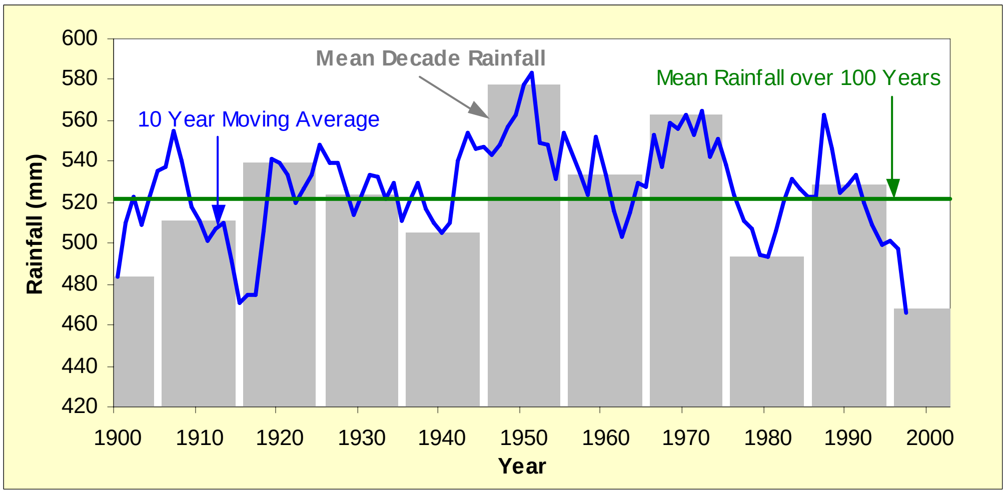


Figure A40 Decadal Rainfall Pattern at Frances (026007).

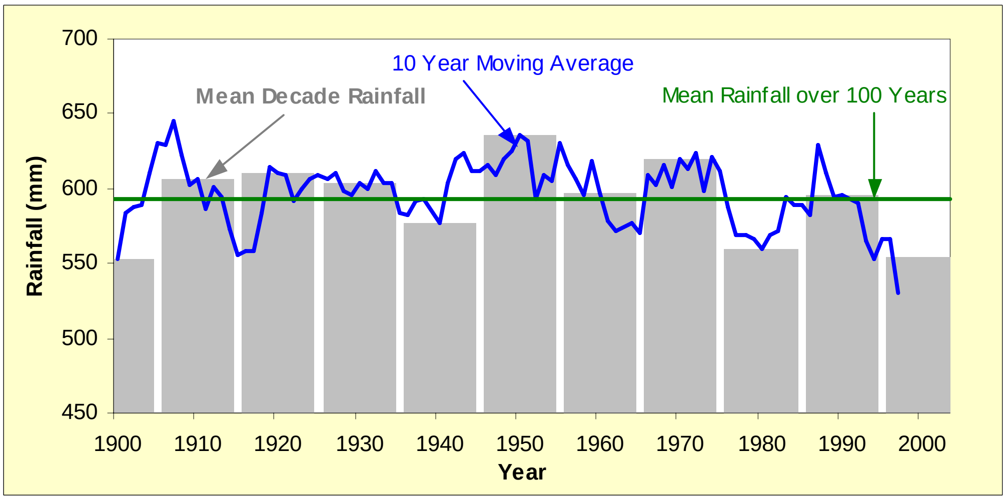


Figure A41 Decadal Rainfall Pattern at Lucindale (026016).

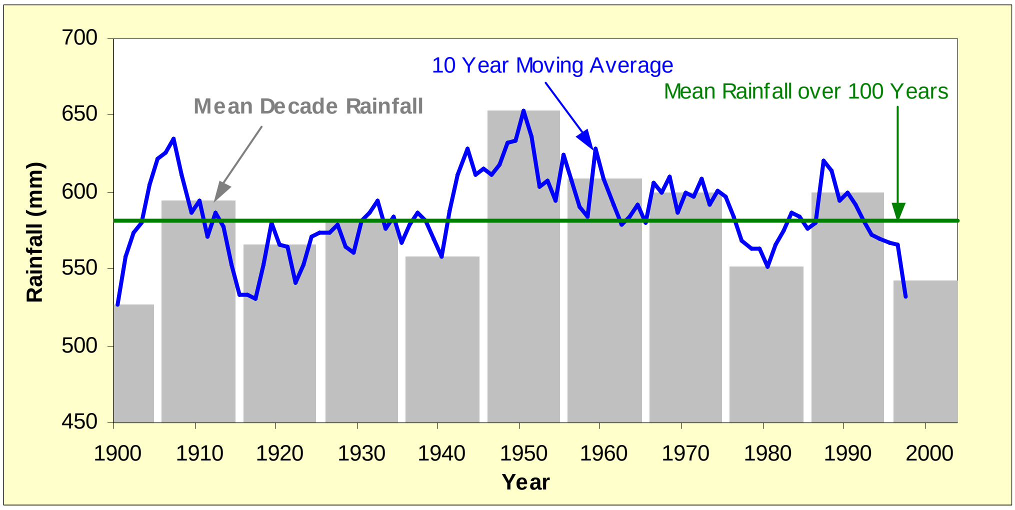


Figure A42 Decadal Rainfall Pattern at Edenhope (079011).

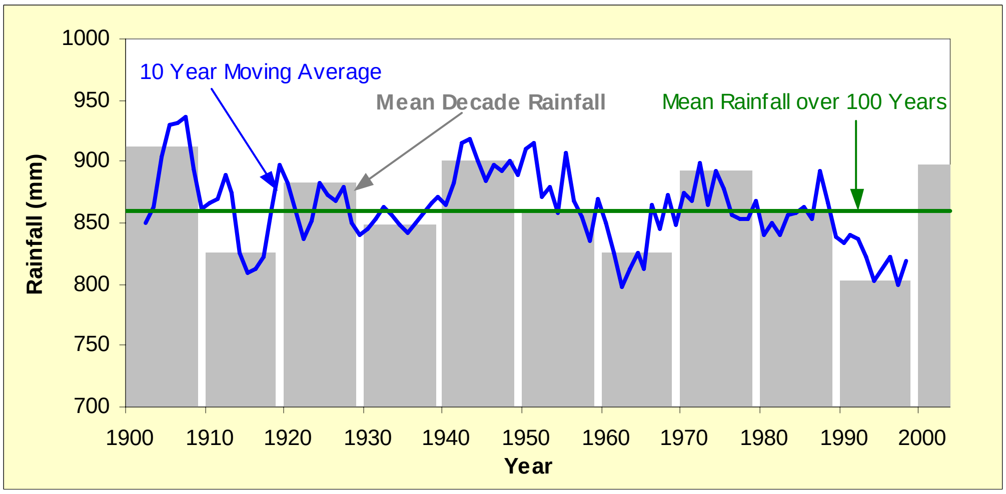


Figure A43 Decadal Rainfall Pattern at Lake Leake (026014).

APPENDIX B EVAPORATION ANALYSIS

Evaporation is the transfer of moisture into the atmosphere, whether from a free water surface such as a dam or reservoir, a soil surface or by the process of transpiration from plants. Accurate estimates are essential for hydrologic water-balance calculations because it influences the amount of rainfall that is intercepted by vegetation and absorbed by the soil before surface runoff will occur, or captured by dams and reservoirs before they fill, overflow and upstream runoff will move down through the catchment.

B.1 Data Availability and Processing

Evaporation data of a reasonable length and good quality is extremely limited in the south east of South Australia. This has necessitated the extrapolation of data from those available stations to other areas. Table B1 lists the available stations and data types recorded by the Bureau of Meteorology that were used during the data processing stage.

Table B1 Climate Stations used to Generate and Evaluate Evaporation Datasets for Modelling.

Station Number	Location	Data Type	Period of Record Available	Percentage of Missing Data
026013	Kybybolite Research Centre	Pan Evaporation	1948-1995	0.6
026021	Mount Gambier	Pan Evaporation	1967-2004	<0.1
		Temperature	1943-2004	<0.1
		Sunshine Hours	1967-2004	<0.1
026023	Padthaway	Temperature	1963-2000	<0.1
026082	Struan	Pan Evaporation	1975-1999	1.4
026089	Padthaway	Pan Evaporation	1978-2000	1.4
026091	Coonawarra	Temperature	1986-2002	1.0
026100	Padthaway South	Pan Evaporation	2000-2004	-

Pan Evaporation Data

Processing of the pan evaporation data, which included the infilling of missing data, disaggregation of accumulated data and adjustments for homogeneity or exposure changes was undertaken by Murdoch (2004). In particular:

- The primary stations to be used for modelling are located at Mount Gambier (026021), Struan (026082) and the combination of Padthaway (026089) and Padthaway South (026100).
- Mount Gambier (026021)
  - A Class A Pan without a standard bird-guard was installed in 1965. A bird-guard was fitted in 1973;
  - Missing data was infilled using a linear relationship with data from the station at Kybybolite (026013). The correlation of daily evaporation values between Mount Gambier and Kybybolite was 0.841;
  - A double mass analysis (refer Section A.1) with Kybybolite (026013) identified a significant change in slope at the point when the bird-guard was installed. A bird-guard had been installed at the Kybybolite station in 1967. The Mount Gambier record between 1967 and 1973 was then adjusted by the ratio of the double mass slope to ensure consistency in evaporation values. This ratio resulted in a

reduction of 11.2%, which is consistent with the predicted 10 to 12 % reduction specified by Kernich (1984); and

- No other adjustments for homogeneity were undertaken.

- Padthaway (026089) and Padthaway South (026100)
  - A Class A Pan without a standard bird-guard was installed at Padthaway (026089) in 1977 and a bird-guard fitted in 1982. This station was closed in September 2000;
  - In December 2000, the station at Padthaway South (026100) was opened with a Class A Pan and standard bird-guard;
  - Although there is no overlap in the records to form comparisons and assess homogeneity due to changes in exposure, the combined records were compared with data from the station at Mount Gambier (026021). No obvious deviations were evident and the combined record was considered valid without adjustments;
  - Missing data was infilled using linear relationships with data from stations at Konetta (026070), Kaniva (078078), Struan (026082) and Mount Gambier (026021). The correlation between the daily evaporation values from Padthaway (026089) and these stations was 0.891, 0.873, 0.859 and 0.818 respectively;
  - The station (026089) was relocated at the same time the bird-guard was fitted. A double mass analysis (refer Section A.1) with Mount Gambier (026021) revealed no detectable change in slope at this point. While it has been stated (Kernich, 1984) that the installation of a bird-guard reduces evaporation by 10 to 12%, it was concluded that the combination of the change in exposure and bird-guard attachment compensated for each other; and
  - No other adjustments for homogeneity were undertaken.
- Struan (026082)
  - A Class A Pan with standard bird-guard was installed in 1968. The station was closed in 1999;
  - Missing data was infilled using linear relationships with data from stations at Coonawarra (026091), Mount Gambier (026021), Kybybolite (026013) and Padthaway (026089). The correlation between daily evaporation values at Struan and these stations was 0.907, 0.861, 0.856 and 0.859 respectively;
  - The linear relationships were also used to extend the data to 2004; and
  - No adjustments for homogeneity were undertaken.

Potential Evaporation Data

Daily sunshine hours data and temperature data is collected by the Bureau of Meteorology (BoM). Table B1 shows the stations that were used during the data processing stage to calculate an evaporation data set. Data from the station at Mount Gambier (026021) that measures sunshine hours and temperature were directly used in the evaporation calculations, with temperature data from Coonawarra (026091) and Padthaway (026023) and cloud cover data from Mount Gambier (026021) used to infill missing data (described below). There were very low numbers of days with missing sunshine or temperature data at Mount Gambier (026021).

Missing sunshine hours records were estimated from a fitted third order polynomial (Chiew and McMahon, 1991) between sunshine hours data and cloud cover data. Cloud cover data is the average value of between one and eight measurements for each day. Regression relationships were required for each month to ensure a reasonable correlation between variables. Figures B1 shows this relationship for January using data from the station at Mount Gambier (026021). Although there appears a reasonable spread of values for each month, the majority of values lie around the curves. For a given level of cloud cover, outlying points generally only have one or two days of data associated with them, whereas points around the regression curve have the majority of the recorded data. Days with only one measurement also have the potential to deviate further from the regression relationship.

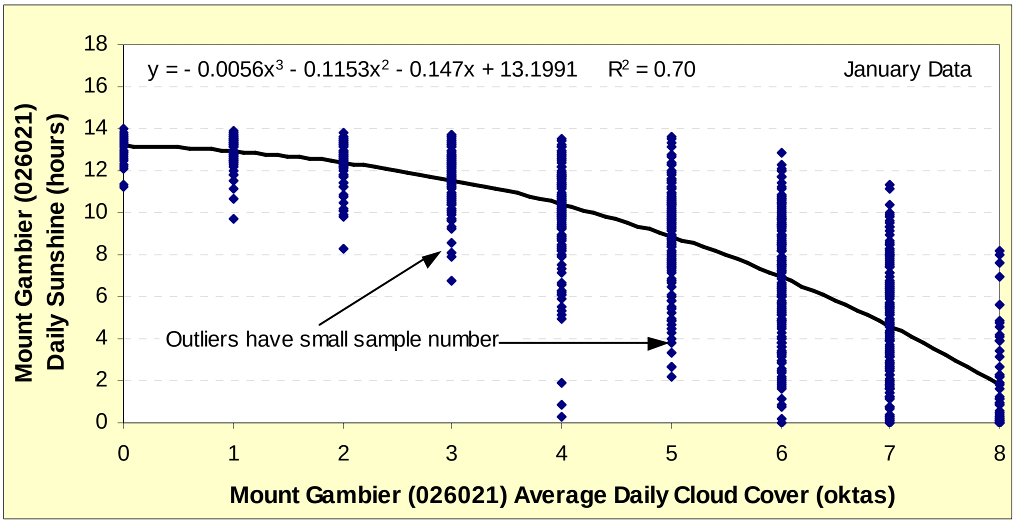


Figure B1 Regression Relationship between Daily Sunshine and Average Daily Cloud Cover at Mount Gambier (026021) for January.

The limited number of stations recording sunshine hours precludes a double mass analysis of the data above using other records of sunshine hours. While it is preferable to compare a given dataset against another dataset or an average of datasets of the same meteorological variable, it is not necessary. The main criteria is that a stationary dataset is used, that is, one that is homogeneous. Rainfall data from the station at Kalangadoo (026009) has previously been assessed and adjusted for homogeneity (refer Table A10).

Figure B2 shows the double mass curve for the sunshine hours data from Mount Gambier (026021) against this homogeneous rainfall data from Kalangadoo (026009). Unlike double mass comparisons between rainfall datasets where the curve is relatively straight, the double mass curves for other variables have an annually repeating curved pattern. Therefore, when considering any changes in slope it is important to construct a straight line through the same points on the intra-annual curves, for example, the peaks or troughs. A significant change in slope was found to occur during mid-1993, increasing the slope of the accumulated data by over 11%. The data from section 2 (mid-1993 until 2004) was then adjusted using the slope of section one (1967 to mid-1993).

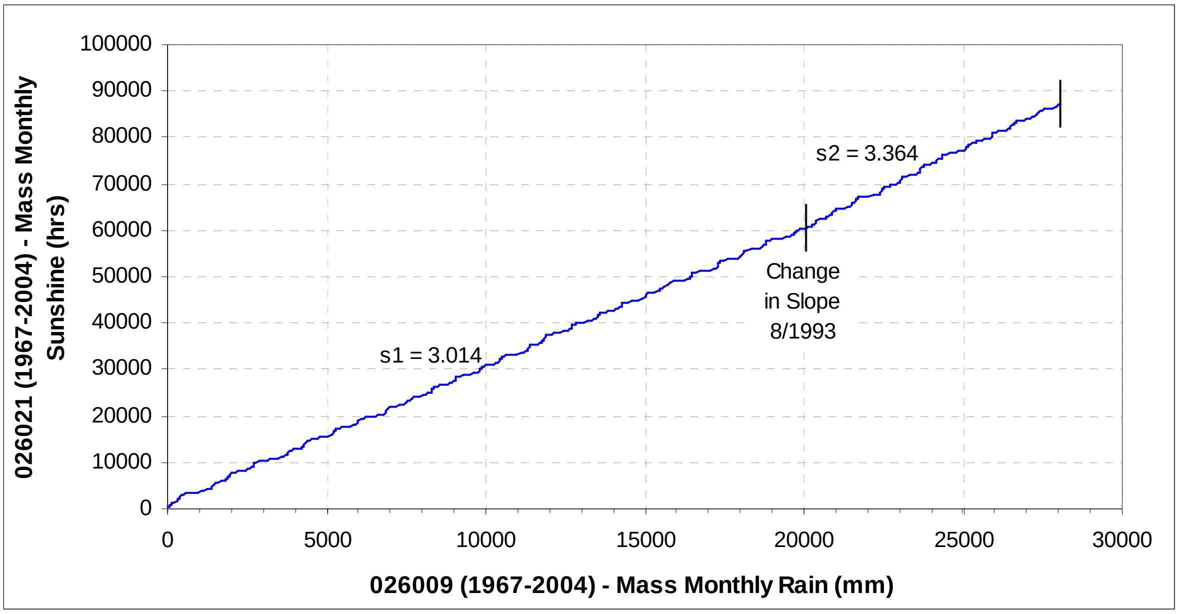


Figure B2 Double Mass Curve for Sunshine Hours from Mount Gambier (026021) against Rainfall from Kalangadoo (026009).

To infill missing temperature records a linear relationship was formed with a nearby site, in particular, missing temperature data from Mount Gambier (026021) was infilled using data from Coonawarra (026091) and Padthaway (026023). The regression relationships between the daily maximum and minimum temperature records each had a good correlation on an annual basis. If this had not been the case, monthly relationships would have been used. Figures B3 show these relationships between Mount Gambier (026021) and Coonawarra (026091).

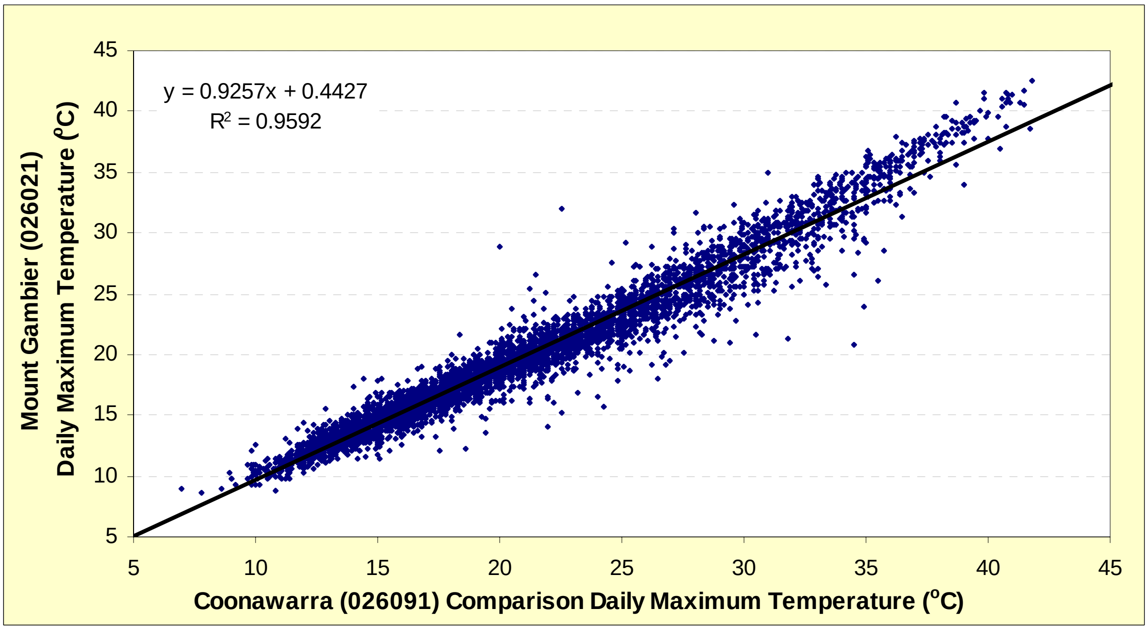


Figure B3 Regression Relationship between Daily Maximum Temperature at Mount Gambier (026021) and Coonawarra (026091).

B.2 Data Generation Method

Evaporation data (mm/day) was generated using the Priestley-Taylor method (Priestley and Taylor, 1972), using sunshine hours data and temperature data. This is a radiation based model and can be written as:

$$E_p = \frac{\alpha \,(R_n + G)\,\Delta}{\lambda\,(\Delta + \gamma)} \qquad \text{(B.1)}$$

where:

R_n = net radiation at the surface (MJ m^{-2} d^{-1});

G = soil heat flux (MJ m^{-2} d^{-1});

α = constant, equal to 1.3 for Australian conditions (Bates, 2000);

Δ = slope of the saturation vapour pressure versus temperature curve (kPa $°C^{-1}$);

λ = latent heat of vaporisation of water (MJ kg^{-1}); and

γ = psychrometric constant (kPa $°C^{-1}$);

Solar radiation is not widely monitored in Australia and often has to be estimated, spatially interpolated or extrapolated using relationships between solar radiation and sunshine hours and temperature. In this case, a method using sunshine hours and temperature was used. A complete description and equations used are described in Heneker (2002) and uses information from Smith (1991), Shuttleworth (1993), Allen *et al*. (1998) and Bates (2000).

B.3 Data Analysis

Analysis of the recorded pan evaporation data for Mount Gambier (026021) and Padthaway (026089-026100) and the calculated evaporation data for Mount Gambier (026021) was undertaken at annual and monthly time scales. As discussed in Section 3.2, the annual pan and potential evaporation data showed decreasing trends over the 38 years of record. An analysis of monthly trends indicated a significant increasing trend in evaporation for almost all months. Full results for the pan evaporation from Mount Gambier (026021) were presented in Section 3.2. The remaining results are presented below.

Padthaway (026089-026100) : Pan Evaporation

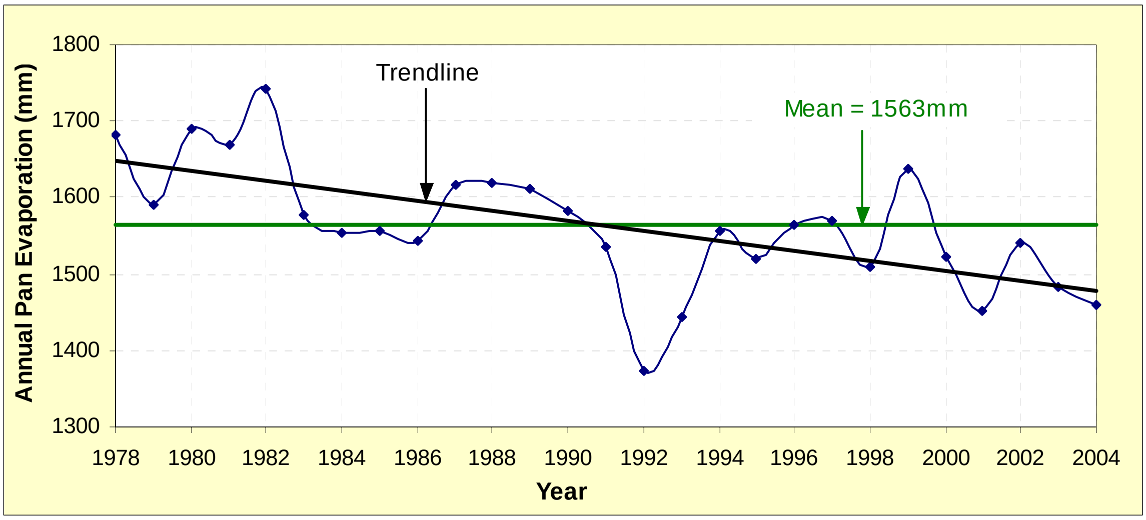


Figure B4 Annual Pan Evaporation and Long Term Trends at Padthaway (026089-026100).

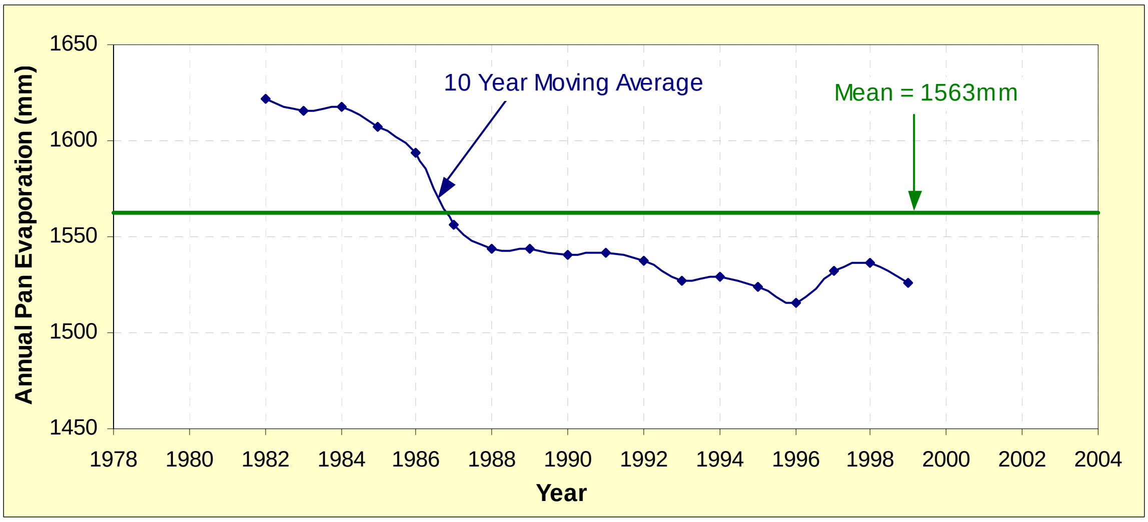


Figure B5 Ten-Year Moving Average of Pan Evaporation at Padthaway (026089-026100).

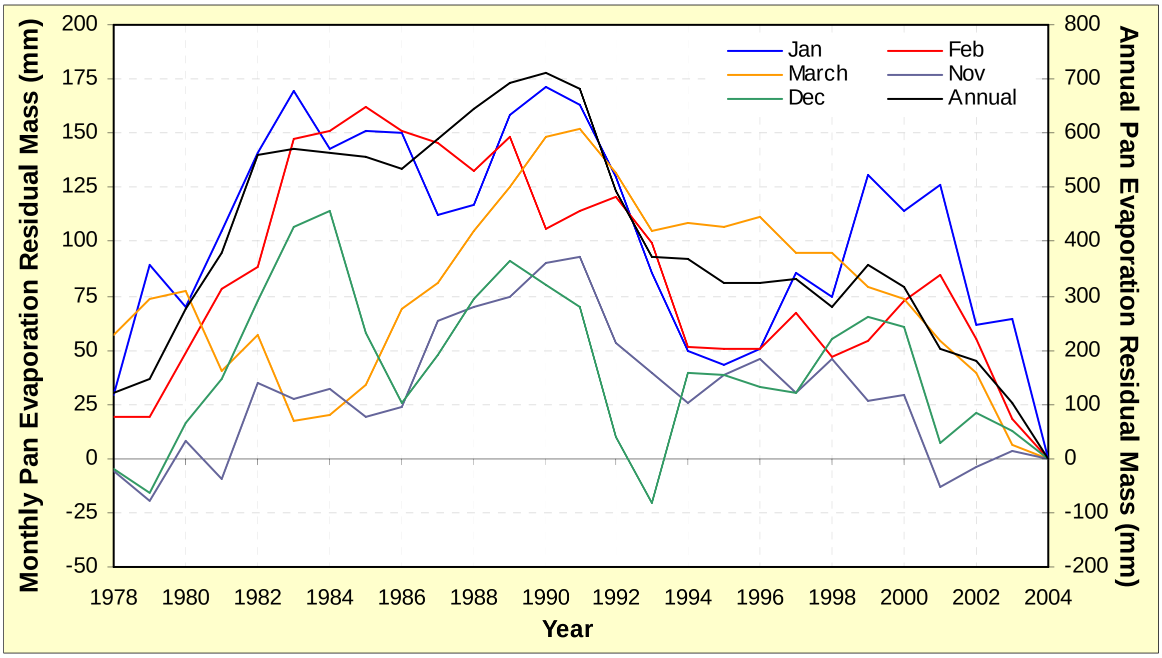


Figure B6 Residual Mass Curves for Pan Evaporation at Padthaway (026089-026100).

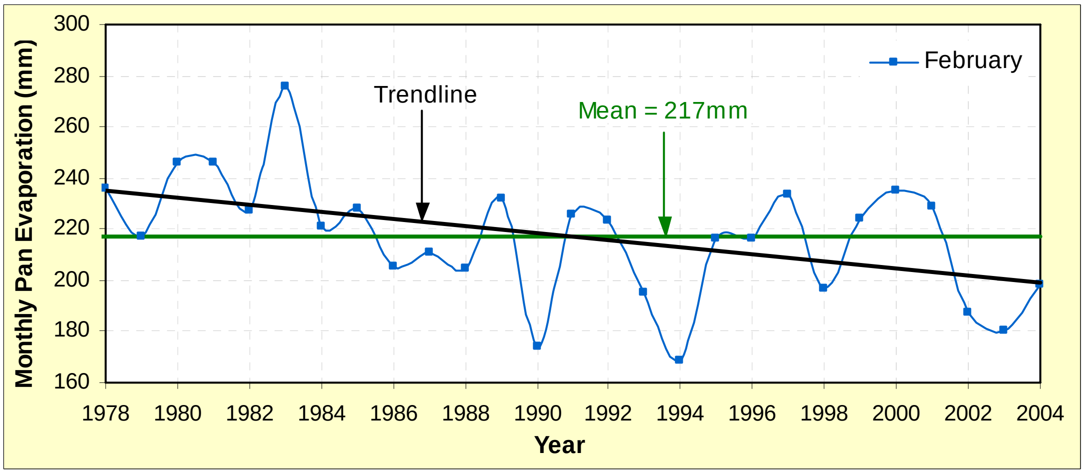


Figure B7 Long-Term Trends in February Pan Evaporation Totals at Padthaway (026089-026100).

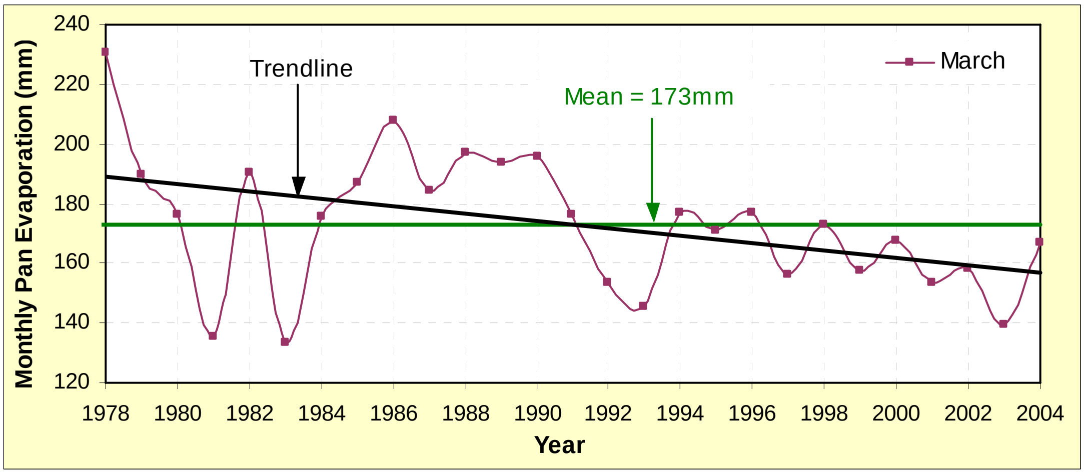


Figure B8 Long-Term Trends in March Pan Evaporation Totals at Padthaway (026089-026100).

Mount Gambier (026021) : Potential Evaporation

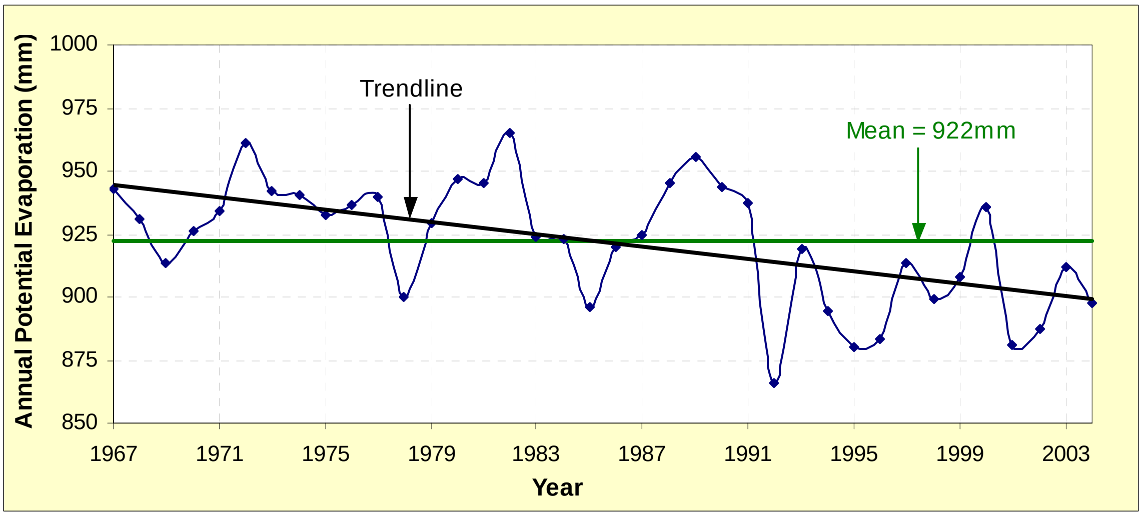


Figure B9 Annual Potential Evaporation and Long Term Trends at Mount Gambier (026021).

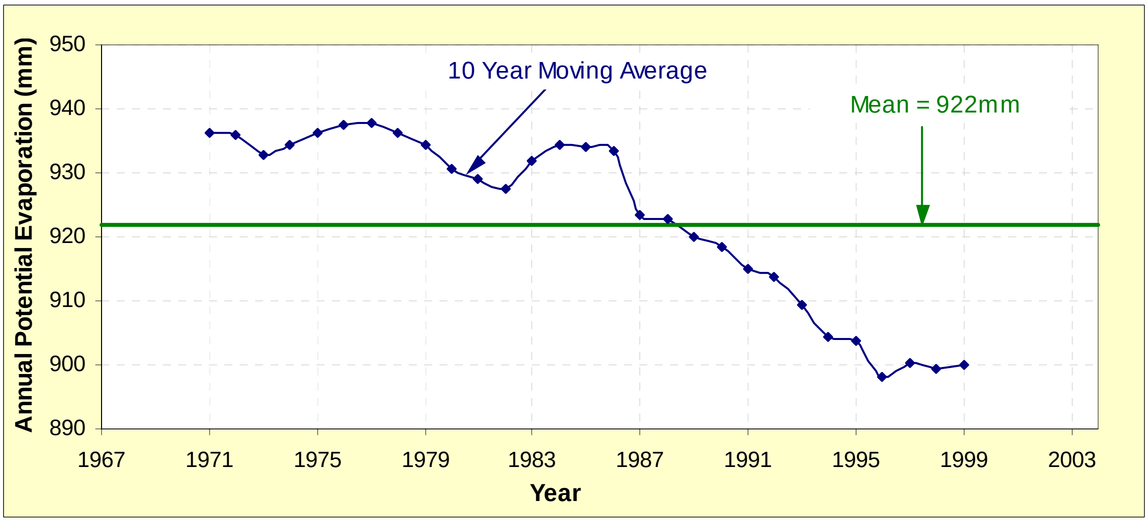


Figure B10 Ten-Year Moving Average of Potential Evaporation at Mount Gambier (026021).

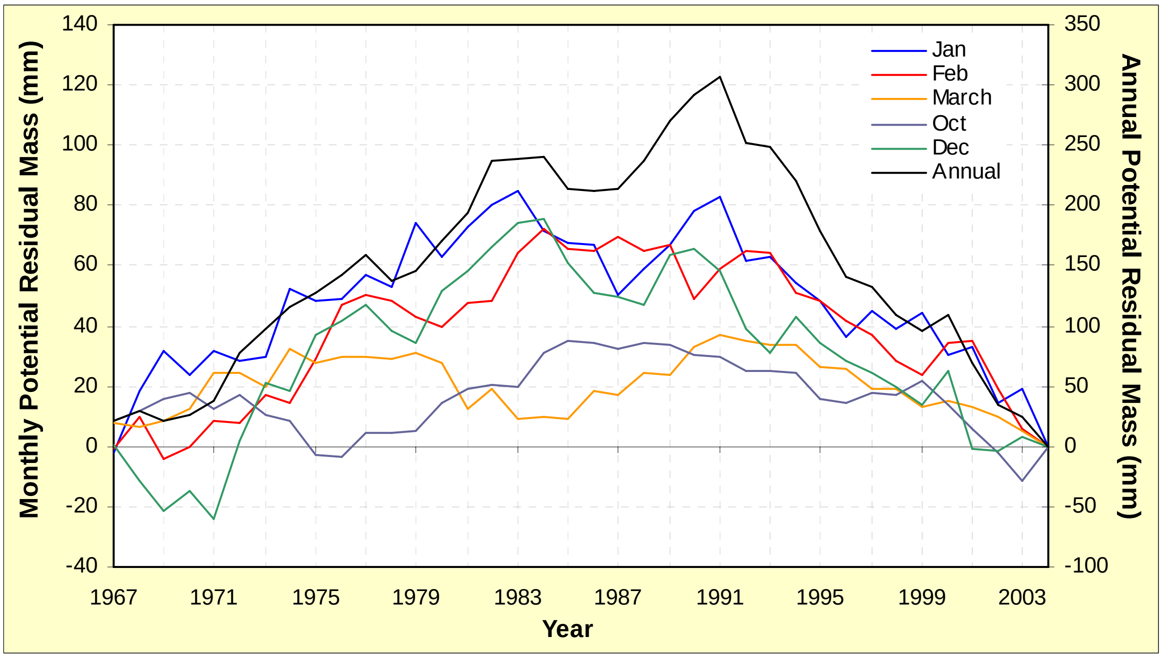


Figure B11 Residual Mass Curves for Potential Evaporation at Mount Gambier (026021).

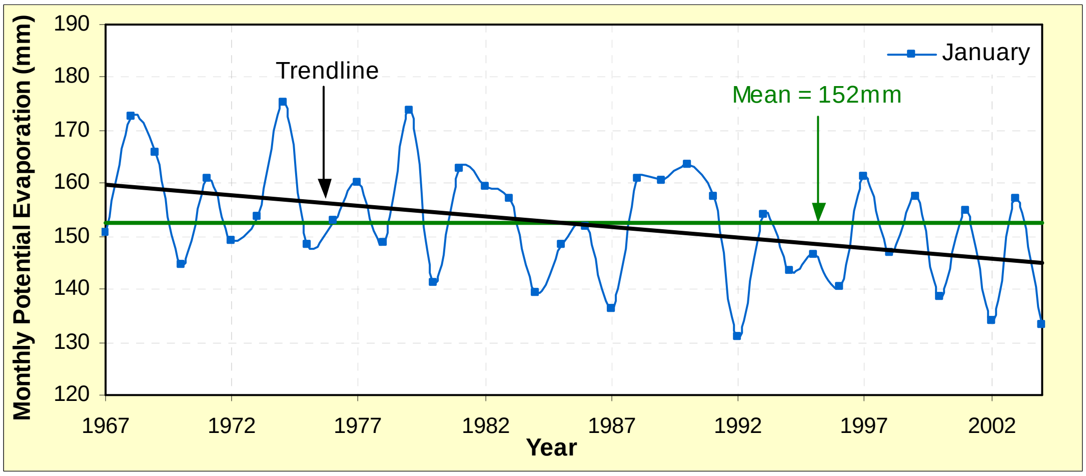


Figure B12 Long-Term Trends in January Potential Evaporation Totals at Mount Gambier (026021).