Department of Water
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Lefroy Brook Hydrology Summary

Department of Water

Surface Water Hydrology Series

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Subject of cover photograph: Lefroy Brook Cascades (by Simon Brett)

For more information about this report, contact the Manager, Surface Water Assessment Section of the Department of Water.

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1 Introduction

Lefroy Brook is located approximately 280 km south of Perth in the south-west of Western Australia. The brook flows in a southerly direction before joining the Warren River approximately 25 km inland (east-north-east) from the mouth of the river, which flows westwards to the coast (Figure 1). This report describes the hydrology of the brook and will be used to help develop environmental flow requirements for the Lefroy Brook catchment.

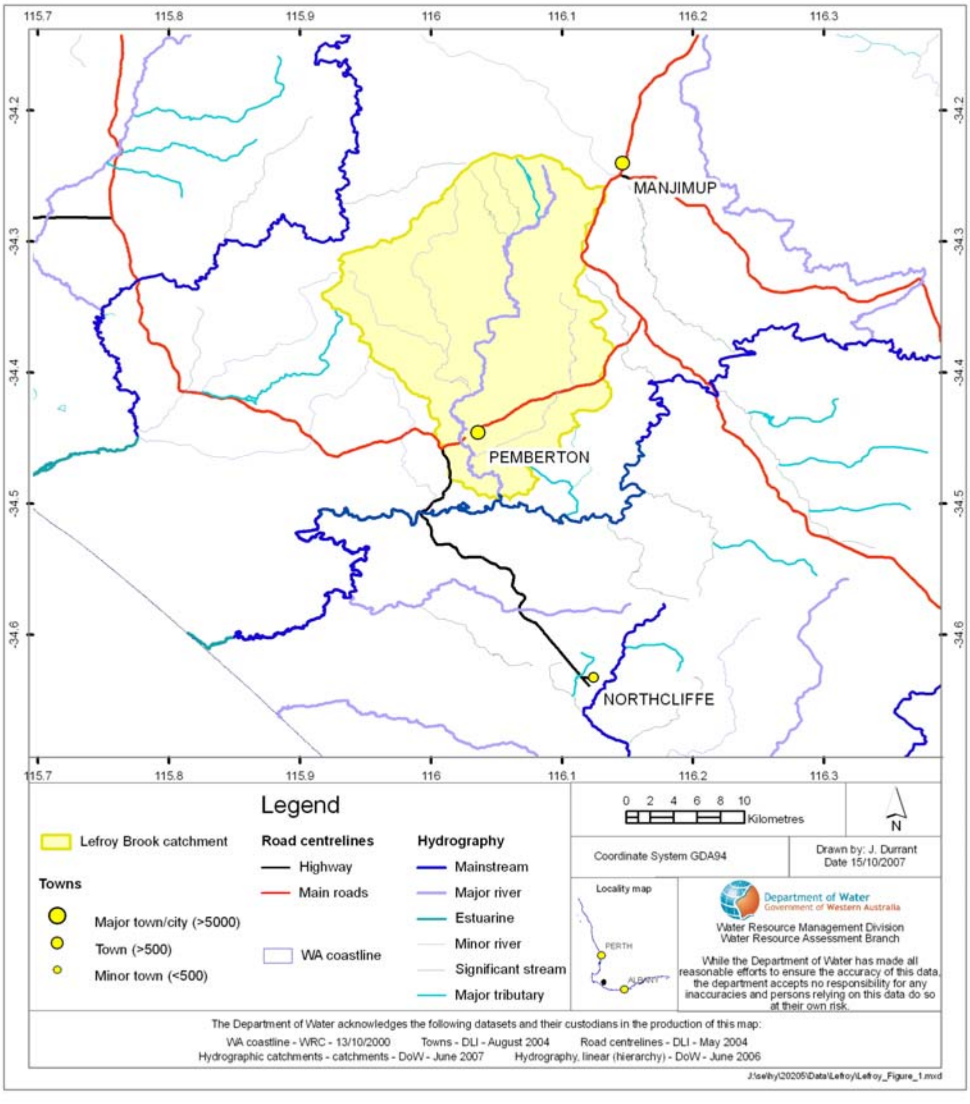

Figure 1 Location of the Lefroy Brook catchment in the south-west of Western Australia

2 Catchment description

The catchment is situated between latitudes 34°14′ and 34°30′ S and longitudes 115°54′ and 116°08′ E. A number of smaller tributaries flow into Lefroy Brook, including Four Mile Brook, Five Mile Brook, Big Brook, Scabby Gully, Jarnadup Brook and East Brook. The total catchment represents an area of approximately 358 km^2.

2.1 Land use

The catchment is approximately 37 per cent cleared. The upper and eastern areas surrounding Lefroy Brook, Scabby Gully, Jarnadup Brook and East Brook have a higher percentage of land clearing (approximately 50 per cent) compared to the western catchment area surrounding Big Brook, Four Mile Brook and Five Mile Brook (approximately 20 per cent cleared).

Agricultural land-use activities in the catchment include cattle and sheep grazing, intensive livestock production, cropping, viticulture and other horticulture (especially apples and vegetables). Cleared catchment areas are characterised by the appearance of private farm dams and water-supply reservoirs (Figure 2). The forests within and surrounding the Lefroy Brook catchment and the town of Pemberton contain significant areas of tall karri trees (*Eucalyptus diversicolor*) and are well known for their tourism value and natural beauty (Figure 3).

Figure 2 Private dams are a common feature of the Lefroy Brook catchment (photograph by Simon Brett)

Figure 3 Karri trees in Lefroy Brook catchment (photograph by Simon Brett)

Large areas of the catchment are allocated to forestry activities and timber reserves, as well as significant areas for national parks, state forest and nature reserves (Figure 4).

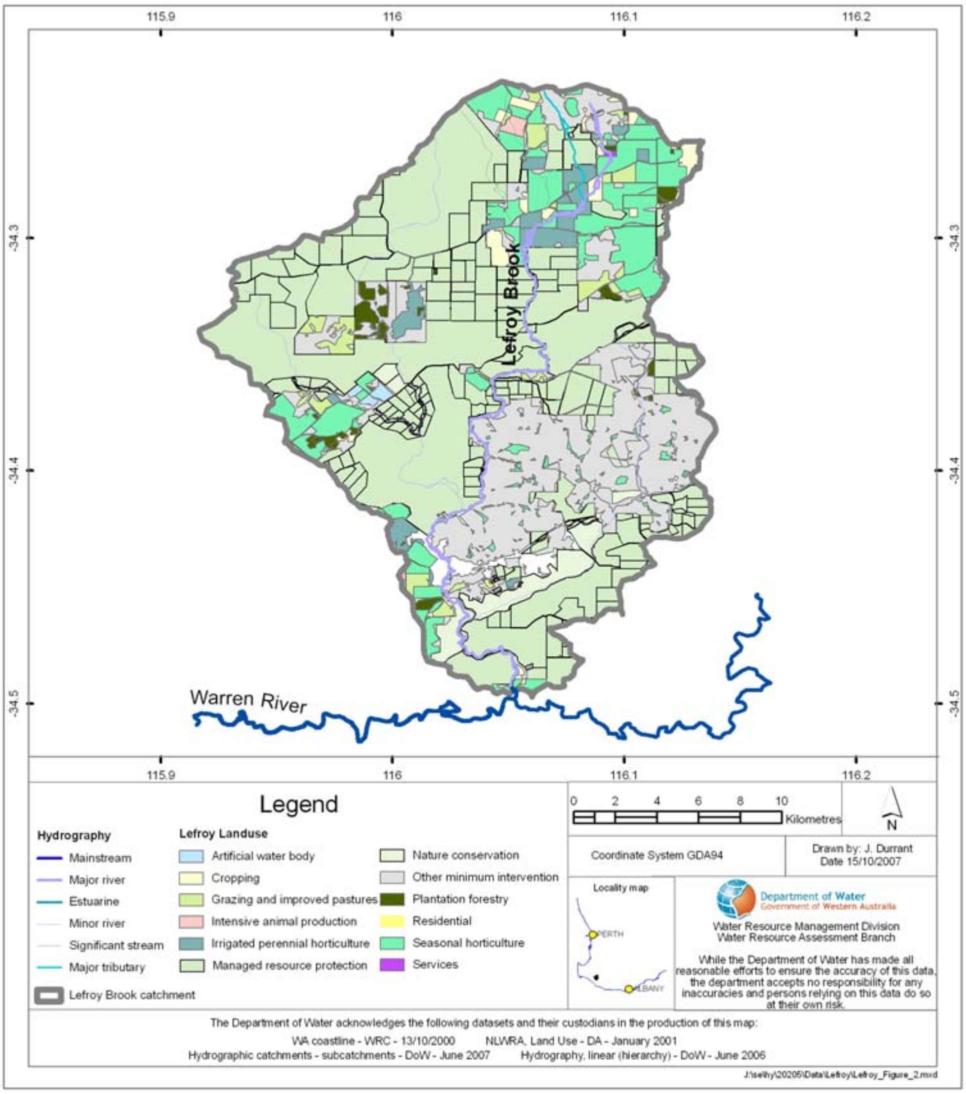

Figure 4 Land use within the Lefroy Brook catchment

2.2 Physiography, geology, landform and hydrogeology

The Lefroy Brook catchment sits on the southward-sloping part of the Darling Plateau known as the Ravensthorpe Ramp physiographical region (De Silva 2004). The area is geologically located on Biranup Complex within the Proterozoic Albany–Fraser Orogen. The Biranup Complex is a deformed metamorphic belt with high-grade quartzofeldspathic gneiss and minor layers of paragneiss (De Silva 2004). The physiography has also been described as dissected undulating land of small relief (Beard 1990).

Groundwater in the Lefroy Brook catchment occurs mainly in the permeable zones of weathered gneissic rocks and is usually semi-confined or confined by an impermeable pallid clay horizon. The weathered rock profile, which overlies bedrock, can be between 5 and 30 m thick. Groundwater flow within the weathered-rock aquifer is characterised mainly by local flow systems. The groundwater salinity is typically less then 1000 mg/L TDS (De Silva 2004). The aquifer recharges through direct rainfall infiltration, and discharges directly to watercourses and wetlands and via evapotranspiration (De Silva 2004). The Lefroy Brook catchment also contains several pocket areas of quartz veins and quartzite in its central and south-eastern areas. These areas form high-yielding fractured-rock aquifers that can store significant amounts of groundwater. Such groundwater pockets are typically fresh with salinity less than 500 mg/L TDS (De Silva 2004).

The soils in the catchment are naturally not very productive agriculturally, but have good physical structure favouring tree growth. They vary from hardsetting loamy soils on the slopes and valleys to leached sandy soils on the upper slopes and ridges (Beard 1990). Karri trees typically dominate on the deep reddish-brown loam soils of hill slopes and valleys, and form high open forests with dense mesophytic undergrowth (Figure 5). Mixed jarrah and marri trees (*Eucalyptus marginata* and *E. calophylla*) are the dominant tree species on the paler leached sands and lateritic podzolic soils of the upper slopes and ridges (Beard 1990) (Figure 6).

Figure 5 Typical characterisation of the vegetation structure found in the loamy hill slopes and valleys (photograph by Simon Brett)

Figure 6 Jarrah and marri trees dominate the lateritic and sandy soil zones (photograph by Simon Brett)

3 Climate

Lefroy Brook catchment has a temperate climate (based on the Köppen classification system) with a typically cool wet winter and a distinct short (3–4 month) warm to hot, dry summer season (Bureau of Meteorology 2006; Beard 1990; De Silva 2004).

In the Lefroy Brook catchment (Figure 7) there is currently one operational meteorological gauging station, at Pemberton (009592). Other meteorological gauges have measured rainfall and other climatic variables at sites within the Lefroy Brook catchment at various times during the last 100 years (Figure 8). Extensive (derived/modelled) rainfall data are available for the Pemberton (009592) and Drummonds meteorological gauging stations (009606).

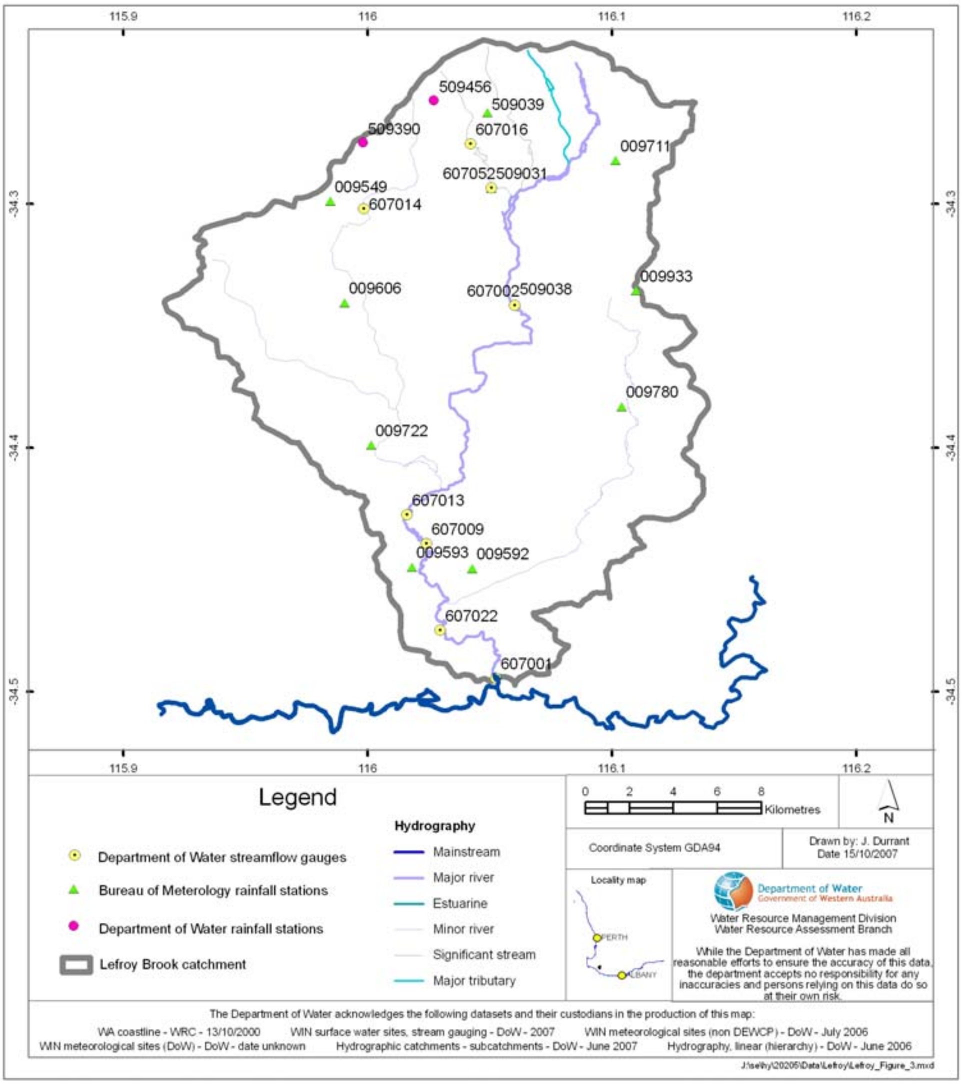

Figure 7 Rainfall and streamflow monitoring stations within the Lefroy Brook catchment

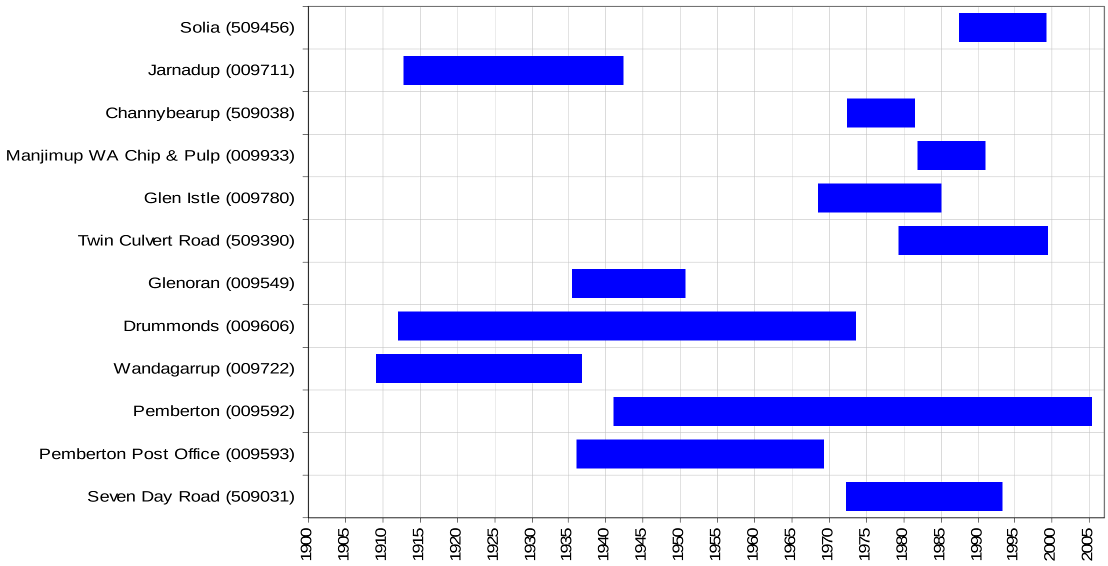

Figure 8 Rainfall monitoring has been undertaken in the catchment since the early 1900s

Variation in rainfall patterns across the catchment is minimal, with mean annual rainfalls (1975 to 2003) of 1123 mm and 1138 mm recorded at Drummonds (009606) and Pemberton (009592) respectively. Annual rainfall at both sites is relatively consistent with a coefficient of variation of 0.18. Many catchments located in the south-west of Western Australia have experienced a significant decrease in mean annual rainfall from the long-term mean since the early 1970s. However, while there has been such a reduction in the Lefroy catchment since 1975 (Figures 9 and 10), it is not as great as observed elsewhere.

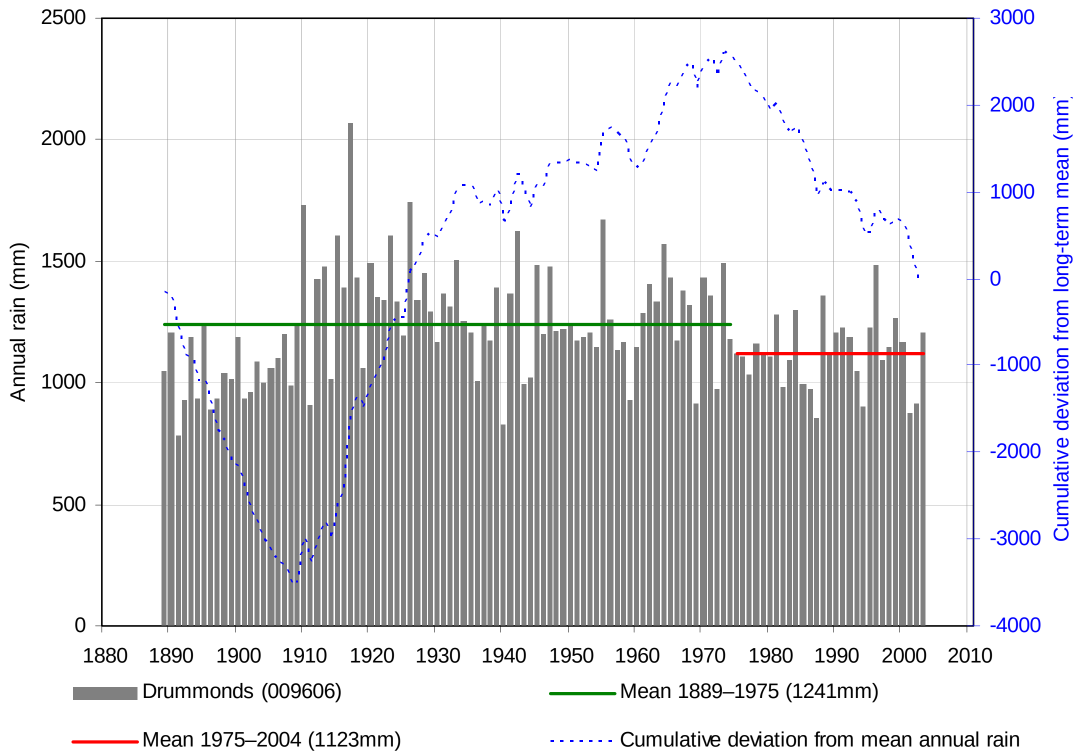

Figure 9 Observed and patched rainfall data for Drummonds (009606)

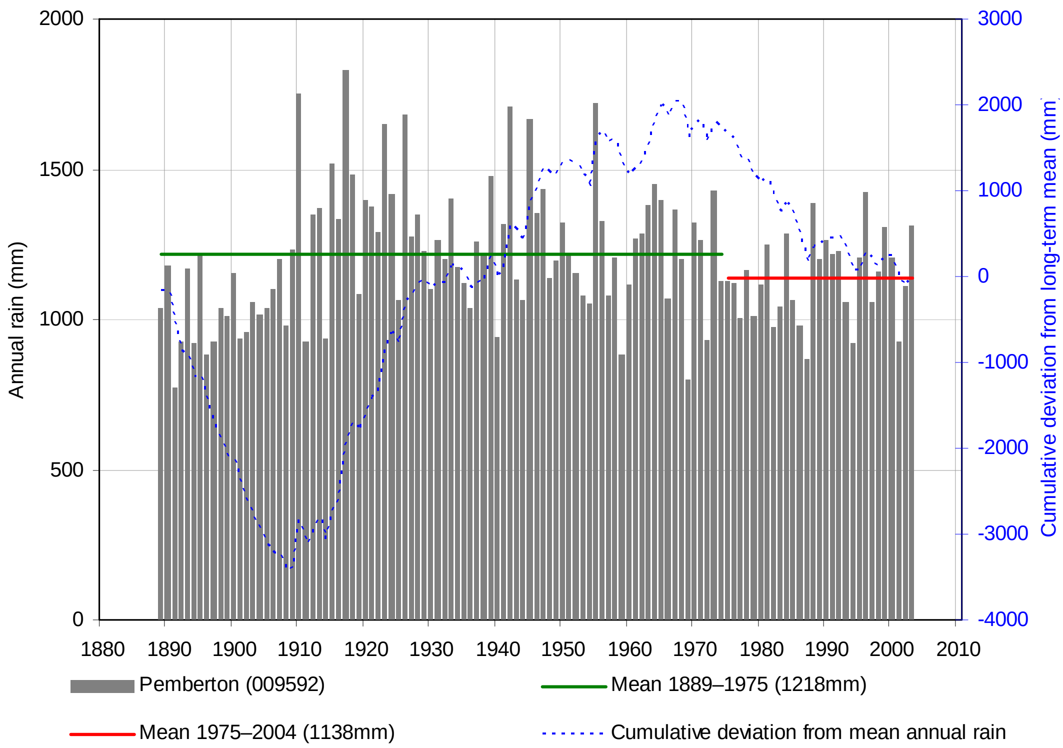

Figure 10 Observed and patched rainfall data for Pemberton (009592)

Rainfall in the Lefroy Brook catchment is highly seasonal, with 73 per cent of the annual rainfall at both Drummonds and Pemberton occurring between May and September (Figure 11). Rainfalls are typically derived from cold fronts crossing the coast in winter; however, high-intensity summer storms do occur as a result of ex-tropical cyclones bringing rain from the north-west.

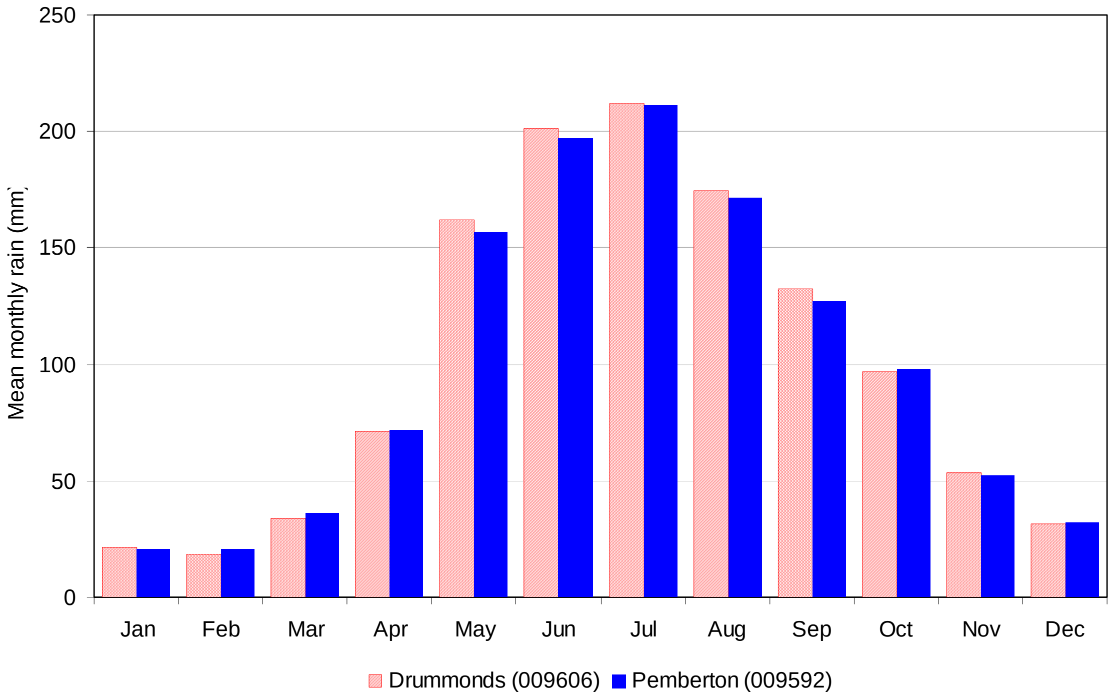

Figure 11 Seasonal rainfall distribution in the Lefroy Brook catchment

4 Streamflow

Within the Lefroy Brook catchment there are currently two operational streamflow-gauging stations, both located on Lefroy Brook: at Rainbow Trail (607013) and at the Cascades (607022) (Figure 12). The Cascades station (607022) records flows from an area of 346 km^2, representing approximately 97 per cent of the catchment. Located approximately 3.3 km upstream of the Warren River confluence, the Cascades gauging station commenced operation in July 1997. This gauging station is of particular interest in terms of characterising flows from the entire Lefroy Brook catchment, as it is the closest to the confluence with the Warren River and it is currently still operational. The Rainbow Trail gauging station is situated a further 5.5 km upstream (approximately 1.5 km upstream of the Pemberton Weir) and it records flows from a catchment area of 249.3 km^2, or 70 per cent of the Lefroy Brook catchment. It commenced operation in May 1979.

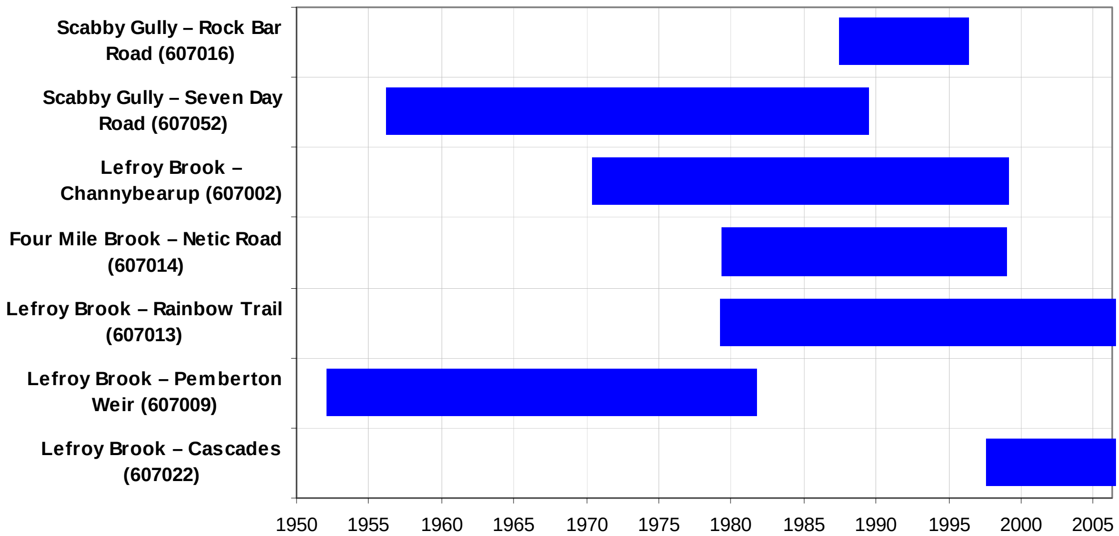

Figure 12 Streamflow gauging stations in the Lefroy Brook catchment

The observed streamflow records from the Rainbow Trail gauging station have been extended back to 1952 using a correlation (r^2 = 0.996, Figure 13) with observed daily streamflow records, 1.5 km downstream, at the Pemberton Weir gauging station (607009).

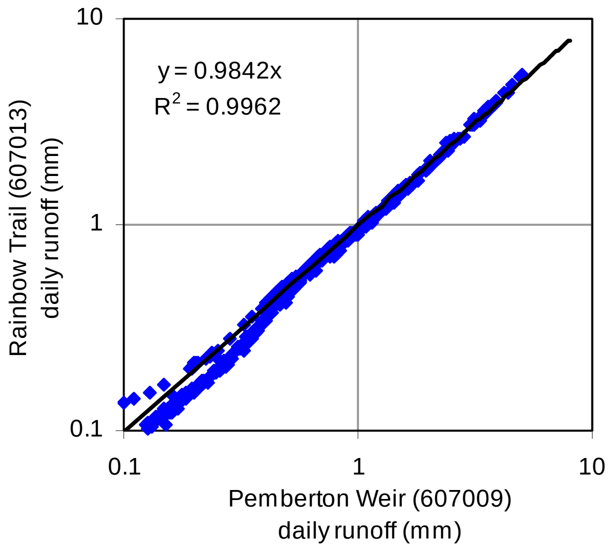

Figure 13 Streamflow correlations between Rainbow Trail (607013) and Pemberton Weir (607009)

To complete missing data and gaps in the correlated and observed set of records for the Rainbow Trail gauging station (extended from 1952 to 2004), the Continuous Simulation System (CSS) was prepared and calibrated, based upon 16 years of uninterrupted observed data (1989 to 2004). Calibrated parameters were then applied to a daily rainfall runoff model to simulate runoff using the AWBM 2000 model. Figure 14 compares observed discharge with the estimated discharge produced by the model for monthly and yearly totals over the calibration period. Calibration results were assessed using several methods, including the coefficient of efficiency (E) (Nash & Sutcliffe 1970), the mean absolute error (MAE) and the root of the mean square error (RMSE). These results, along with the final parameter set, can be found in the Appendix. The monthly discharge totals predicted by the model have a coefficient of efficiency (E) of 0.93. Similarly, yearly totals have an E of 0.84.

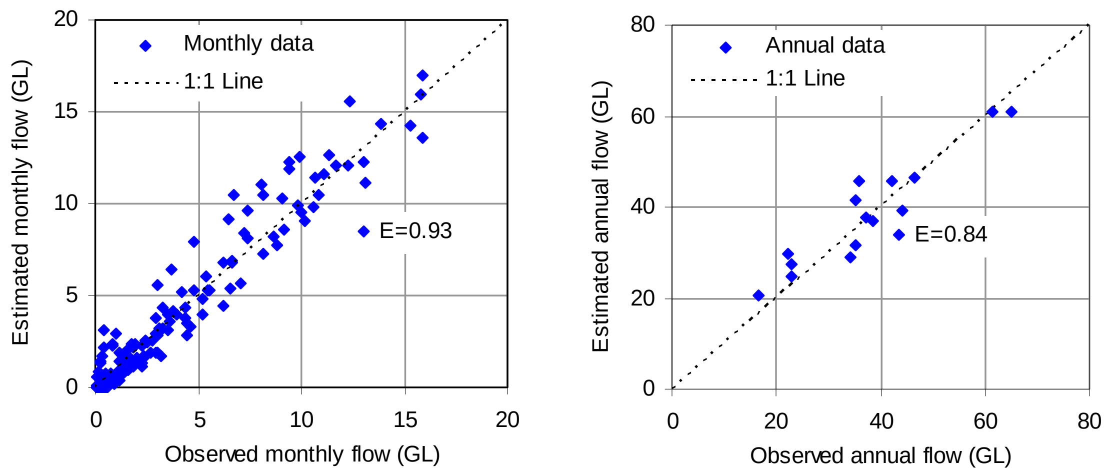

Figure 14 Comparison between observed and modelled discharge at Rainbow Trail gauging station (607013)

The calibrated model parameters were then applied to the longer period (1952 to 2004) of daily rainfall and evaporation data to obtain estimated streamflow records for the Rainbow Trail gauging station for the extended period. The modelled streamflow records were then used to complete data gaps in the observed records at this station.

The relatively short period of record available at the Cascades gauging station made extending the data series, through the use of modelling, impractical. However, a strong positive correlation (r^2 = 0.962) with observed daily streamflow from the Rainbow Trail gauging station has made it possible to derive estimations for the Cascades data series, extending streamflow records back to 1952 (Figure 15).

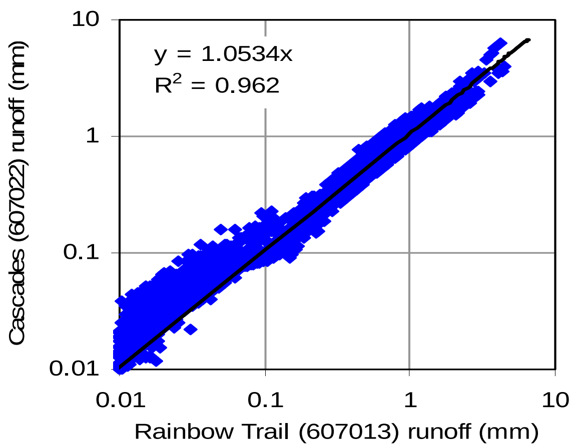

Figure 15 Correlation between observed streamflow at Cascades (607022) and Rainbow Trail (607013).

4.1 Annual streamflow

Annual flow in the Lefroy Brook at the Cascades is variable. The observed mean annual flow in the seven complete years of record (1997 to 2004) is 50.9 GL, with a coefficient of variation of 0.42. A minimum observed annual flow of 22.3 GL was recorded in 2001; this corresponds with the sixth driest year on record. A maximum observed annual flow of 90.3 GL was recorded in 1999, the only year of observed streamflow to exceed the estimated long-term annual mean. The combined observed and estimated annual streamflow data set at the Cascades has an estimated long-term annual mean of 69.2 GL and a coefficient of variation of 0.40 (Figure 16). Consistent with a decrease in rainfall, there is also a noticeable decrease in streamflow from the early 1970s. Since 1975 the estimated mean annual streamflow has decreased to 57.9 GL with a coefficient of variation of 0.35. It is estimated that annual flows reached their maximum in 1963 with an approximate volume of 138.0 GL, almost twice the long-term annual mean, while 1987 was the driest year between 1952 and 2004, with the annual flow as low as 17.2 GL, or less than one-quarter of the long-term mean.

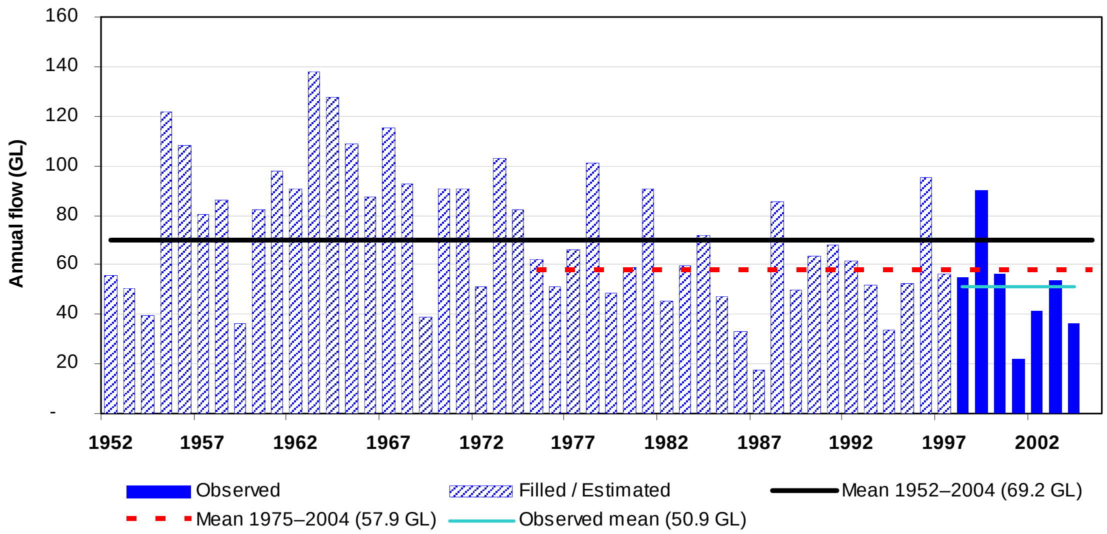

Figure 16 Annual streamflow at Cascades (607022)

4.2 Monthly streamflow

Monthly streamflow is highly seasonal and follows trends similar to those observed in rainfall records (Figure 17), with 85 per cent of the annual flow occurring between June and October.

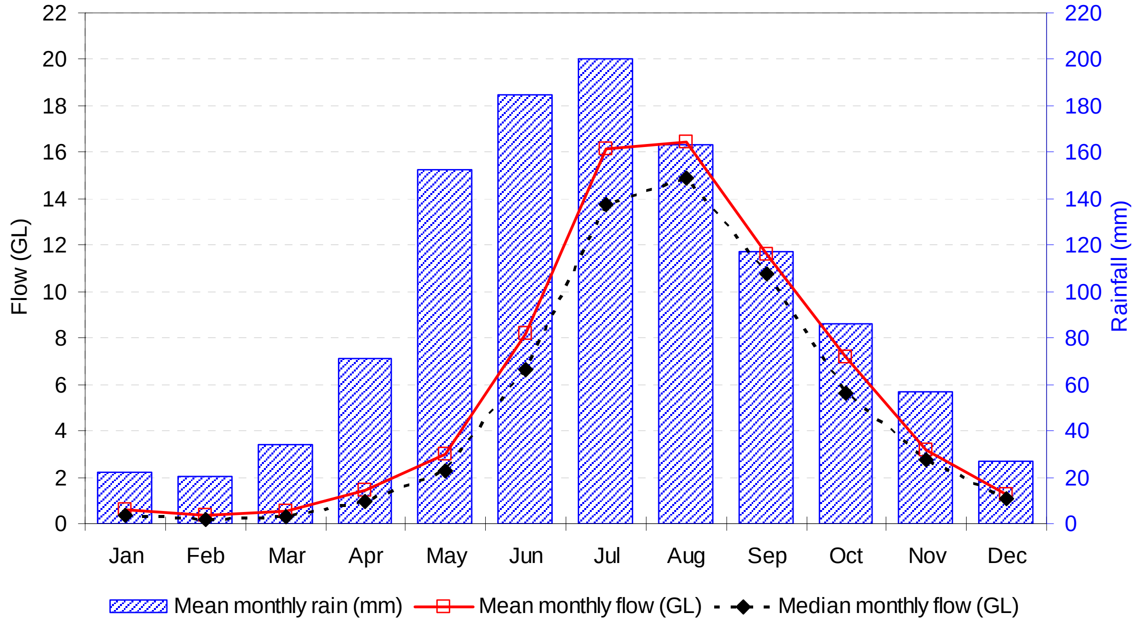

Figure 17 Monthly streamflow at Cascades (607022)

There is a lag of approximately one month between the peak in the mean monthly rainfall and that in the mean monthly streamflow. This is characteristic of soils with large storage capacity, but the lag is also a response to the large storage of the catchment, primarily brought about by the high number of private dams retaining large quantities of runoff.

Highest flow volumes (both median and mean) are recorded in August, with very little flow occurring between December and April.

A Log Pearson type III distribution was fitted to the peak annual flow series for the Cascades extended data set (Figure 18).

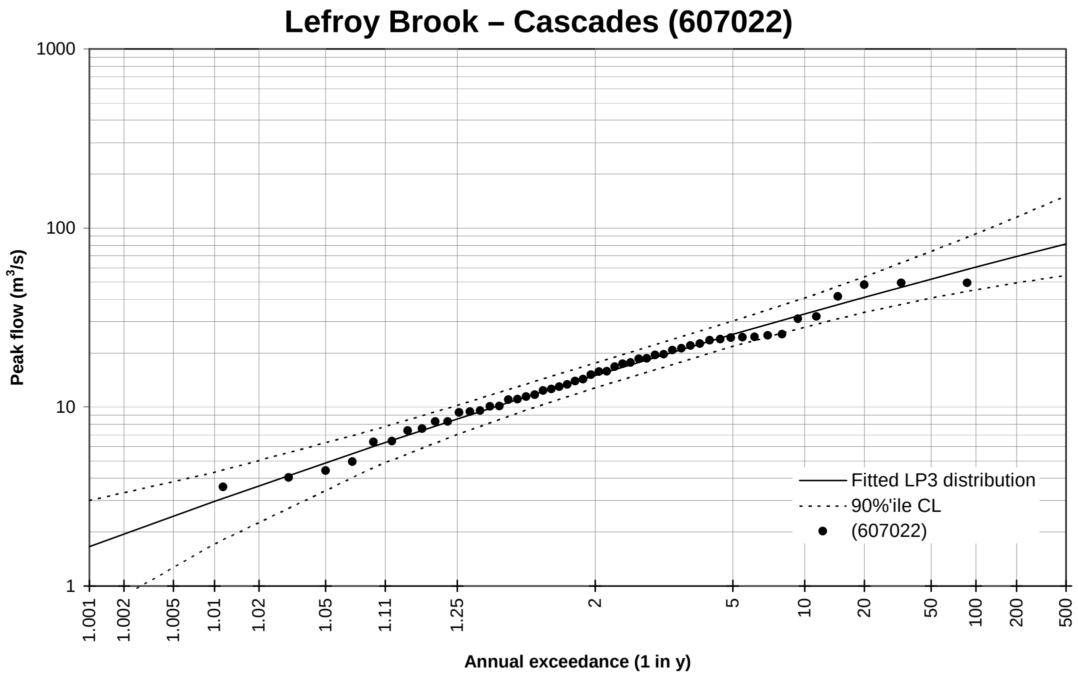

Figure 18 Flood-frequency analysis plot for Cascades (607022)

Table 1 Annual series flood-frequency data for Lefroy Brook at Cascades (607022)

Average recurrence interval (1:year)	Annual exceedance probability (%)	Peak annual flow (m^3/s)	50% AEP growth factor
1:1.1	90.9	6.09	–
1:2	50	15.0	–
1:5	25	25.4	1.69
1:10	10	33.2	2.21
1:20	5	41.0	2.73
1:50	2	51.9	3.46
1:100	1	60.4	4.03

4.3 Daily streamflow

The baseflow occurring at the Cascades gauging station (607022) was calculated and modelled using the FLBFLOW component of the Continuous Simulation System (CSS). FLBFLOW partitions a given streamflow into surface runoff and baseflow, and it is also used to calculate the Baseflow Index. This indicated that on average 66.5 per cent of the total annual flow is derived from baseflow (i.e. a baseflow index of 66.5 per cent). Annual flows had a range of baseflows, from 58 per cent to as high as 74 per cent. However, for individual storm events the baseflow index can vary much more than the annual baseflow index. For example, in 1965 a March storm event had a total baseflow index of 43 per cent and, during the peak day of flow, a baseflow index of 13 per cent was observed. This indicates a high proportion of the total flow was a result of infiltration excess, whereas a storm event in late October the same year had a total baseflow index of 85 per cent.

Highest streamflow discharges at the Cascades (607022) were estimated to have occurred during storm events in August 1962 and August 1964, with daily flows of 4170 ML/d and 4220 ML/d respectively.

Flow-duration analysis for all the observed data indicated that 95 per cent of all days had flow greater than or equal to 0.01 ML, the median daily flow being 77.6 ML (Figure 19). Categorising of the daily flows into months suggested two groupings at the Cascades (Figure 20):

- December through April, where the median daily flow is less than 32 ML/d and flows greater than 0.01 ML/d are exceeded 81–94 per cent of the time
- May through November, where the median daily flow is greater than 61 ML/d and flow is continuous throughout the month.

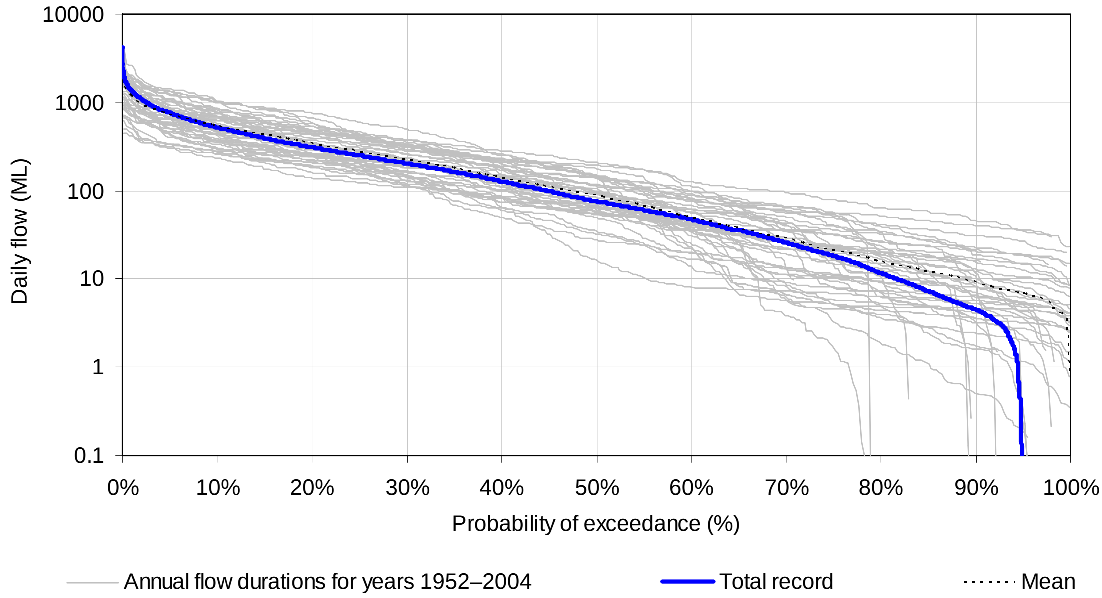

Figure 19 Daily flow-duration curves for Cascades (607022)

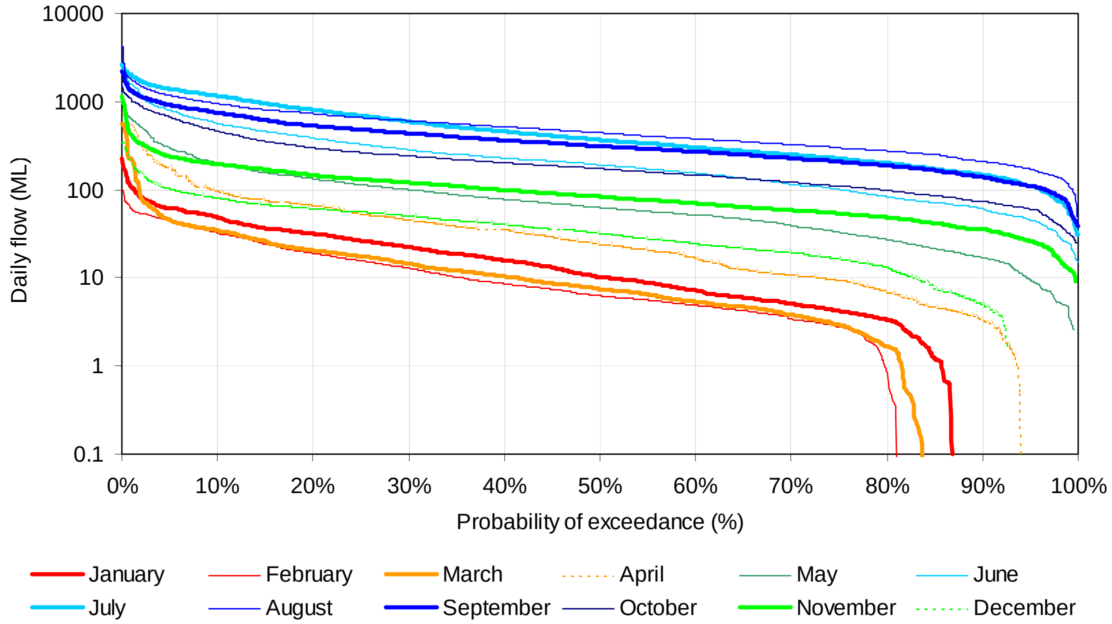

Figure 20 Daily flow-duration curves for Cascades (607022), categorised into months

5 Conclusion

The Lefroy Brook catchment is located in south-west Western Australia. The catchment covers an area of 358 km^2 and is approximately 37 per cent cleared. Rainfall data have been taken from the Drummond and Pemberton gauges within the catchment. Rainfall is highly seasonal, and mean annual rainfall has slightly decreased since the early 1970s. The streamflow record at Cascades gauging station (607022) has been extended through correlation with the Rainbow Trail and Pemberton Weir gauging stations. A daily rainfall runoff model has been used to fill gaps in the streamflow record and to develop a baseflow series for the Brook. An average of 66.5 per cent of flow observed at the gauging station is from baseflow contribution; however, this can vary seasonally and with individual storm events.

The extended flow record has a mean annual flow of 69.2 GL. Inter-annual variation in flow is comparable to that of other south-west streams, with a coefficient of variation of 0.4. There has been a decrease in annual flow since the 1970s, average annual flow from 1975 to present being 57.9 GL compared to the long-term average of 69.2 GL. Streamflow is highly seasonal, with 85 per cent of annual flow occurring between June and October. There is a one-month lag between peak flow and peak rainfall, indicating a large soil and catchment storage capacity.

Though flow is not perennial, daily flow has been greater than 0.01 ML for 95 per cent of days. Daily flow-duration analysis indicated that flow is continuous from May to November, with a median daily flow of 61 ML.

Appendix

Table A Statistics comparing the observed and simulated results of the CSS calibration for Lefroy Brook at Rainbow Trail

Statistic (1976–1995)	Observed	Modelled
Annual		
Average (mm)	151.38	153.51
Standard deviation (mm)	53.15	46.74
Mean absolute error (MAE) (mm)		17.01
Root mean square error (RMSE) (mm)		20.61
Coefficient of efficiency (E)		0.84
Monthly		
Average (mm)	12.62	12.79
Standard deviation (mm)	16.00	16.73
Mean absolute error (MAE) (mm)		2.58
Root mean square error (RMSE) (mm)		4.08
Coefficient of efficiency (E)		0.93
Daily		
Average (mm)	0.41	0.42
Standard deviation (mm)	0.61	0.61
Mean absolute error (MAE) (mm)		0.13
Root mean square error (RMSE) (mm)		0.25
Coefficient of efficiency (E)		0.82

Where:

MAE is calculated as $\frac{1}{N}\sum\left|O_i - S_i\right|$ and has a range of 0 to infinity and a perfect score of 0

RMSE is calculated as $\sqrt{\frac{1}{N}\sum\left(O_i - S_i\right)^2}$ and has a range of 0 to infinity and a perfect score of 0

and E is calculated as $1 - \frac{\sum\left(O_i - S_i\right)^2}{\sum\left(O_i - \overline{O}\right)^2}$ and has a range of negative infinity to 1 and a perfect score of 1

and where O represents the observed data point, S the simulated data point and N the total number of observations.

Table B Final CSS parameter set for Lefroy Brook at Rainbow Trail

Parameter	Value
Capacity C1 – mm	9
Capacity C2 – mm	260
Capacity C3 – mm	985
Area A1 0<=A1<=1	0.119
Area A2 0<=A2<=1	0.255
Area A3 0<=A3<=1	0.626
Baseflow index (BFI) 0<=BFI<=1	0.665
Baseflow recession constant Kbase 0<=KBase<=1	0.942
Surface runoff recession constant Ksurf 0<=Ksurf<=1	0.650

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