Department of Water
Government of Western Australia

Looking after all our water needs

Wilyabrup Brook hydrology summary

Department of Water

Surface Water Hydrology Series

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Subject of cover photograph: Wilyabrup Brook (by Mary-ann Coppolina)

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1 Introduction

Wilyabrup Brook is located between Cape Naturaliste and Cape Leeuwin on the south-west coast of Western Australia, approximately 250 km south of Perth (Figure 1). The brook originates west of the Dunsborough Fault and flows westward to the coast. This report discusses the hydrology of the brook and will be used as an aid in developing ecological water requirements for the Wilyabrup Brook catchment.

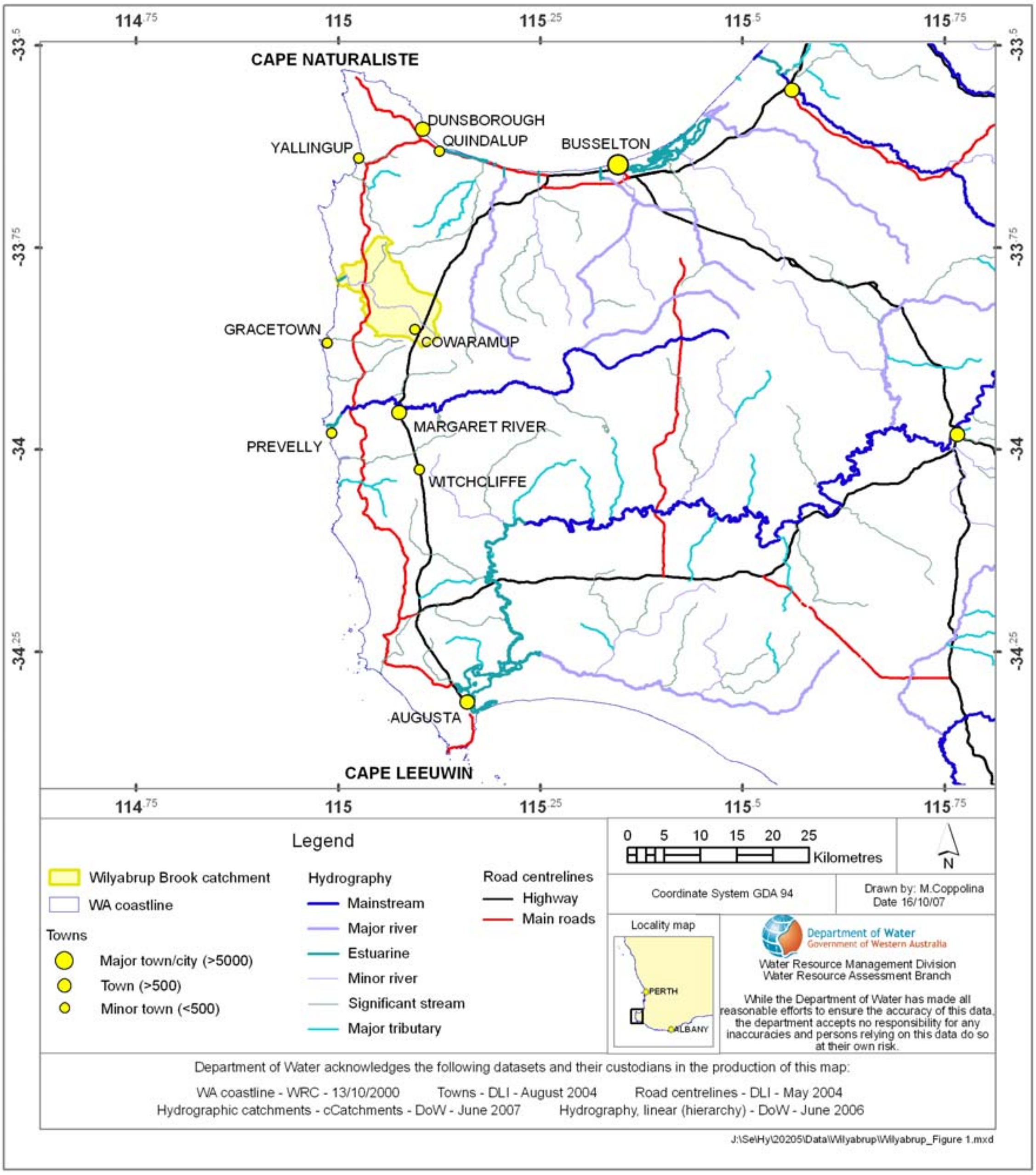

Figure 1 Location of Wilyabrup Brook, south-west corner of Western Australia

2 Catchment description

The Wilyabrup Brook catchment covers an area of 89.2 km^2. The Brook courses north-west and discharges to the Indian Ocean at Wilyabrup Estuary. The town of Cowaramup lies on the Bussell Highway towards the catchment's eastern boundary.

Wilyabrup Brook extends approximately 11.5 km inland with a total stream length of almost 20 km. Woodlands Brook flows from the north-east corner of the catchment and joins Wilyabrup Brook 2 km upstream of the Woodlands gauging station (610006) (Figure 2). A second gauging station that records flows from the upper section of Wilyabrup Brook was opened in 2004 (Juniper 610028). Three meteorological stations in the catchment provide the data used in this study (Figure 2).

2.1 Land use

The Wilyabrup Brook catchment has been progressively cleared for farming, grazing and viticulture. By 1996, 75 per cent (or 66.6 km^2) had been cleared, but most clearing took place around 1925/1930 as part of Settlement Schemes (Public Works Department 1984). The levels of clearing for the two gauged catchments are 79 per cent (610006) and 80 per cent (610028), indicating a uniformity of clearing across the catchment. Below gauge 610006 the catchment is predominantly uncleared to the outlet. Viticulture is the dominant land use, with olive growing and dairy farming also taking place.

A significant number of dams have been constructed both on and off Wilyabrup Brook in association with different land-use needs. The impact of these dams on the water balance of the catchment has yet to be quantified, but is likely to be significant. The total volume of these dams has been calculated in a study parallel to this work (Boniecka in press), and this information will be used in the development of ecological flows for the catchment.

2.2 Geology

Wilyabrup Brook crosses two physiographic regions – the Leeuwin–Naturaliste Coast and the Margaret River Plateau. The former is a 0.2–6 km strip of land along the Cape to Cape coast, while the Margaret River Plateau is 5 to 15 km wide and is dissected by a series of valley systems (Tille & Lantzke 1990).

The two major geological features within the catchment are the Leeuwin Complex and the Leederville Formation. The Leeuwin Complex was formed in the Proterozoic period (Marnham et al. 2000), and is overlain by the Cowaramup, Caves Road and Quindalup regolith-landform systems (Marnham et al. 2000).

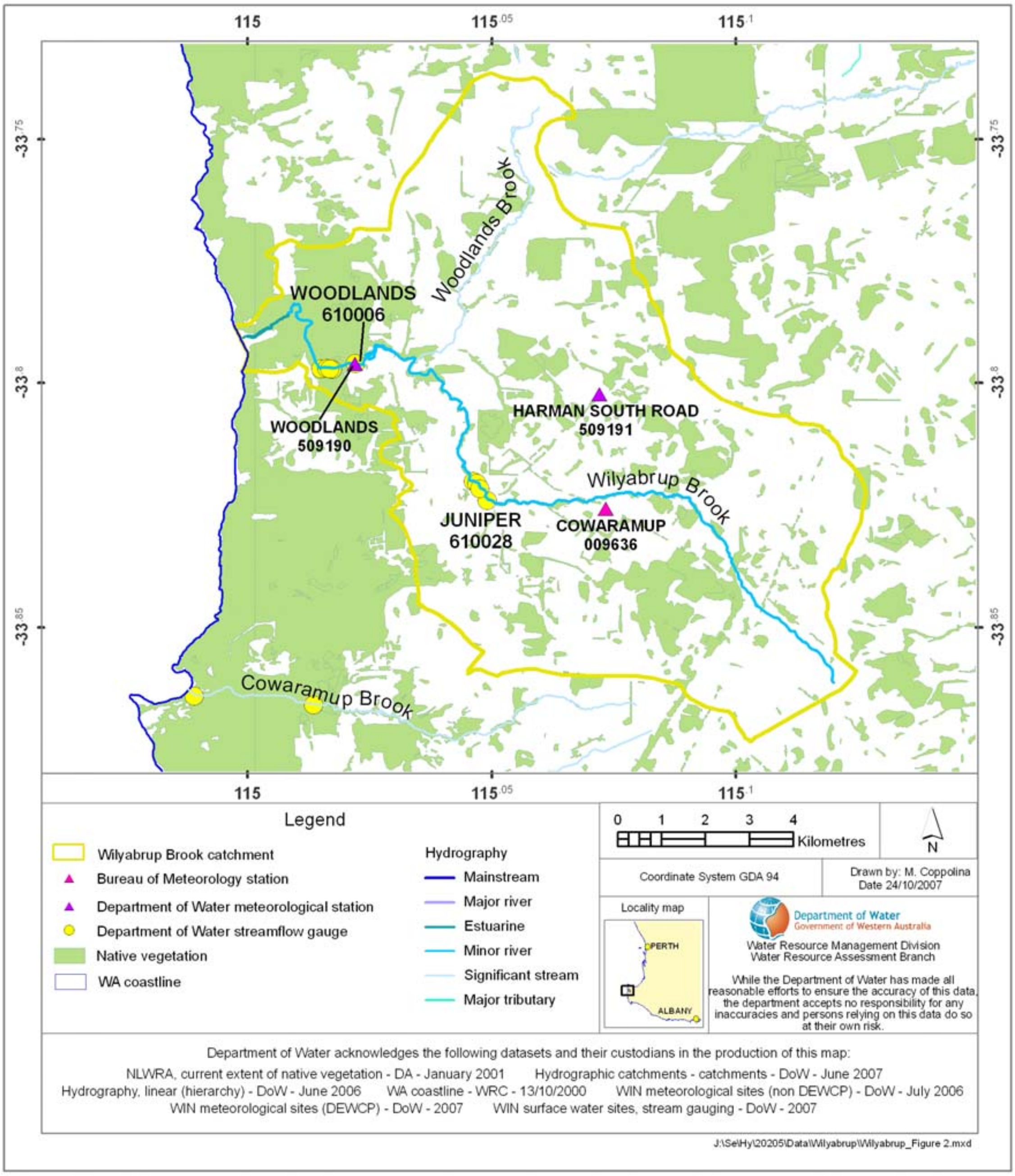

Figure 2 Wilyabrup Brook catchment, showing streamflow and rainfall gauges and vegetated area

The Leederville Formation, which is part of the cretaceous sequence, onlaps the Leeuwin Complex on the eastern side of the catchment (Marnham et al. 2000). The Treeton regolith-landform system is underlain by the Leederville Formation (Marnham et al. 2000). The Spearwood regolith-landform system is the only other system occurring in the Wilyabrup catchment (Marnham et al. 2000).

The Cowaramup System is the dominant landform system in the catchment (Figure 3). It consists of low hills and rises, with gentle to moderate slopes (Marnham et al. 2000), and nearly all of the streamlines within the catchment lie within it. The range of alluvial deposits in the streambeds includes boulders, silty, clayey sand and fresh to slightly weathered bedrock. Granulite and granite outcrops are evident where the streambed is incised into the Proterozoic Leeuwin Complex (Figure 4). These outcrops become more common toward the coast (Marnham et al. 2000).

The Caves Road System, which occurs in patches across the north of the catchment, contains thick podzolised sands composed almost entirely of quartz (Marnham et al. 2000).

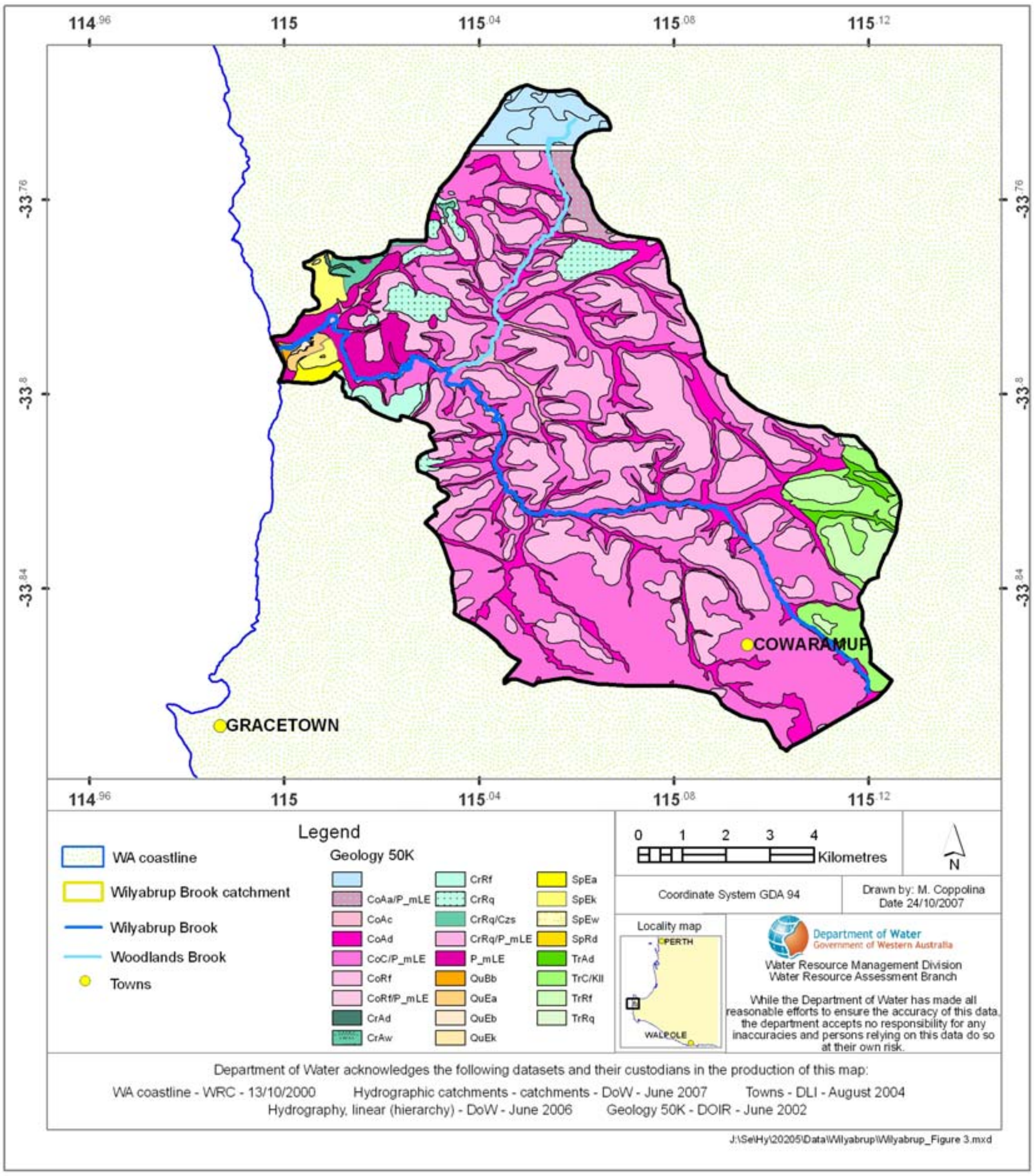

Figure 3 50K geology mapping of Wilyabrup Brook catchment

2.3 Groundwater

Research suggests that small to moderate supplies of fresh shallow groundwater are locally available from the sand and duricrust covers of the Treeton System (Blackwood Plateau groundwater system) (Marnham et al. 2000). Within the Cowaramup System (Margaret River Groundwater System) the groundwater tends to be brackish to saline and is generally low yielding (Marnham et al. 2000). Within the Quindalup and Spearwood systems (Leeuwin–Naturaliste Coast Groundwater System) rapid channel flow occurs within the limestone, as a consequence of which a watertable is often not developed (Marnham et al. 2000).

Figure 4 Proterozoic crystalline material in lower Wilyabrup Brook (photo taken February 2006)

Despite this, there are numerous private bores across the catchment, the first recorded drilling having taken place in 1920. The majority of these bores were drilled to a maximum depth of 10 m below the ground surface. The Water Corporation drilled several bores in 1995, with the deepest reaching 46 m. The majority of the private bores are used for watering livestock, with some operated for domestic or household use. When about half of these bores were sampled in 1977, it was found that water levels ranged from 4.6 to 0.0 m below the ground surface and salinity ranged from 100 to 840 mg/L.

2.4 Vegetation

Based on clearing figures from 1996, only 25 per cent of Wilyabrup Brook catchment remains forested. The catchment would once have been covered in marri/jarrah forest, but the suitability of the land for grazing and viticulture has led to the large amounts of clearing (Tille & Lantzke 1990).

Several weed species have been identified in the catchment. ‘Declared' weeds are those listed in the *Agriculture and Related Resources Protection Act 1976* because they are considered to have a potential or actual detrimental impact on agricultural activities. ‘Environmental’ weeds, not listed in the Act, are thought to be a threat to local or regional biodiversity. During a weed audit conducted by the Shire of Busselton it was found that three declared and two environmental weed species were present in the catchment, the declared weeds being apple of sodum, arum lily and cape tulip, and the environmental weeds bridal creeper and watsonia (Shire of Busselton 2002).

3 Climate

Wilyabrup Brook catchment has a temperate climate (based on the Köppen classification scheme), with a distinctly dry (and warm) summer and marked winter rainfall (Bureau of Meteorology 2006).

Three gauges have recorded rainfall in the catchment (Figure 2). Two of these were pluviometers (509190 and 590191) operated from 1973 to 1999 by the Water and Rivers Commission. The remaining gauge, 009636, is operated by the Bureau of Meteorology and has been open since 1926. The bureau's station records both rainfall and evaporation.

Annual rainfall recorded at the three gauges from 1973 onwards is shown in Figure 5. Rainfall in the catchment increases from north to south and west to east.

Using the Thiessen weighted polygon method, a centroidal daily rainfall series was developed for the catchment. As stations 509190 and 509191 began operation in mid-1973 and closed in early 1999, these two years were excluded and the series was analysed from 1974 to 1998. The monthly breakdown of this series shows the highly seasonal nature of the rainfall where, on average, more than 100 mm falls each month from May to September (Figure 6). The catchment receives 78 per cent of its annual rainfall over this period.

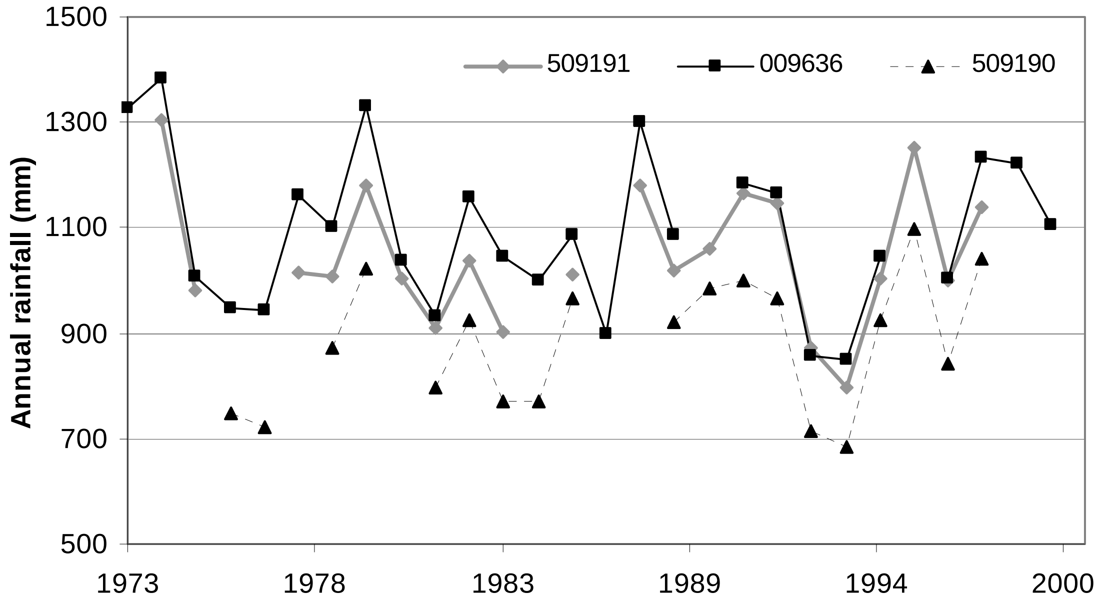

Figure 5 Annual rainfall records at stations 509190, 509191 and 009636

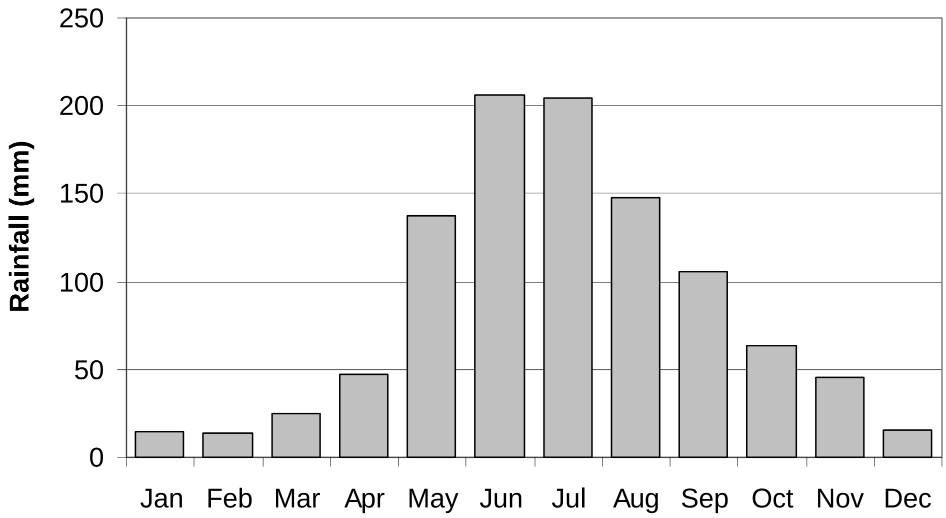

Figure 6   Monthly centroidal rainfall averages for Wilyabrup Brook catchment

Station 009636 is the only gauge in the catchment that has recorded long-term rainfall. Although the gauge began operation in March 1926, no observed data are available for 1928 to 1940. Modelled rainfall from the SILO dataset has been included for this period and for several other years where data gaps existed.

The record at 009636 shows a decrease in rainfall in the catchment (Figure 7). Based on the plot of cumulative deviations from the mean, the decline in rainfall began in the latter half of the 1960s. During the period 1926 to 1974 the average rainfall was 1180 mm/year while for 1975 to 2003 the average was only 1065 mm/yr, a drop of 10 per cent. The largest observed annual rainfall, of 1540 mm, was measured at the gauge in 1961, when there were five events that brought about total daily rainfalls of greater than 50 mm. The only other year when this phenomenon occurred was 1956. The lowest observed annual rainfall occurred in 1969, when only 820 mm was recorded.

Station 009636 is also the only site within the catchment where evaporation has been recorded. Average annual evaporation for 1975 to 2003 was 1340 mm, 1.26 times the average rainfall. During this period, annual evaporation ranged from 1210 mm to 1530 mm.

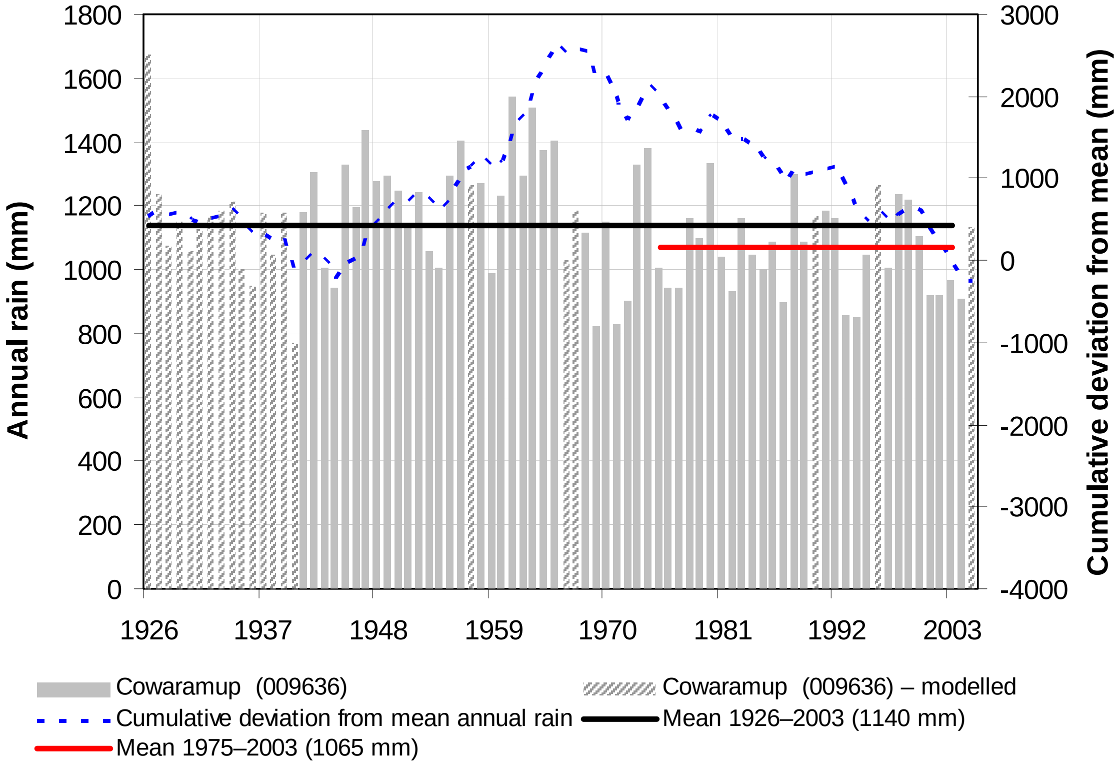

Figure 7 Annual rainfall record at station 009636

4 Streamflow

Two streamflow gauges (610006 and 610028) operate along Wilyabrup Brook (Figure 2). The Woodlands gauge (610006), which records flow from 82.3 km^2 of the catchment, has been operating since 1973. The second gauge, Juniper (610028), commenced operation in 2004 and records streamflow from a 43.6 km^2 catchment. Figure 8 shows the catchments for the two gauges.

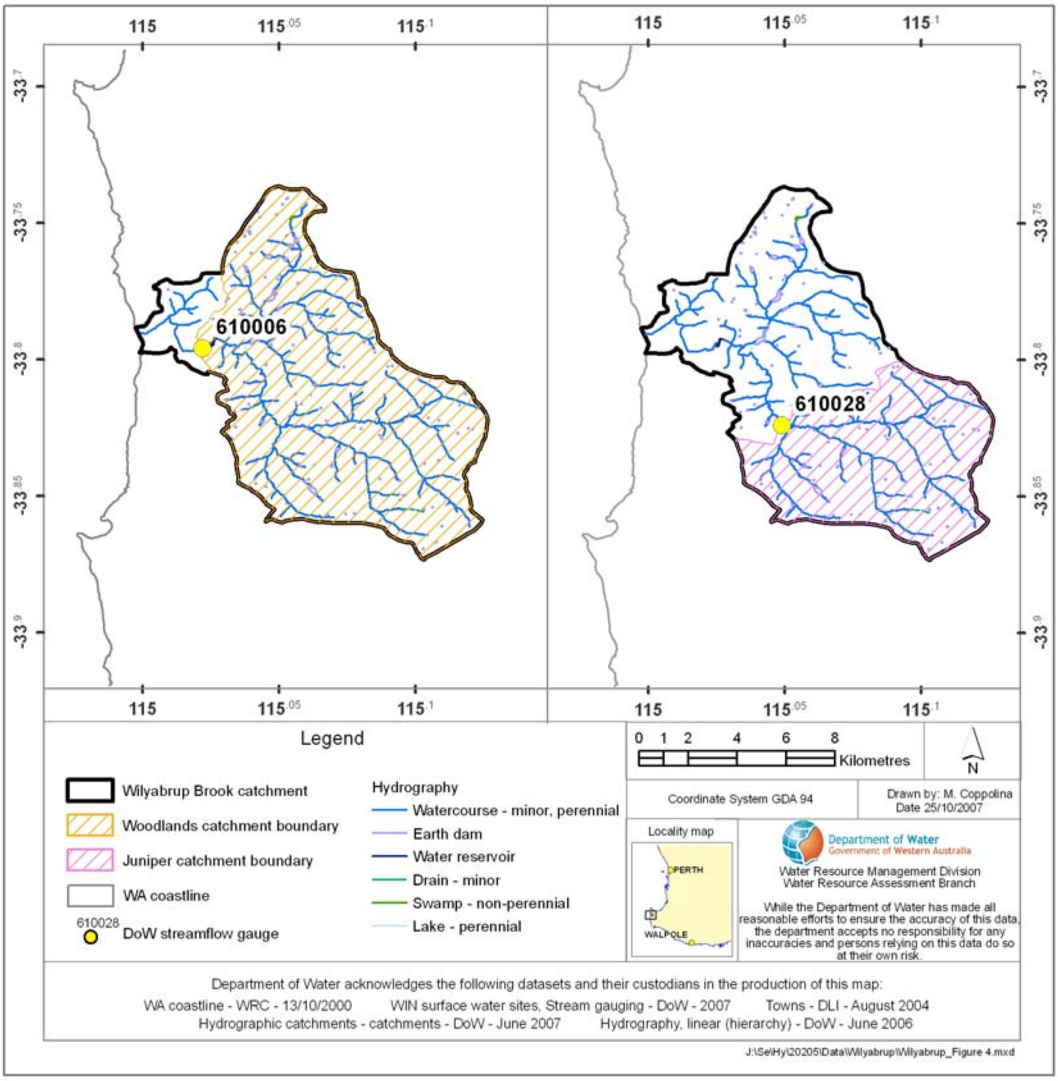

Figure 8 The catchments contributing to the Woodlands (610006) and Juniper (610028) streamflow gauges

The Woodlands gauge provides the long-term record for the catchment, the most valuable data set available to describe the hydrology of the brook. As a result, the main focus of this chapter is an analysis of the data at the Woodlands gauge. The data at the Juniper gauge have been extended using the Woodlands gauge records, and are discussed later in the chapter.

4.1 Woodlands — 610006

Analysis of the Woodlands gauge records showed two periods of missing data, the longest of these being 41 consecutive days. The Continuous Simulation System (CSS) was run in order to fill the data gaps and also to develop a partitioned baseflow series. The CSS is a suite of tools that can be used to calibrate individual parameters of a rainfall–runoff model. The calibrated model can then be used to simulate runoff. The rainfall–runoff model that forms part of the CSS is AWBM2000.

AWBM2000 requires a daily rainfall file, the area of the catchment, evaporation records and nine calibrated parameters in order to simulate daily runoff. The centroidal rainfall derived by means of the Thiessen weighted polygon (described in section 2.4) was used as the catchment rainfall series. The model was calibrated from 1976 to 1995 and verified for the years 1974, 1975 and 1996 to 1998.

The calibration produced a good fit to the observed data. The model calibration uses three tools, each focusing on different parameters, and is an iterative procedure using manual and automated processes. 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. Monthly and annual model efficiencies (E) for the calibration period were calculated at greater than 0.9 (Figure 9). At a daily timestep the model also performed well, with an efficiency of 0.78. Hydrographs for the calibration and verification periods further illustrate the accuracy of the CSS calibration (Figure 10).

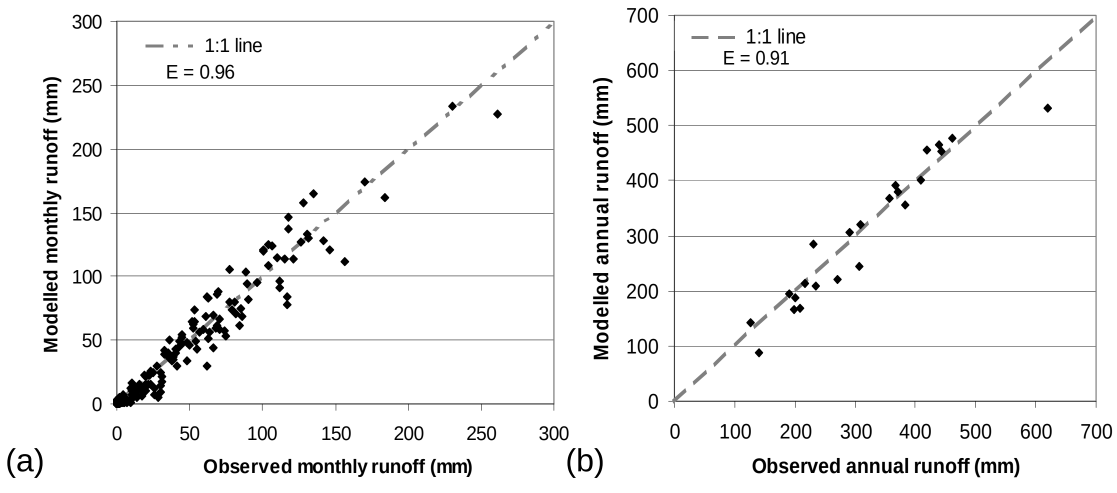

Figure 9 Modelled runoff versus observed runoff at Woodlands gauge: results for (a) monthly timescale and (b) annual timescale

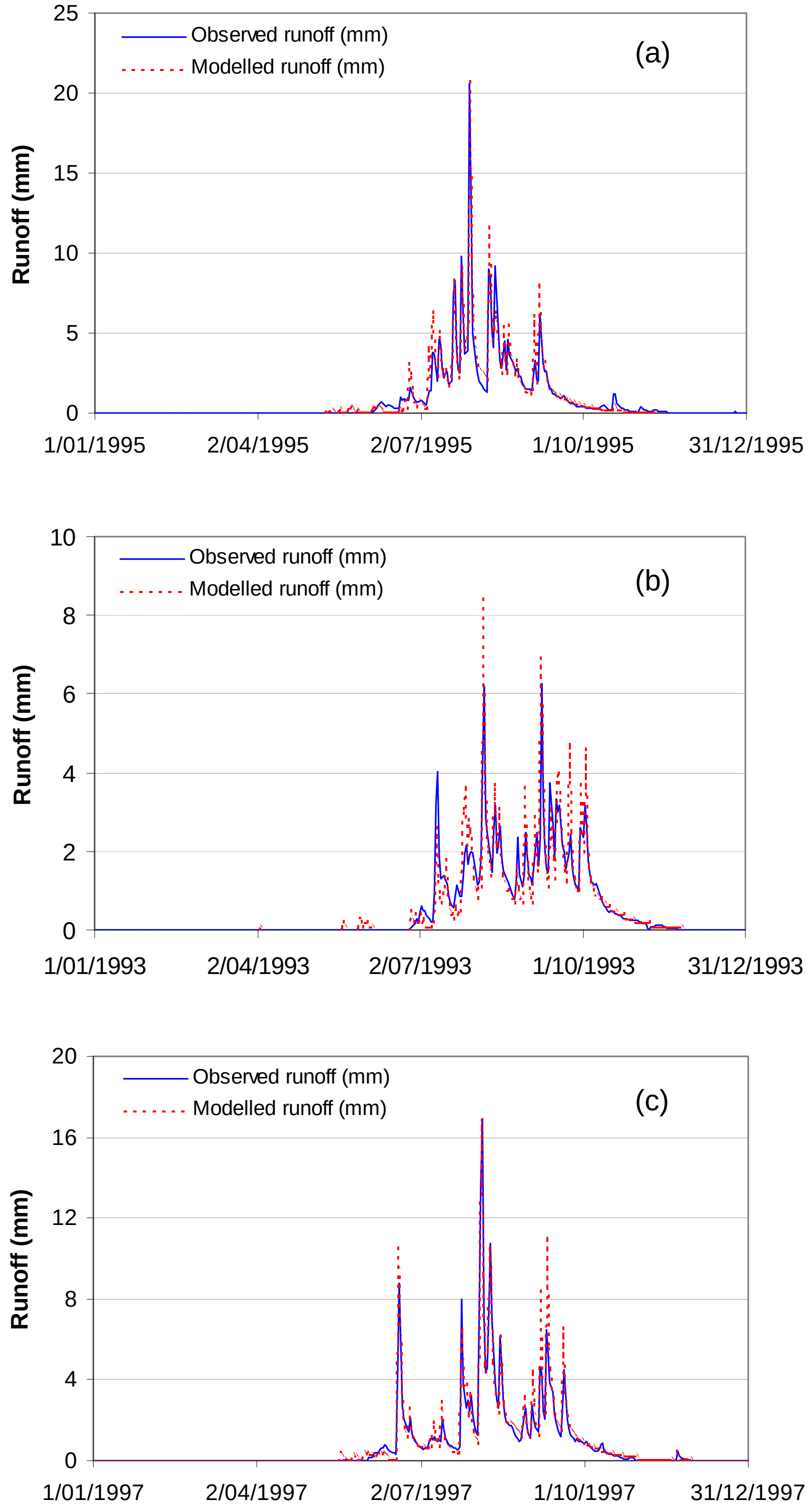

Figure 10 Comparison of observed and CSS-modelled daily flows for (a) a calibration period average-flow year (1995), (b) a calibration period low-flow year (1993) and (c) a verification period average-flow year (1997)

Annual streamflow

The CSS-derived streamflow was used to fill the gaps in the observed record to complete the data set (Figure 11). Using this data set, a series of statistics was calculated for the flows at the Woodlands gauge site (Table 1). The standard period for analysis in studies such as this is 1975 to 2003 (Loh 2004). The record at 610006 extends slightly outside this period and may be referred to; however, all major statistics and averages will be for the standard period.

The highest flow (51.0 GL) occurred in 1974, this being more than double the 1975 to 2003 average flow of 23.9 GL. This average equates to a runoff of 290 mm/year and, when compared to the average rainfall for the period (1060 mm/yr at station 009636), gives an annual runoff coefficient of 27.5 per cent. This large annual runoff coefficient may be due to factors such as high rainfall, extensive clearing and soil characteristics.

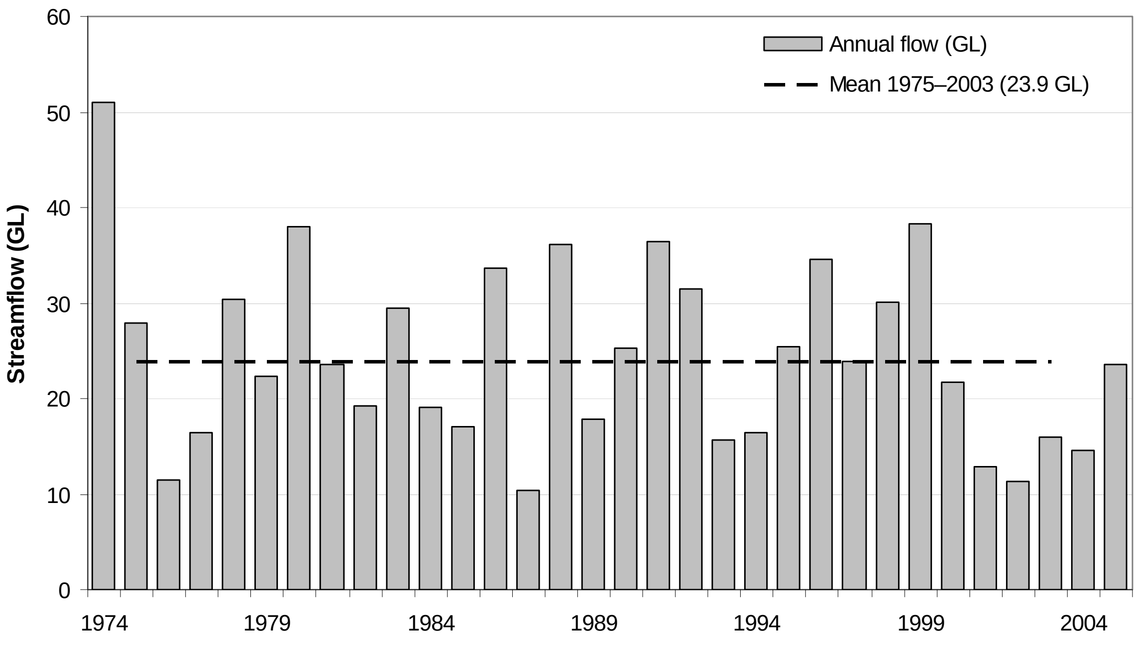

Figure 11 Annual streamflow record at Woodlands – 610006

Table 1 Annual streamflow statistics at Woodlands – 610006

Statistic (1975–2003)	Value
Average (GL)	23.9
Median (GL)	23.6
Standard deviation (GL)	8.7
10th percentile (GL)	12.6
90th percentile (GL)	36.1
Coefficient of variation	0.36

The median and average flows were very similar at the annual time-step (Table 1), with 6 of the 29 years having annual totals that fell within 10 per cent of the mean. The annual coefficient of variation for the data was calculated as 0.36, confirming the low variability in the annual flow record.

Monthly streamflow

Streamflow in Wilyabrup Brook is seasonal with, on average, 98 per cent of the flow occurring between June and October. The mean and median flows for these months were quite similar (Figure 12), indicating even distributions of the monthly streamflow totals around the mean.

In the summer and autumn months (December to May) there were large differences between the mean and median values. In these months the streamflow totals tend to be low but, due to weather events such as thunderstorms, there can be flows that significantly increase the total for that month. This skews the distribution and increases the mean monthly total.

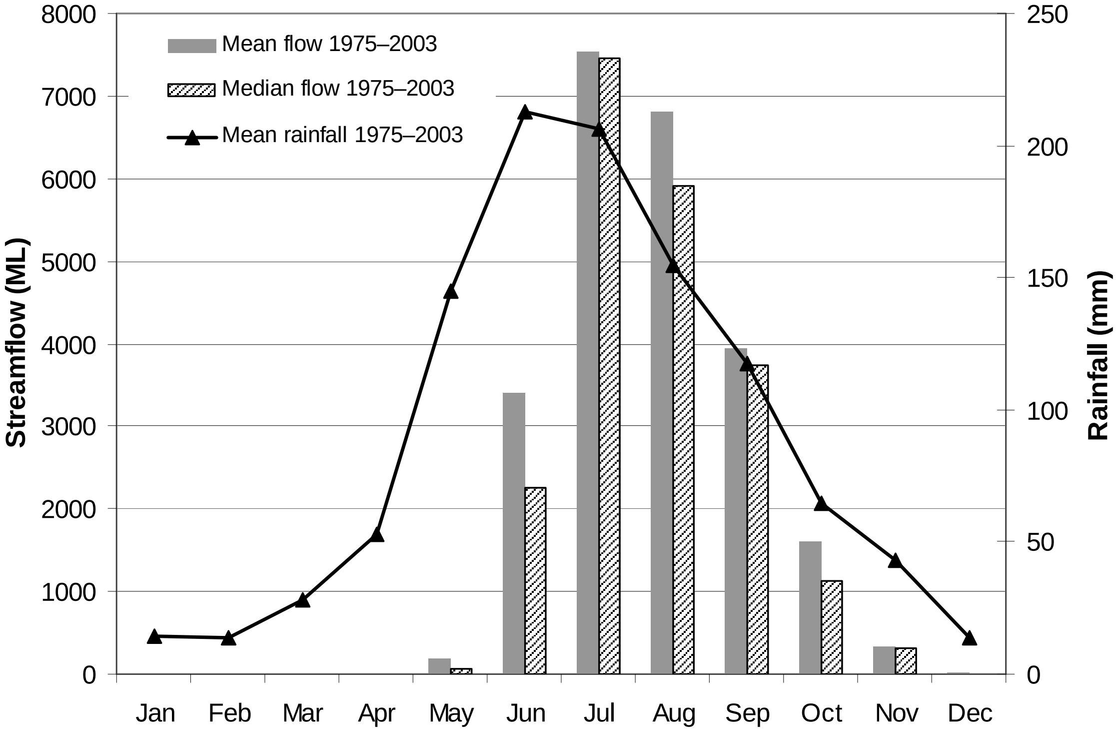

Figure 12 Mean and median monthly streamflow at Woodlands and mean monthly rainfall at station 009636

Daily streamflow

Flow-duration curves were calculated using daily data at both annual and monthly time-steps. For the annual analysis, daily flows for each year were ranked and assigned probabilities and then plotted (Figure 13). The grey lines indicate the yearly flow-duration curves, with the curve for the total period (1975 to 2003) represented by the thick black line.

These curves can be used to describe the current flow regime and will be important in the development of ecological flows. Figure 13 shows that, based on the data for the total period, flows greater than or equal to 0.01 ML/d are experienced 78 per cent of the time, and the median flow exceeded was 2.2 ML/d.

The individual yearly flow-duration curves provide an indication of the variability in the Wilyabrup Brook flow regime. This variability occurs both vertically and horizontally around the flow-duration curve for the total period. Looking horizontally, flows greater than or equal to 0.01 ML/d are experienced over a range of 63 to 100 per cent of the time (0.01 ML/d equates to roughly 400 L/h or about 0.1 L/s). Similarly, a vertical analysis of flows exceeded 50 per cent of the time shows they range from 0.05 to 12.5 ML/d.

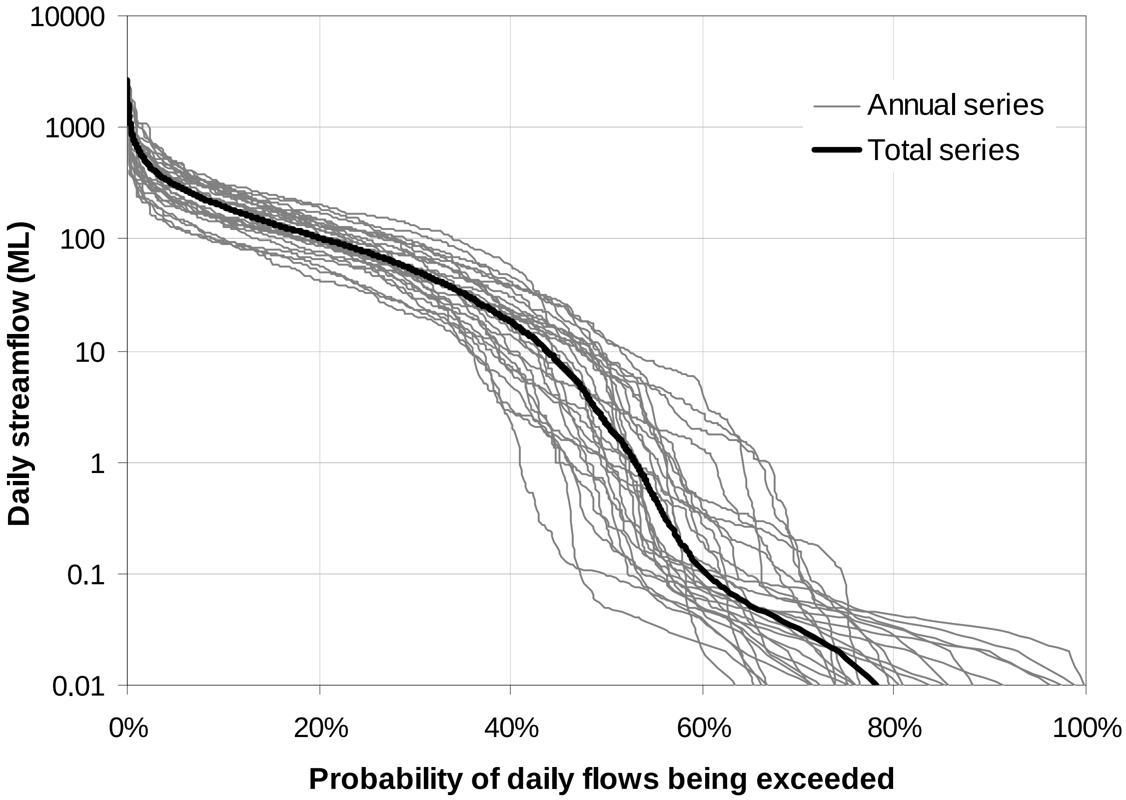

Figure 13 Yearly flow-duration curves at Woodlands – 610006

Flow-duration curves for the Woodlands flow data were also calculated for each month using data from the period 1975 to 2003 (Figure 14). During the months from July to September the brook was always flowing at or above 10 ML/d. This is illustrated in Figure 14, where the value of streamflow exceeded 100 per cent of the time was greater than 10 ML, i.e. there was never zero flow in these months. From the graph, the months can be grouped into three clusters:

- January to April, where flows greater than or equal to 0.1 ML/d are only exceeded 11 per cent of the time or less
- June to November, where flows greater than or equal to 0.01 ML/d are experienced 100 per cent of the time and median daily flows are greater than 6.6 ML/d
- May and December, whose curves lie between the two aforementioned clusters and where median daily flows range from 0.07 to 0.38 ML/d.

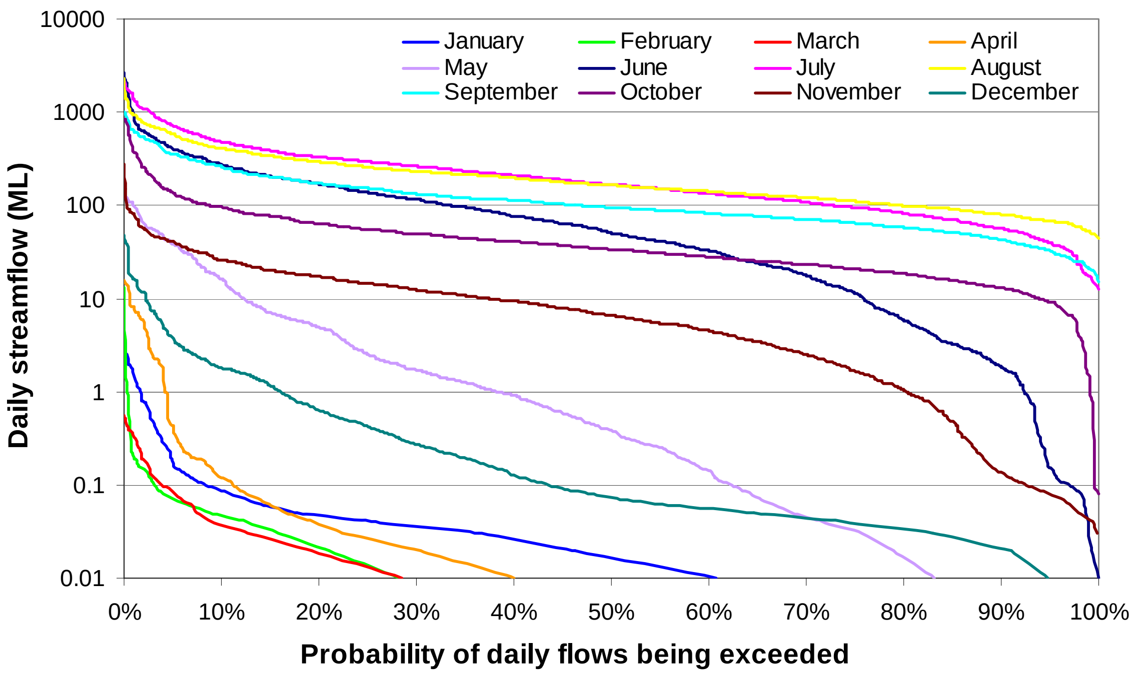

Figure 14 Monthly flow-duration curves at Woodlands – 610006

Flood frequency

As a further analysis of the streamflow data, a flood-frequency curve for the Woodlands gauge was constructed using a Log Pearson III distribution (Figure 15). The curve was developed using the program FLIKE, and was developed using all of the data available at the gauge (1974 to 2004).

The results (Table 2) were consistently higher than the flood-frequency results for other similar catchments within the high-rainfall zone across all probabilities. This difference may be due to the high level of clearing in the catchment, its soil properties and the channel characteristics of the brook. A flood-frequency analysis on the Woodlands gauge that was performed as part of the Toby's Inlet flood study (Tan 1990) produced results similar to those found in this study.

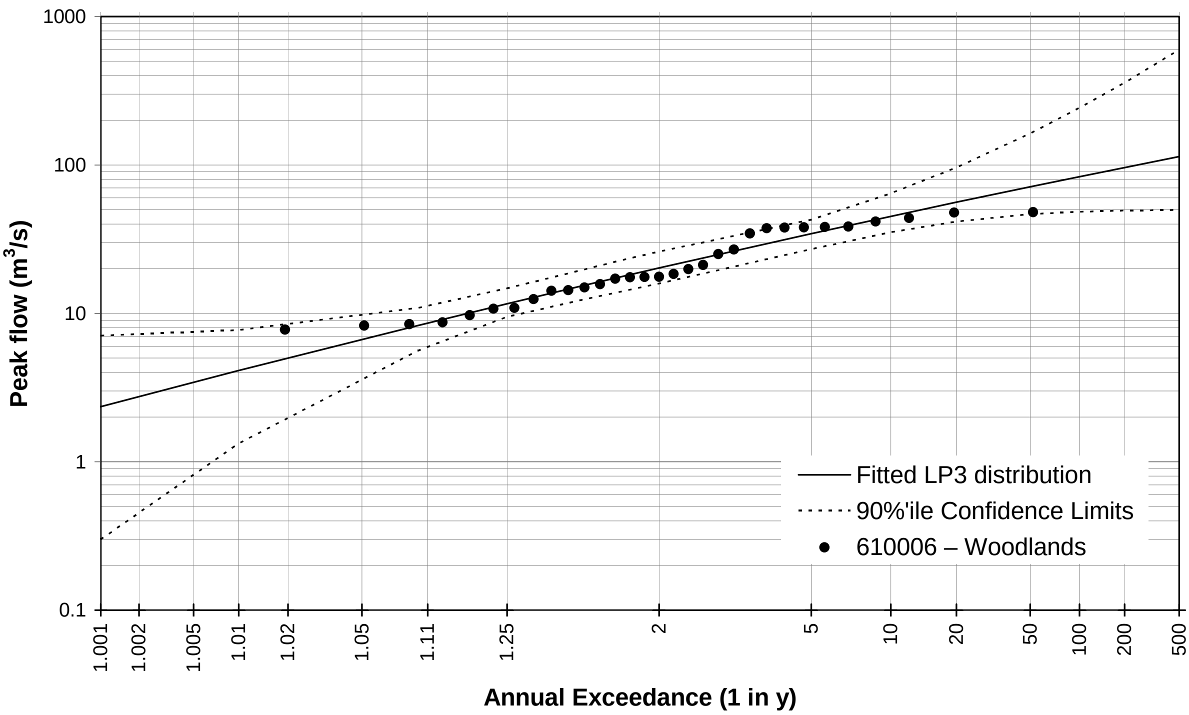

Figure 15 Flood-frequency plot for Woodlands – 610006

Table 2 Results of FLIKE flood-frequency analysis for Woodlands – 610006

Average recurrence interval (1:year)	Annual exceedance probability (%)	Peak annual flow (m^3/s)	50%AEP growth factor
1:1.1	90.9	8.3	–
1:2	50	20.2	–
1:5	25	34.4	1.70
1:10	10	45.1	2.23
1:20	5	56.0	2.77
1:50	2	71.2	3.52
1:100	1	83.4	4.13

Baseflow analysis

Finally, the calibrated CSS parameters were used to partition the observed runoff to obtain a baseflow series. The modelled baseflow sequence can be seen annually in Figure 16 and daily – for an example year (1980) – in Figure 17. The partitioning used an average baseflow index of 0.512, or 51 per cent, with annual values ranging from 48 to 57 per cent. This is a significant contribution to the total streamflow. A monthly analysis of the data revealed that, on average, from September to December baseflow accounted for between 65 and 74 per cent of the total streamflow. The timing and volume of this baseflow contribution may play an important role in sustaining ecological processes in and along the brook.

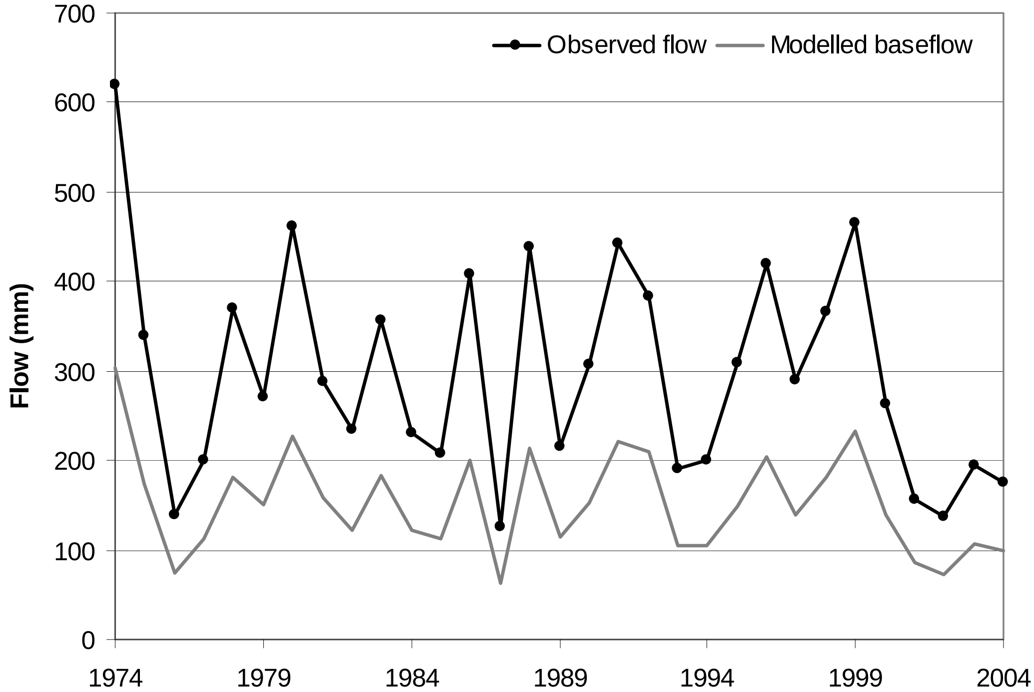

Figure 16 Annual observed streamflow and modelled baseflow series for Woodlands – 610006

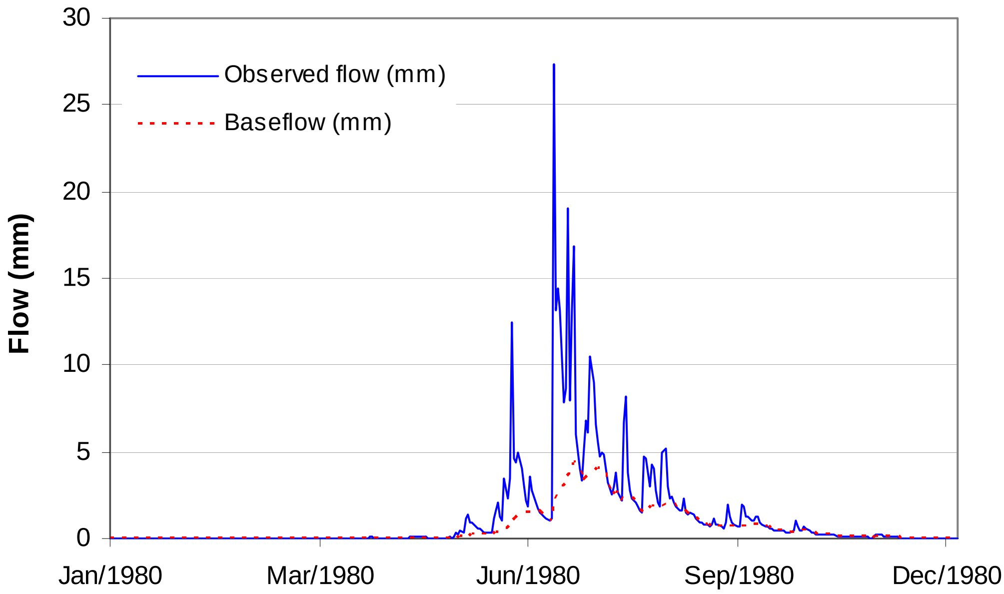

Figure 17 Daily observed streamflow and modelled baseflow for Woodlands – 610006

4.2 Juniper — 610028

Due to the short period of record at 610028 it was not considered feasible to use a rainfall runoff model to generate the necessary data series. Instead, a relationship was developed between the observed flow at Juniper (November 2004 – July 2006) and the observed flow at Woodlands.

Given that both gauges are on Wilyabrup Brook, and their catchments receive similar rainfall and have similar soil and vegetation types, it is not surprising that a good correlation existed between the two data sets. Figure 18 shows the daily series for each station over the period of common record, and Figure 19 shows the results of the correlation using the 614 days available for comparison.

Based on this correlation, the daily streamflow record for 610006 was transformed to generate a daily streamflow record for 610028 for the standard analysis period (1975 to 2003). As a test, the record at 610006 was also transformed up to 2006 so that it could be compared to the observed data at 610028. Figure 20 shows the result, with the transformed series proving to be a good match in terms of magnitude and timing of events.

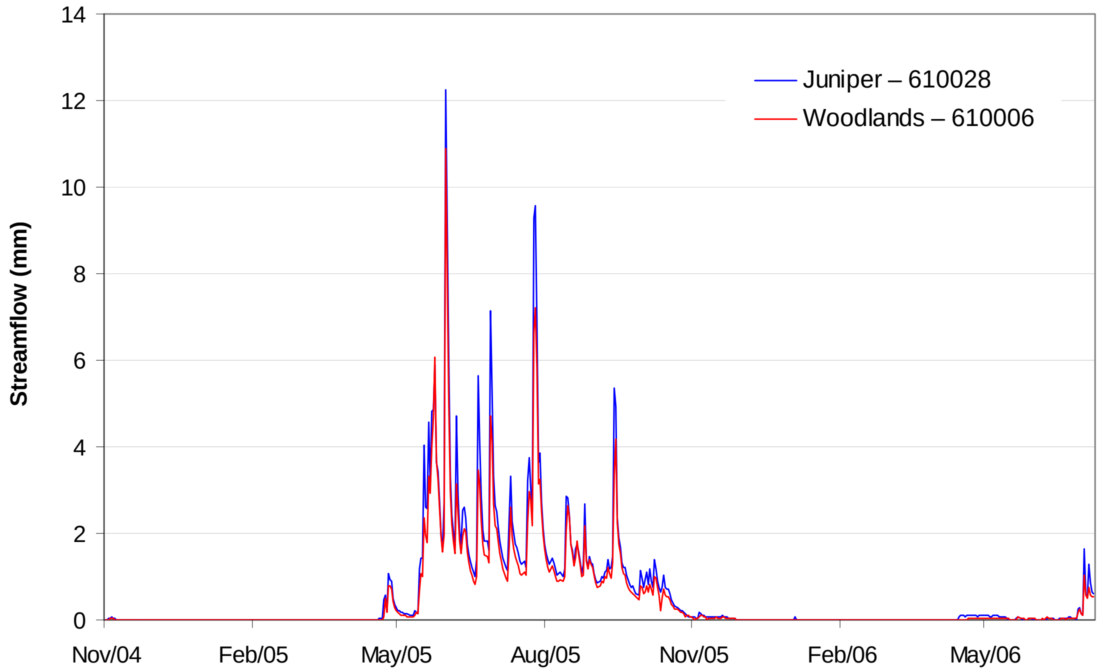

Figure 18 Daily record at 610028 and 610006

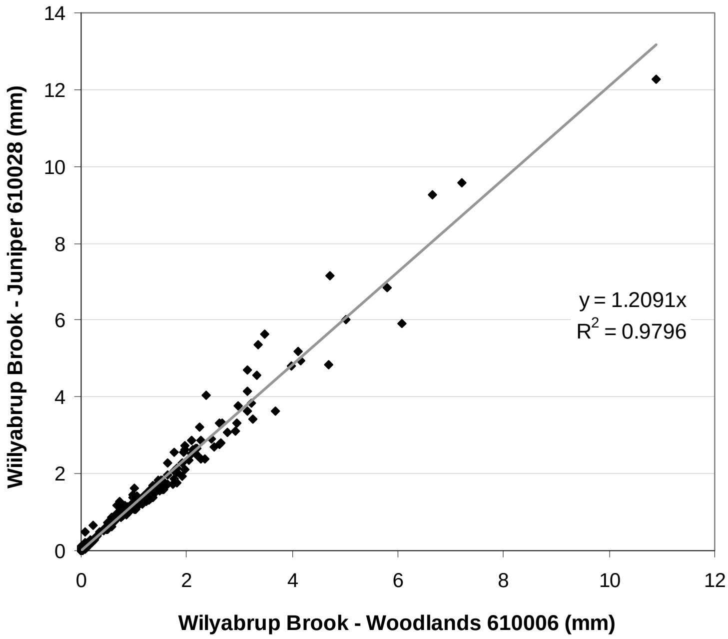

Figure 19 Correlation between stations 610028 and 610006 using data from end November 2004 to end July 2006

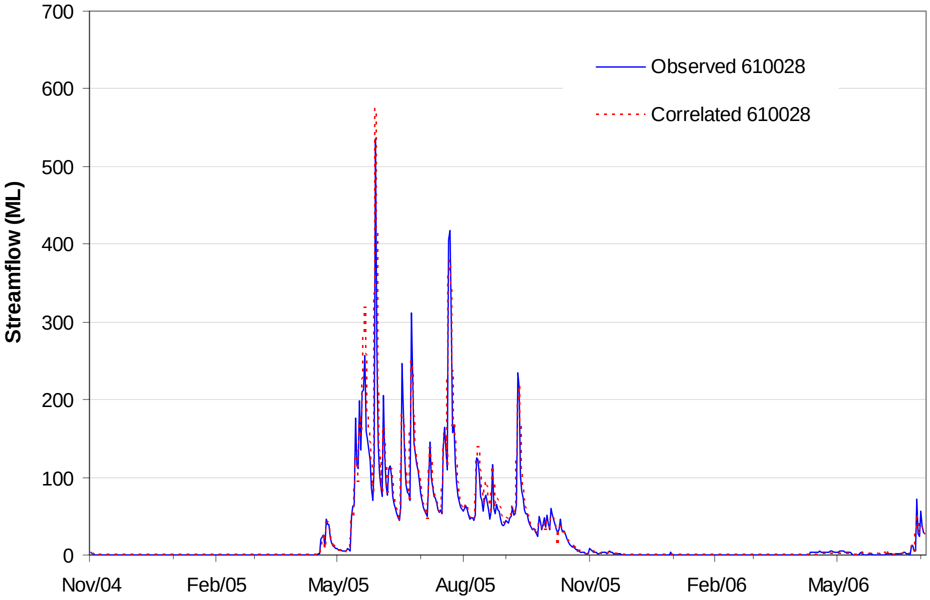

Figure 20 Verification of the compatibility of the transformed data series to the observed record at Juniper – 610028

Annual streamflow

Using this transformed data set, an annual flow series was produced (Figure 21) and statistics were calculated for the flows at the Juniper gauge for the standard analysis period (Table 3). The highest flow (24.6 GL) occurred in 1999, while the 1975 to 2003 average flow was 15.3 GL. This average equates to a runoff of 350 mm/yr and, when compared to the average rainfall for the period (1060 mm/yr at station 009636), gives an annual runoff coefficient of 33 per cent.

The median and average flows in Table 3 are very similar, indicating an even distribution in the data. The annual coefficient of variation for the data was calculated as 0.36, which also indicates low variability in the annual flow record.

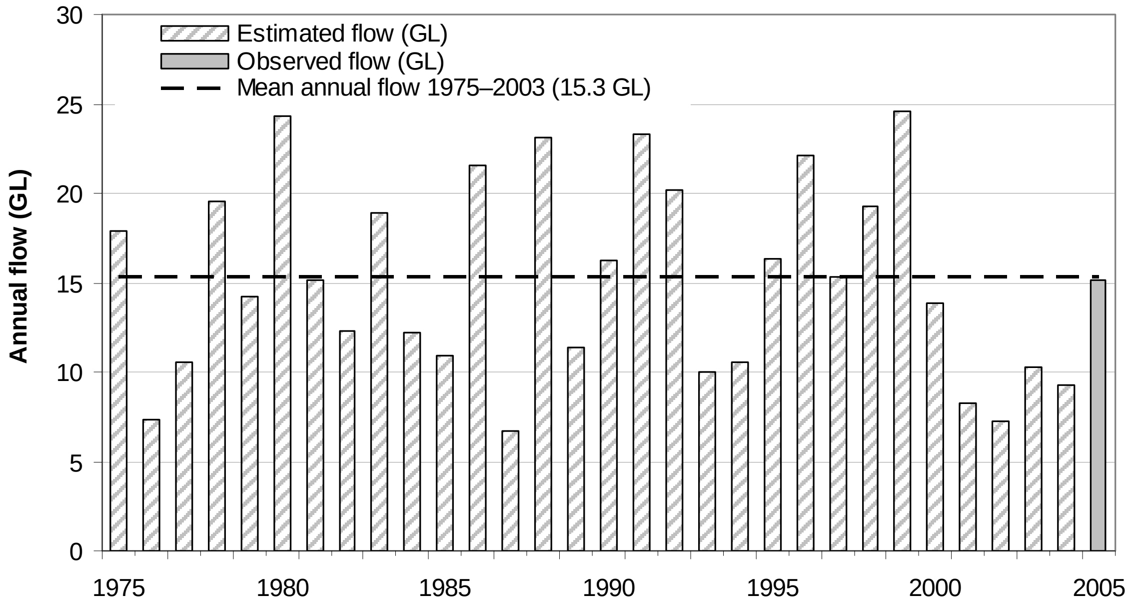

Figure 21 Annual streamflow at Juniper – 610028

Table 3 Annual streamflow statistics at Juniper – 610028

Statistic (1975–2003)	Value
Average (GL)	15.3
Median (GL)	15.2
Standard deviation (GL)	5.56
10th percentile (GL)	8.09
90th percentile (GL)	23.2
Coefficient of variation	0.36

Monthly streamflow

Similar to the analysis for 610006, the seasonality of flows is quite evident in Figure 22, where, on average, 98 per cent of the flow occurs between June and October. The mean and median flows for these months were similar, indicating even distributions of the monthly streamflow totals around the mean.

In the summer and autumn months (December to May) there were large differences between the mean and median values. In these months the streamflow totals tend to be low but, due to weather events such as thunderstorms, there can be flows that significantly increase the total for a particular month. This skews the distribution and increases the mean monthly total.

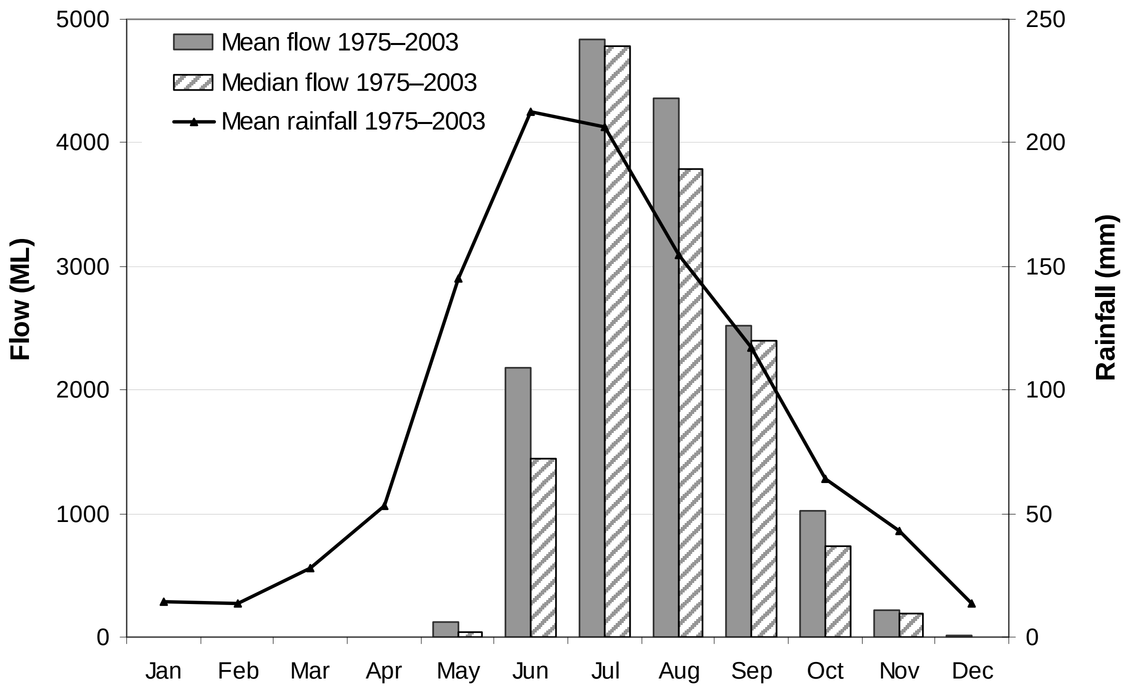

Figure 22 Mean and median streamflows at Juniper and mean rainfall at station 009636

Daily streamflow

Flow-duration curves were calculated using daily data at both annual and monthly time-steps. For the annual analysis, daily flows for each year were ranked and assigned probabilities and then plotted (Figure 23). The grey lines indicate the yearly flow-duration curves, with the curve for the total period (1975 to 2003) represented by the thick black line.

Due to the regression analysis that was performed in order to produce the long-term series at Juniper, Figure 23 is very similar to Figure 13, the flow-duration curve for the Woodlands gauge. The main difference between the two analyses is that the

Juniper values are slightly lower than those for Woodlands. This can be seen in the graphs, where the curves for the Juniper analysis are shifted slightly to the left in comparison to those at Woodlands. Given that conditions across the catchment are quite uniform (land use, rainfall etc.), this difference is to be expected, and is due to the Juniper gauge receiving flow from a smaller catchment area. The Woodlands gauge also receives flows from Wilyabrup Brook and Woodlands Brook.

At Juniper a flow of greater than 0.01 ML/d was never experienced on every day of the year (i.e. the curves never reached 100 per cent at this value) and, based on the total series plot, the brook at Juniper flows at greater than 0.01 ML/d less than 74 per cent of the time. Also based on the total series, the median daily flow at Juniper is 1.41 ML.

The individual yearly flow-duration curves provide an indication of the variability in the Wilyabrup Brook flow regime. This variability occurs both vertically and horizontally around the flow-duration curve for the total period. Looking horizontally, flows greater than or equal to 1 ML/day are experienced over a range of 40 to 64 per cent of the time. Similarly, a vertical analysis of flows exceeded 50 per cent of the time shows they range from 0.03 to 8.02 ML/d.

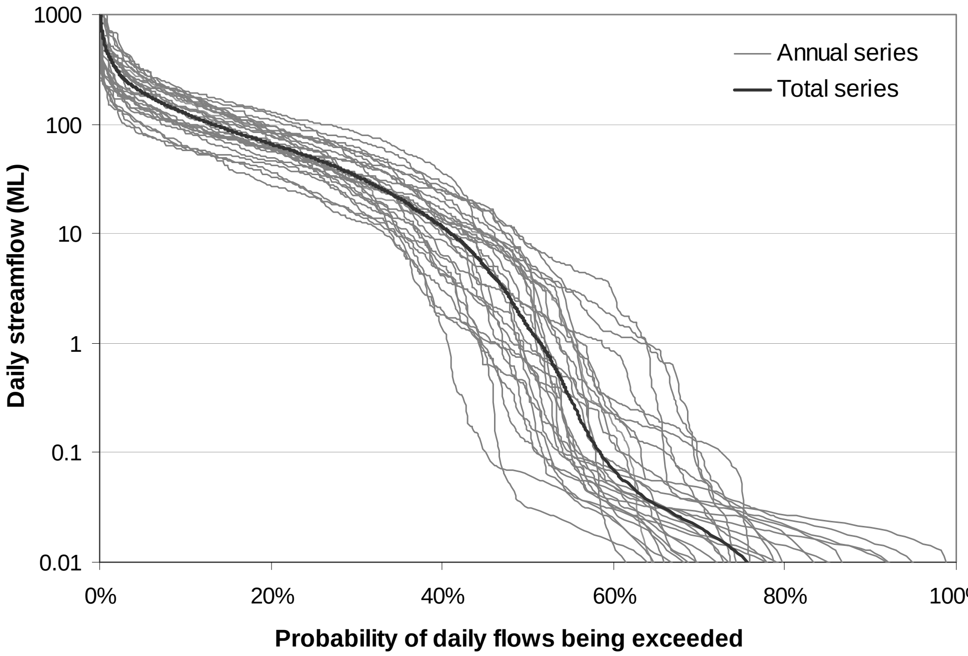

Figure 23 Yearly flow-duration curves at Juniper – 610028

Flow-duration curves for 610028 were also calculated for each month using data from the period 1975 to 2003 (Figure 24). During the months from July to September the brook was always flowing at or above 1 ML/d. This is illustrated in Figure 24, where the value of streamflow exceeded 100 per cent of the time was greater than 1 ML, i.e. there was never zero flow in these months.

From the graph, the months can be grouped into three clusters:

- January to April, where flows greater than or equal to 0.1 ML/d are only exceeded 9 per cent of the time or less
- June to November, where flows greater than or equal to 0.006 ML/d are experienced 100 per cent of the time and median daily flows are greater than 4.2 ML/d
- May and December, whose curves lie between the two aforementioned clusters and where median daily flows range from 0.045 to 0.24 ML/d.

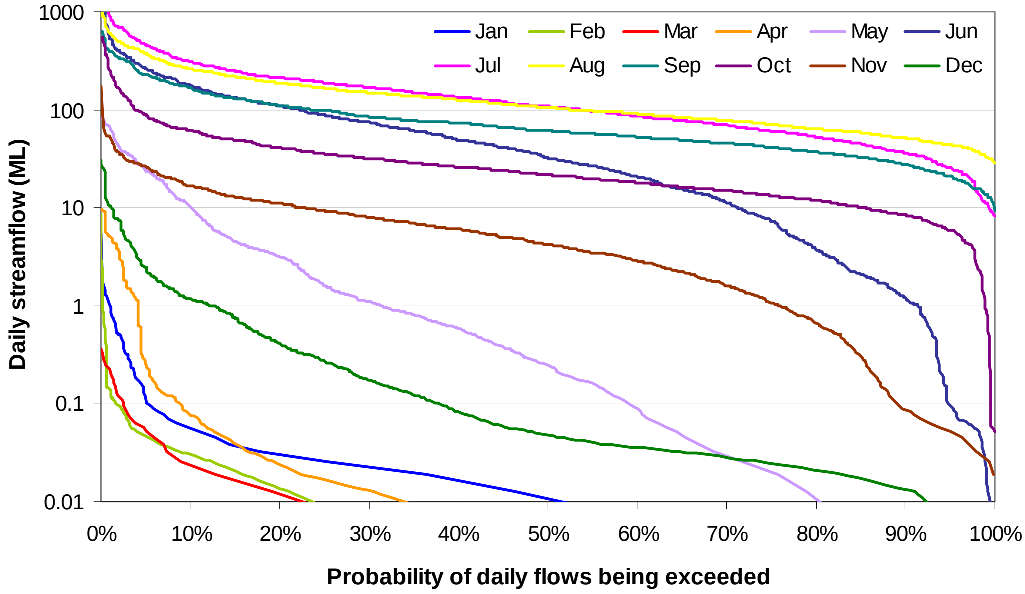

Figure 24 Monthly flow-duration curves at Juniper – 610028

Flood frequency

A flood-frequency analysis for the Juniper gauge was performed based on the results of the flood-frequency analysis at the Woodlands gauge. The Woodlands analysis fitted a Log Pearson III distribution to 31 annual peaks recorded at the gauge, the results being reported in Table 2. Based on the method described by Grayson et al. (1996) for estimating high flows in ungauged catchments, a set of flood-frequency values was calculated for the Juniper gauge using the following equation:

$$Q_J = Q_W \left(\frac{A_J}{A_W}\right)^{0.7}$$

Where: Q_J = flow at Juniper A_J = area of Juniper catchment

Q_W = flow at Woodlands A_W = area of Woodlands catchment

The results of the analysis for significant average recurrence intervals are listed in Table 4.

Table 4 Results of FLIKE flood-frequency analysis for Juniper – 610028

Average recurrence interval (1:year)	Annual exceedance probability (%)	Peak annual flow (m^3/s)	50%AEP growth factor
1:1.1	90.9	5.3	–
1:2	50	13.0	–
1:5	25	22.1	1.70
1:10	10	28.9	2.23
1:20	5	35.9	2.77
1:50	2	45.7	3.52
1:100	1	53.5	4.12

5 Conclusion

Wilyabrup Brook is located in the south-west corner of Western Australia in the Cape to Cape region. The catchment is 89.2 km^2, of which 75 per cent is cleared and viticulture is the dominant land use.

Three rainfall stations have operated in the catchment, and data from these stations was used to develop a catchment centroidal rainfall series. Based on this series, 78 per cent of the average annual rainfall occurs in the five-month period from May to September. Analysis of the only long-term station revealed that rainfall for the period 1975 to 2003 was 10 per cent lower than the average for the previous 48 years. As well, average annual evaporation was found to be 1.26 times the average annual rainfall.

Two streamflow gauges operate in the catchment. The Woodlands gauge (610006) records flow from 82.3 km^2 of the catchment and has been operating since 1973. The second gauge, Juniper (610028), which began recording in 2004, records streamflow from 43.6 km^2. A rainfall–runoff model was used to fill data gaps in the Woodlands gauge record and to develop a daily baseflow series. The record at the Juniper gauge was extended on the basis of a correlation with the Woodlands gauge.

The average flows at the Woodlands and Juniper gauges were 23.9 GL/y and 15.3 GL/y respectively. At both gauges, 98 per cent of the average annual streamflow occurs in the five-month period from June to October. The annual runoff coefficient calculated for the catchment (at Woodlands) was high at 27.5 per cent. The modelled baseflow index was 51 per cent. The seasonality of the baseflow contribution may play an important role in sustaining ecological processes in and along the brook.

The critical outcome of this hydrology analysis has been to produce daily streamflow series for both gauges for the period 1975 to 2003. These series will be used in the future to determine the ecological water requirements of Wilyabrup Brook.

Appendix

Table A Statistics comparing the observed and simulated results of the CSS calibration for Wilyabrup Brook at Woodlands

Statistic (1976–1995)	Observed	Simulated
Annual		
Average (mm)	289	278
Standard deviation (mm)	106	116
Mean absolute error (MAE) (mm)		24.6
Root mean square error (RMSE) (mm)		30.6
Coefficient of efficiency (E)		0.91
Monthly		
Average (mm)	24.1	23.2
Standard deviation (mm)	39.1	39.6
Mean absolute error (MAE) (mm)		3.85
Root mean square error (RMSE) (mm)		6.90
Coefficient of efficiency (E)		0.97
Daily		
Average (mm)	0.79	0.76
Standard deviation (mm)	1.78	1.77
Mean absolute error (MAE) (mm)		0.29
Root mean square error (RMSE) (mm)		0.84
Coefficient of efficiency (E)		0.78

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

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 Wilyabrup Brook at Woodlands

Parameter	Value
Capacity C1 – mm	12.8
Capacity C2 – mm	188.4
Capacity C3 – mm	373.6
Area A1 0<=A1<=1	0.051
Area A2 0<=A2<=1	5.74
Area A3 0<=A3<=1	0.375
Baseflow index (BFI) 0<=BFI<=1	0.512
Baseflow recession constant Kbase 0<=KBase<=1	0.9421
Surface runoff recession constant Ksurf 0<=Ksurf<=1	0.3526

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