Department of Water
Government of Western Australia

Surface Hydrology of the Cape-to-Cape Region of Western Australia

Department of Water

March 2007

Department of Water
Level 4, 168 St Georges Terrace
Perth Western Australia 6000

www.water.wa.gov.au

Telephone +61-8-6364 7600
Facsimile +61-8-6364 7601

For more information about this report, contact
Manager, Surface Water Assessment
Water Resource Management Division
Department of Water

March 2007

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Summary

This study was undertaken to provide a summary of the surface hydrology in the Cape-to-Cape (Whicher) region, focusing on surface water management sub-areas in the local government authorities of Augusta-Margaret, Busselton, Capel and Nannup.

Since 1975, the Cape-to-Cape region has received lower rainfall compared with the long-term average, resulting in a corresponding reduction in streamflow. To incorporate this climate variability, the study focused on the analysis of streamflow data for the period of record of 1975 to the present, while also providing some comparison with longer-term data.

The report includes an overview of the region, and then provides individual sections on surface water management sub-areas for which streamflow data is available.

The Whicher Water Resource Management Committee (Whicher WRMC) was the first local water resource management committee established (September 2002), following the 2001 amendments to the *Rights in Water Irrigation Act 1914*. A priority of the Whicher WRMC is to progress proclamation of the region, so that surface water can be managed through licences. Proclamation of priority areas is currently being progressed and is due for completion in August 2007.

Historically, REG6 was the regional yield estimation tool commonly used by South West regional staff to estimate streamflow yields for ungauged catchments, for which the period 1962-95 was used in the model development. As part of this study, mean annual flow (MAF) for 1975-2003 was compared with mean annual flow for 1962-95 and 1962-2004, which has shown that annual streamflow declined for the period 1975-2003 compared to longer-term periods. The decrease in MAF from the period 1962-1995 to the period 1975-2003 ranges from eight to 36 per cent with an average of 20 per cent across the region. These results indicated that the regional flow estimation tool needed to be revised, leading to the development of REG75.

Mean annual flows in this report will be used to determine allocation limits for surface water use in the region. Mean annual flows have been calculated using streamflow data where available, otherwise they have been estimated using the REG75 regional model (Department of Water, 2006) (Table 1-1).

Analysis of daily flow data has also yielded interesting results. The data from many streamflow-gauging stations indicate that the continuous flow period is decreasing. This can have an impact on environmental flow requirements and licensing decisions such as the suitable period to extract flow from streams. Other streams have more stable periods or are indicating increasing flow periods despite declining rainfall, suggesting groundwater interactions or streamflow regulation such as dam releases. Table 1-1 also provides the minimum flow period observed for each gauged catchment, which is the range from latest start to the earliest ceasing of flow.

The information in this report summarises current available streamflow data in the Cape-to-Cape region and the ramifications of using the period 1975 to 2003 for surface water allocation decisions. It is recommended that more detailed studies be undertaken for priority areas and to investigate surface water – groundwater interactions, which are evident in some of the catchments in the Cape-to-Cape region. These studies should be undertaken in close consultation with the Whicher Water Resource Management Committee.

Table 1-1. Cape-to-Cape flow summary

Sub-area[1]	Whicher Catchments	Sub-area (km^2)	MAF[2,3] (ML/a)	Minimum Flow Period
Nillup	Nillup	71.1	*17,000*	-
Glen Warner	Glen Warner	40.8	*9,100*	-
Glen Warner North	Glen Warner North	57.8	*9,700*	-
Upper Chapman	Upper Chapman	118	36,400	-
Chapman	Chapman	67.0	20,100	May to January
McLeod SW	McLeod	112	*29,700*	-
Rushy	Rushy	22.7	*7,100*	-
Glenarty	Glenarty	42.6	*11,500*	-
Turnwood	Turnwood	47.5	*10,100*	-
Turner SW	Turner	96.4	*24,100*	-
Calgardup	Calgardup	72.1	*21,400*	-
Boodijidup	Boodijidup	62.4	*20,000*	-
Upper Margaret	Margaret	274	*39,200*	-
Middle Margaret		85.9	*25,800*	-
Ten Mile Brook		4.9	*1,200*	-
Margaret Town		31.8	*9,300*	May to January
Lower Margaret		49.2	*14,100*	-
Bramley	Bramley	46.9	*14,900*	-
Ellen	Ellen	27.0	*8,700*	-
Cowaramup	Cowaramup	26.4	*7,800*	-
Biljedup	Biljedup	20.9	*4,900*	-
Wilyabrup	Wilyabrup	89.1	25,900	May to December
Quninup	Quninup	30.3	*6,500*	-
Gunyulgup	Gunyulgup	65.9	*10,200*	-
Naturaliste	Naturaliste	64.0	*4,300*	-
Dunsborough Coast	Mary (to coast)	158	*25,300*	-
Carbunup	Carbunup (to coast)	165	40,400	May to November
Buayanup	Buayanup (to coast)	201	*37,500*	-
Vasse	Vasse Sabina	283	39,700	May to November June to January
Wonnerup	Abba Ludlow	477	*32,700*	May to February June to November
Capel R North Branch	Capel	87.8	*13,600*	Continuous
Capel R South Branch		168	*22,000*	Continuous
Capel R Central		111	*8,400*	Continuous
Capel R West		81.2	*5,700*	Continuous
Gynudup Bk and Tren Ck		188	*21,200*	-
Five Mile Brook		87.4	*6,700*	-
West Bay	West Bay	63.4	*15,000*	-
Twinems Bend	Twinems Bend	39.6	*8,000*	-
Scott	Scott	748	114,300	Continuous
Adelaide	Adelaide	106	*14,600*	-
Careys/Peenebup	Careys	61.5	*7,600*	-
Rosa	Rosa	299	22,300	June to October
Judy	Judy	156	*18,200*	-
Milyeannup	Milyeannup	157	*22,600*	-
Red Gully	Red Gully	146	*17,300*	-
McAtee	McAtee	123	*12,200*	-
Jalbarragup	Jalbarragup	92.9	*7,700*	-
St John	St John	619	47,600	Continuous
Carlotta	Carlotta	180	*20,900*	-
Tanjannerup	Tanjannerup	23.3	*1,500*	-
Barlee	Barlee	392	53,900	May to January
Ellis	Ellis	134	*9,800*	-

Notes: 1 Subarea names and areas from GIS SDE: Surface Water Management Sub-areas (6/09/05)
2 The mean annual flow (MAF)is for the period 1975 – 2003
3 *Italics* indicate the MAF has been estimated from a regional relationship (REG75)

1 Introduction

Since 1975, the south-west of Western Australia has experienced reduced annual rainfall when compared with the long-term mean annual rainfall. This has resulted in a corresponding reduction in streamflow. In November 2004, the Water Resources Allocation Committee (WRAC) endorsed an Allocation Note on the *Adoption of a standard data period for surface water management decisions in the southwest of Western Australia* (Water and Rivers Commission, 2004) subject to the hydrologic tools being available. This policy requires surface water allocations to be based on the period of record of 1975 to 2003.

The Department of Water is responsible for the equitable allocation of surface water resources in Western Australia. At present, the allocation and licensing of surface water throughout the State is not undertaken in a systematic manner. Different approaches are used in each region and there is a lack of consistency in the data used to determine the sustainable yield from a catchment. The Surface Water Allocation Management Framework project is identifying key issues with the regions where management direction is required and developing guidelines to address the issue. The Water Resource Assessment Branch is undertaking this project in conjunction with the Water Allocation Planning Branch.

As part of the Surface Water Management Framework project, Surface Water Management Areas and Sub-areas based on hydrological catchments were defined for the State of Western Australia (Stelfox, 2006, in prep). This report provides a summary of the surface hydrology in the Cape-to-Cape (Whicher) region, focusing on the analysis of streamflow data for the period of record of 1975 to the present, while also providing some comparison with longer-term data. Figures relating to allocation, such as mean annual flow, have been determined for the period 1 January 1975 to 31 December 2003 based on a calendar year, to be consistent with regional streamflow models (and the Allocation Note was not finalised at the time analyses were being undertaken).

2 Region Description

2.1 Background

The Cape-to-Cape region is located in the south-west of Western Australia (Figure 2-1). There is increasing pressure on the surface water in the region as a result of population growth, land use and tourism. Only two river systems in the region have been proclaimed, enabling licensing of surface water resources: the Margaret and Capel rivers. To assist with water resource management, Surface Water Management Areas (SWMAs) and Sub-areas (SWM Sub-areas) were determined for the State, based on hydrological boundaries (Stelfox, 2006, in prep) (Figure 2-2). The Sub-areas in the Cape-to-Cape region are generally the same as the Whicher catchments (Figure 2-3).

Figure 2-1. Cape-to-Cape location map

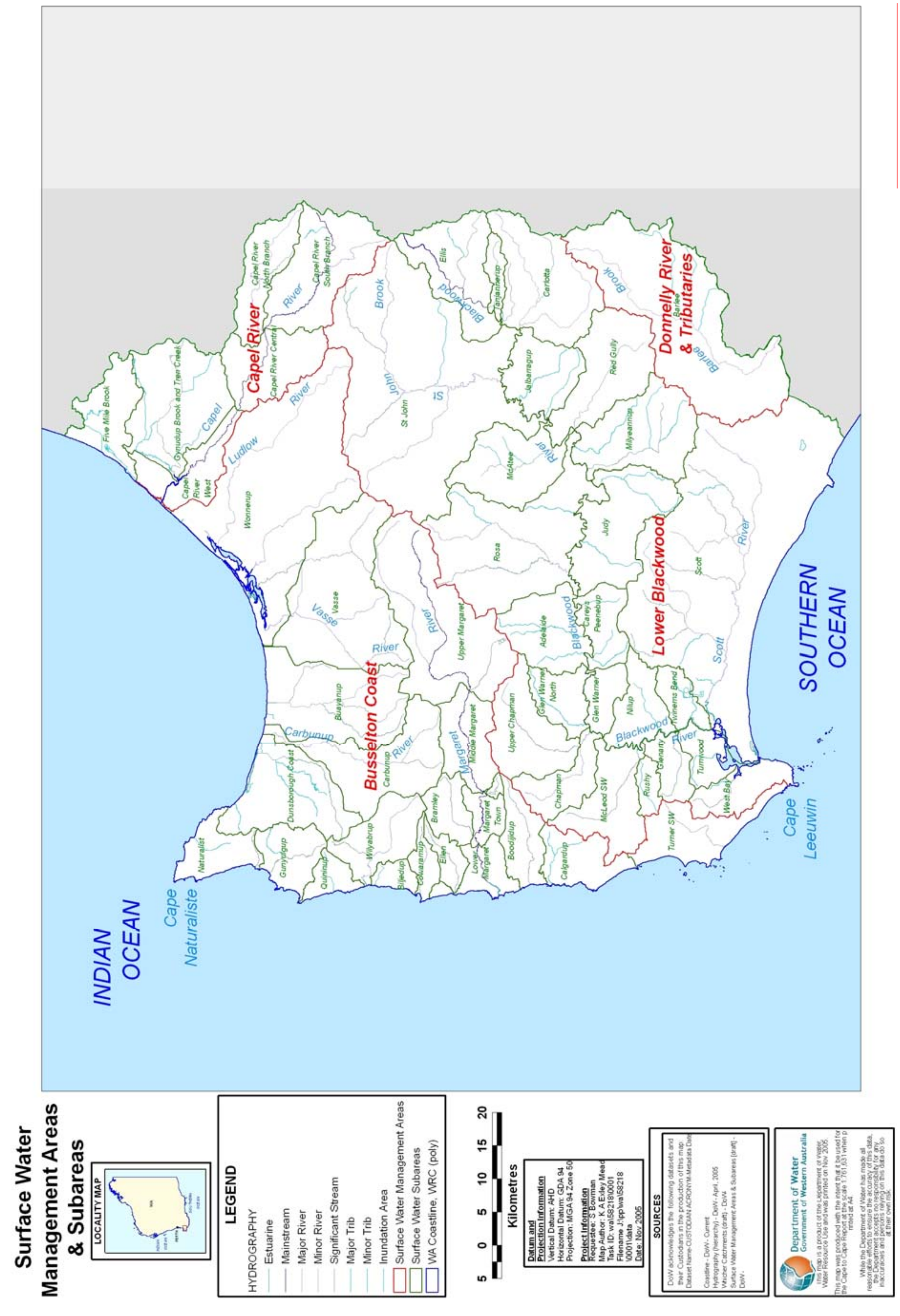


Figure 2-2. Surface water management areas and sub-areas

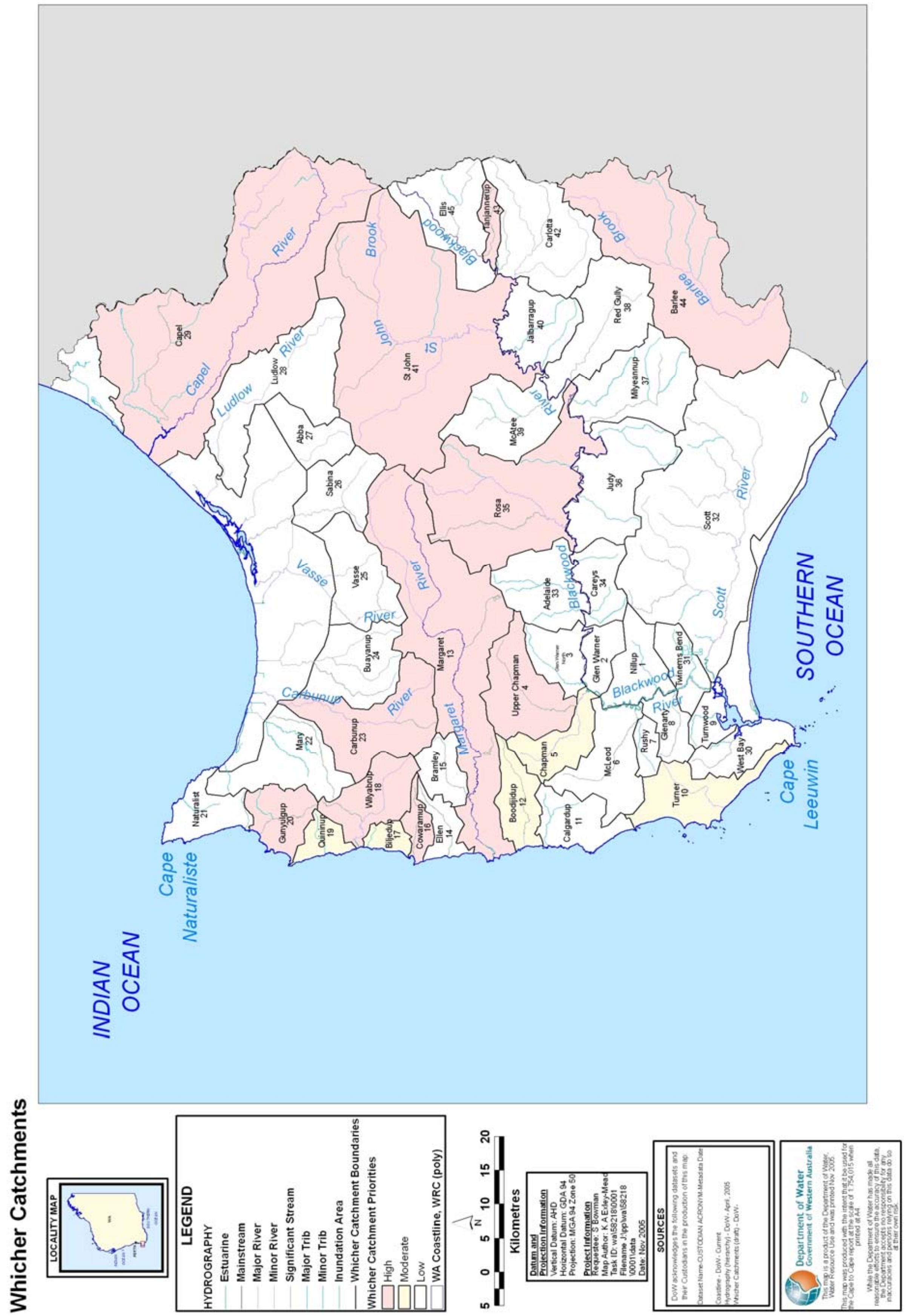


Figure 2-3. Whicher catchments

2.2 Gauging Stations

There are currently 22 operational streamflow gauging stations in the Cape-to-Cape region. Figure 2-4 and Figure 2-5 show the period of record for all of the stations that have operated since the 1960s. Figure 2-6 shows the location of streamflow and rainfall stations that have been used in this study. The sub-areas, Whicher catchments and related gauging stations are summarised in Table 2-1 (Note: Sub-area names and areas from GIS SDE: Surface Water Management Sub-areas (DRAFT) – Department of Environment 6/09/05), indicating that not all catchments have gauged streamflow data. Information in the following sections is provided only where there is streamflow data available for a particular sub-area.

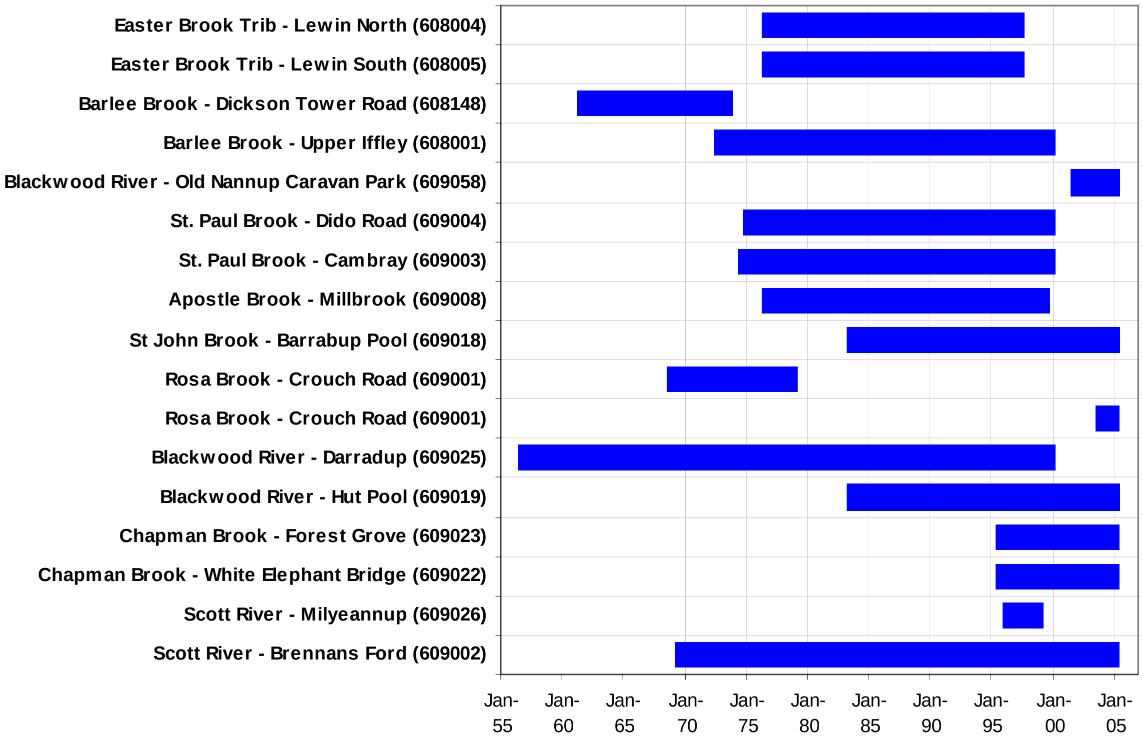


Figure 2-4. Streamflow gauging stations in basins 608 and 609 in the Cape-to-Cape region (as at Jan 2005)

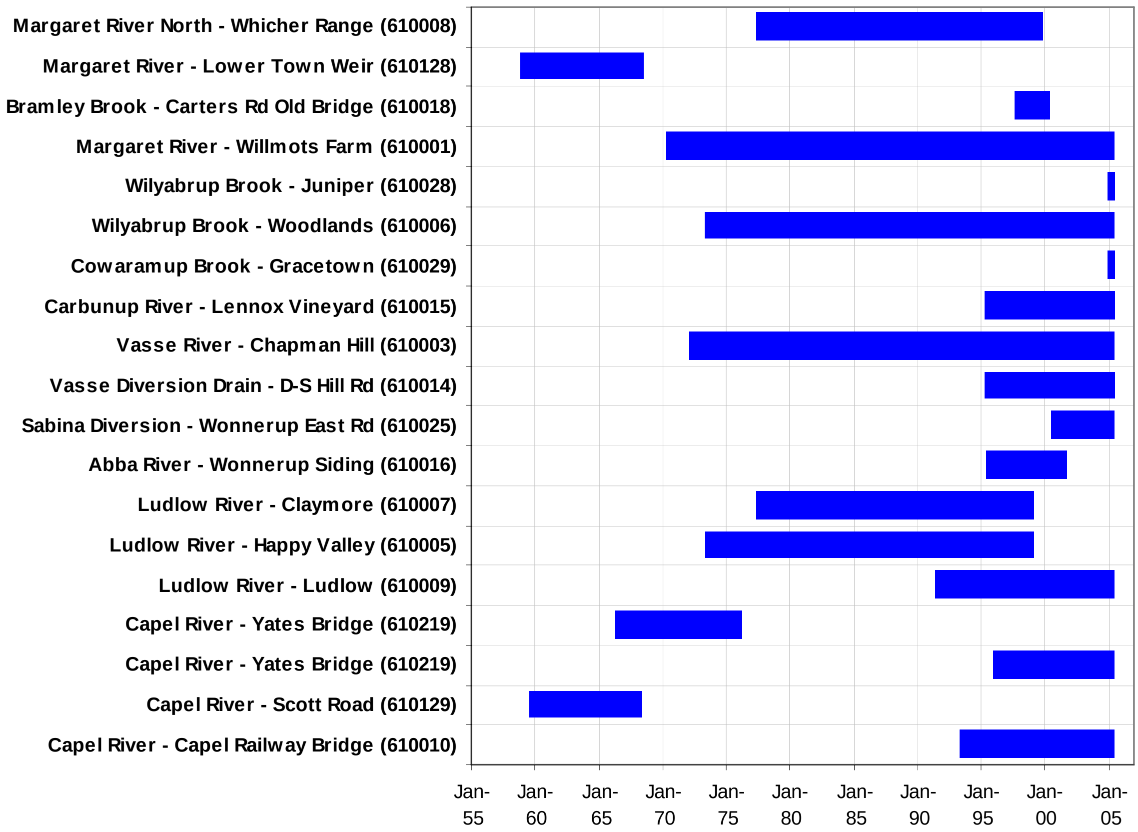


Figure 2-5. Streamflow gauging stations in basin 610 in the Cape-to-Cape region (as at Jan 2005)

Figure 2-6. Streamflow gauging and rainfall stations

Table 2-1. Surface Water Management Sub-areas and Whicher catchments

Sub-area	Whicher Catchments		Gauging Stations	Sub-area (km^2)
Nillup	1	Nillup	-	71.1
Glen Warner	2	Glen Warner	-	40.8
Glen Warner North	3	Glen Warner North	-	57.8
Upper Chapman	4	Upper Chapman	-	118
Chapman	5	Chapman	609023, -022	67.0
McLeod SW	6	McLeod	-	112
Rushy	7	Rushy	-	22.7
Glenarty	8	Glenarty	-	42.6
Turnwood	9	Turnwood	-	47.5
Turner SW	10	Turner	-	96.4
Calgardup	11	Calgardup	-	72.1
Boodijidup	12	Boodijidup	-	62.4
Upper Margaret		Margaret	610008	274
Middle Margaret				85.9
Ten Mile Brook	13			4.9
Margaret Town			610001	31.8
Lower Margaret				49.2
Bramley	15	Bramley	-	46.9
Ellen	14	Ellen	-	27.0
Cowaramup	16	Cowaramup	610029	26.4
Biljedup	17	Biljedup	-	20.9
Wilyabrup	18	Wilyabrup	610028, -006	89.1
Quninup	19	Quninup	-	30.3
Gunyulgup	20	Gunyulgup	-	65.9
Naturaliste	21	Naturaliste	-	64.0
Dunsborough Coast	22	Mary (to coast)	-	158
Carbunup	23	Carbunup (to coast)	610015	165
Buayanup	24	Buayanup (to coast)	-	201
Vasse	25	Vasse	610003	283
	26	Sabina	610025	
Wonnerup	27	Abba	-	477
	28	Ludlow	610007, -005, -009	
Capel R North Branch		Capel		87.8
Capel R South Branch				168
Capel R Central	29		610219	111
Capel R West			610010	81.2
Gynudup Bk & Tren Ck				188
Five Mile Brook				87.4
West Bay	30	West Bay	-	63.4
Twinems Bend	31	Twinems Bend	-	39.6
Scott	32	Scott	609002	748
Adelaide	33	Adelaide	-	106
Careys/Peenebup	34	Careys	-	61.5
Rosa	35	Rosa	609001	299
Judy	36	Judy	-	156
Milyeannup	37	Milyeannup	-	157
Red Gully	38	Red Gully	-	146
McAtee	39	McAtee	-	123
Jalbarragup	40	Jalbarragup	-	92.9
St John	41	St John	609004, -003, -008, -018	619
Carlotta	42	Carlotta	-	180
Tanjannerup	43	Tanjannerup	-	23.3
Barlee	44	Barlee	608004, -005, -001	392
Ellis	45	Ellis	-	134

2.3 Landforms

The landscape of the Cape-to-Cape region is characterised by five distinct physiographic units: the Leeuwin-Naturaliste Ridge along the west coast, the Blackwood Plateau in the centre flanked on the north and south by the Swan and Scott Coastal Plains, and the Darling Plateau to the east (Figure 2-7).

Leeuwin-Naturaliste Ridge

The ridge is 95 km long between Cape Naturaliste and Cape Leeuwin and varies in width between 7 km and 14 km. The ridge is distinctive with prominent rounded hills ranging between 160 m and 220 m in height. The west side is characterised by a rugged coastline of steep limestone cliffs and long asymmetrical sandy bays with steep sand dunes between rocky headlands.

Blackwood Plateau

The Blackwood Plateau slopes southwards from an elevation of around 180 m in the Whicher Range to about 80 m in the south. The plateau surface is composed mainly of laterite developed over Cretaceous sediments. The Darling Scarp, which forms the eastern boundary of the Blackwood Plateau, ranges in elevation up to 140 m, becoming less distinct to the south. The Whicher Scarp, which ranges up to 130 m, forms the northern margin of the plateau. The drainage divide between north and south flowing streams is in the north of the plateau, along the Whicher Range; therefore most of the plateau drains south into the Blackwood River, with a section draining west through the Margaret River. The Blackwood River and its tributaries, such as St John Brook and Rosa Brook, are deeply incised into the plateau surface, with steep-sided valleys 80 m below the general plateau surface.

Swan Coastal Plain

The Swan Coastal Plain slopes gently from the base of the Whicher and Darling Scarps at about 40 m above sea level down to the coast. The plain originated by marine erosion of the underlying Mesozoic rocks, and is covered by late Pliocene-Holocene sediments. The inner part of the plain is an extension of the flat Pinjarra Plain, while the coastal belt contains low dune systems, the Bassendean, Spearwood and Quindalup Dunes, parallel to the coast. The dune systems increase in height and width eastward and northwards. The Swan Coastal Plain is drained by rivers and streams rising in the Whicher and Darling Ranges.

Scott Coastal Plain

The Scott Coastal Plain is a low-lying, swampy plain. It is bounded inland by a subdued scarp with the Donnelly Shelf located at the base of the upper scarp in the north-eastern part of the coastal plain. The inner part of the plain consists mainly of scattered hills of leached sand and intervening swamps (Warren Dunes). The coastal belt contains modern dunes (Quindalup Dunes) backed by discontinuous development of the older Milyeannup Dunes (composed of Tamala Limestone).

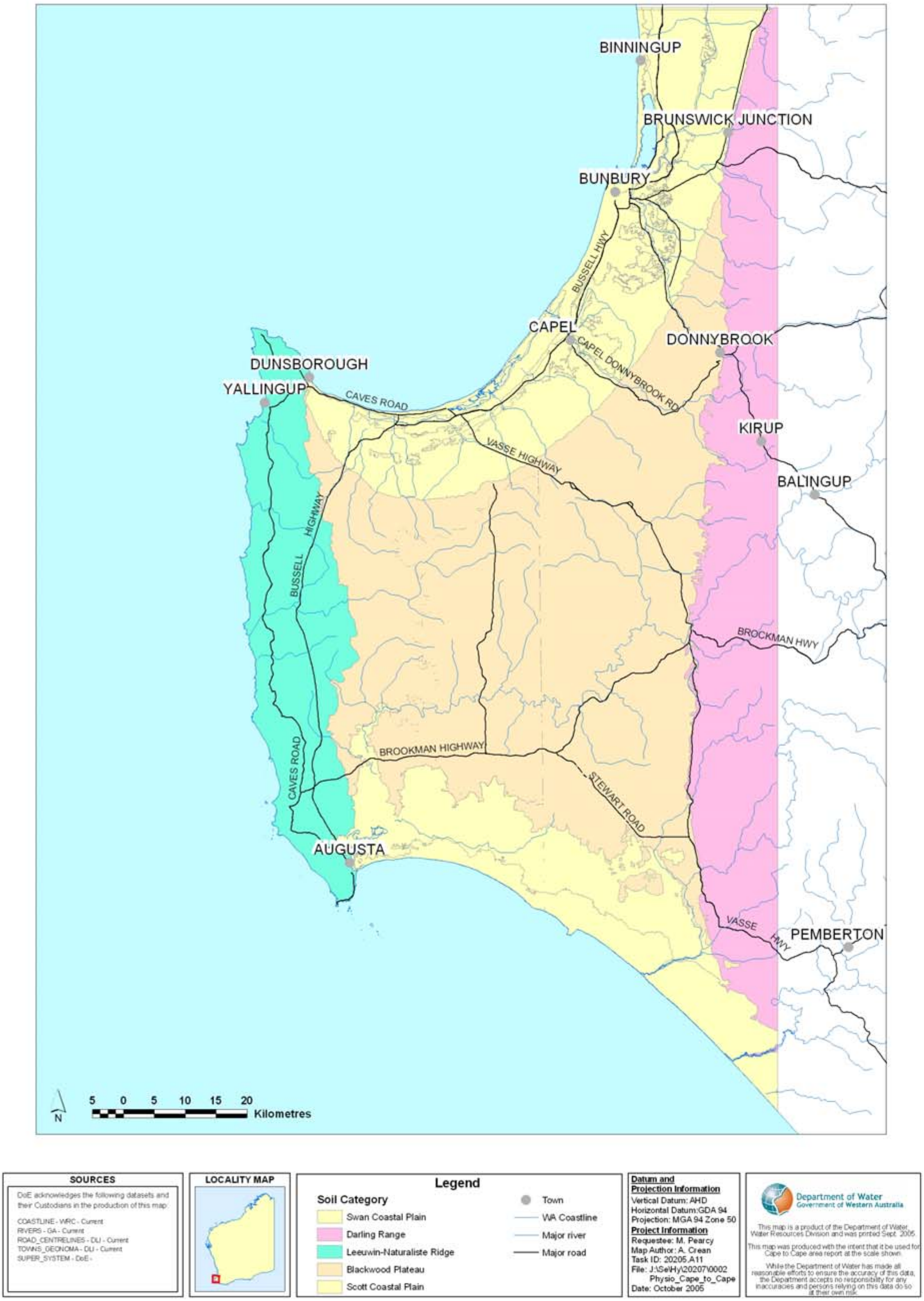


Figure 2-7. Physiography of the Cape-to-Cape region

Darling Plateau

The Darling Plateau is an ancient land area with much of the unit overlying the ancient granites of the Yilgarn Block. The Darling Plateau varies in height from 160 m to 360 m. It is covered by lateritic hardcap and associated clays and has been dissected by present and old river systems. The undulating lateritic uplands of the Darling Plateau are dissected by major valley systems.

2.4 Climate

The Cape-to-Cape region has a temperate climate with distinct wet winter and dry summer seasons. Mean annual rainfall in the region ranges from 800 mm along the Busselton Coast to 1,000 mm in the eastern parts to 1,200 mm close to the west coast (Bureau of Meteorology, 1991). Rainfall in the catchment is 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. Since the mid-1970s there has been a noticeable decrease in the mean annual rainfall for most rainfall stations in the Cape-to-Cape region (Figure 2-6, Figure 2-8 and Figure 2-9). Annual rainfall decreased by up to 10 per cent in the Cape-to-Cape region from 1975-2003 compared to long-term records (Table 2-2). Mean annual rainfall plots for Cape Naturaliste, Cape Leeuwin and Nannup are presented in Appendix 1.

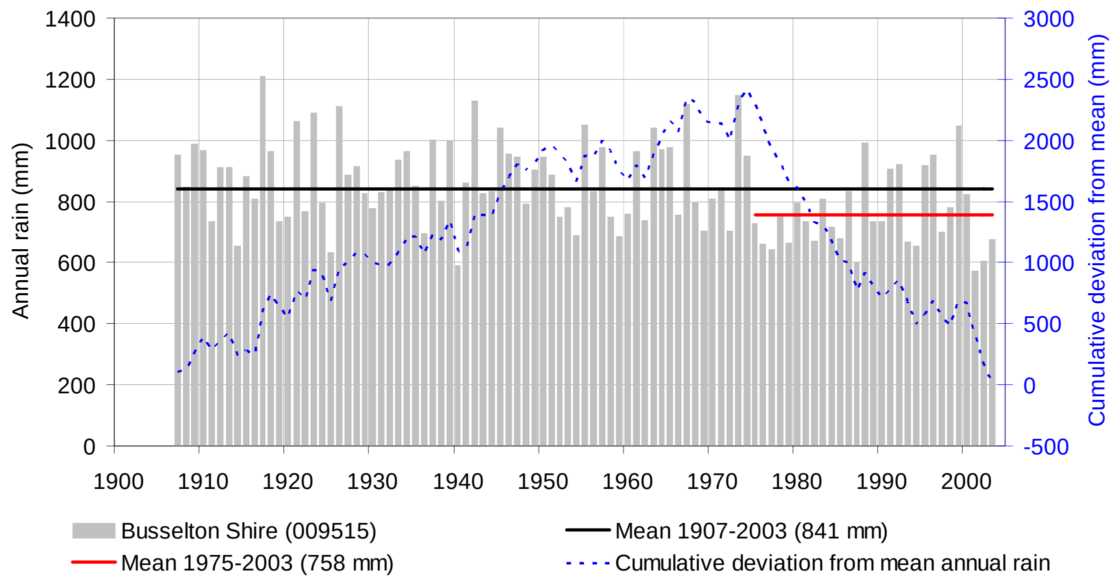


Figure 2-8. Annual rainfall at Busselton (009515)

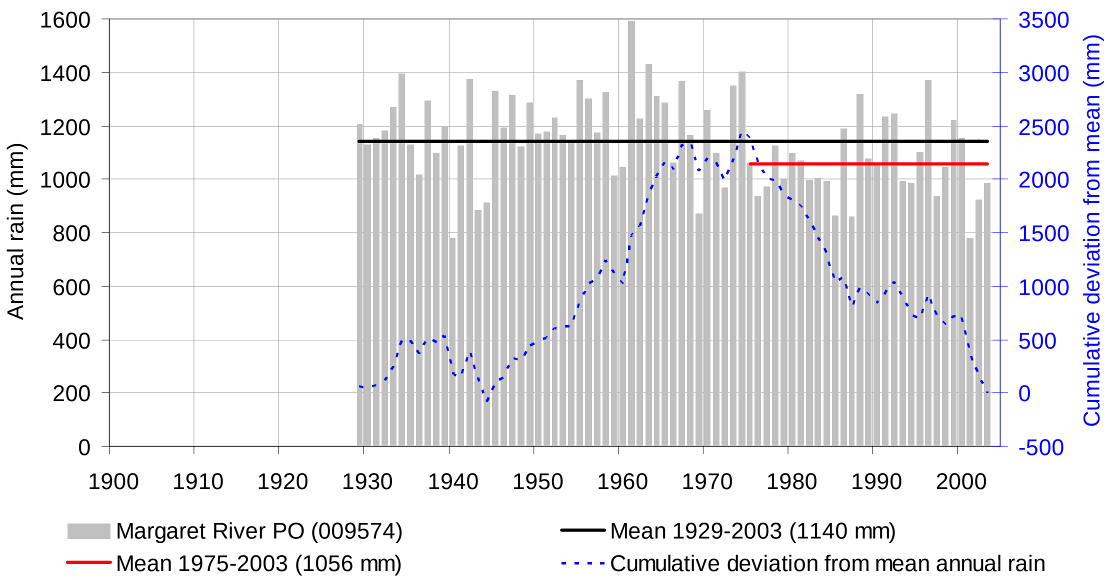


Figure 2-9. Annual rainfall at Margaret River (009574)

Table 2-2. Rainfall statistics for Cape-to-Cape rainfall stations

	Busselton (009515)	Cape Leeuwin (009518)	Cape Naturaliste (009519)	Margaret River (009574)	Nannup (009585)
Period of Record	1907-2003	1907-2003	1907-2003	1928-2003	1907-2003
Min (mm)	574 (2001)	532 (2001)	466 (2002)	781 (2001)	604 (2001)
Max (mm)	1211 (1917)	1467 (1983)	1193 (1917)	1591 (1961)	1413 (1917)
MeanLT (mm)	841	997	826	1140	940
CVLT	0.17	0.17	0.17	0.15	0.17
Mean75 (mm)	758	964	784	1056	856
CV75	0.16	0.18	0.18	0.13	0.14
Change from LT to 75 Mean	-10%	-3.3%	-5.1%	-7.4%	-8.9%

Notes: LT = long-term period (start of record to 2003)
75 = period 1975 to 2003
CV = coefficient of variation, the ratio of the standard deviation to the mean

Rainfall is highly seasonal with 74-80 per cent of rainfall occurring between May and September inclusive, for the stations shown in Table 2-2 for the period 1975 to 2003 (Figure 2-10 and Appendix 1). The monthly rainfall plots also indicate a slight shift in the rainfall distribution during the year. Rainfall as a percentage of the mean consistently increased in August and September from 1975 to 2003 compared to the long-term period, and decreased in March and April.

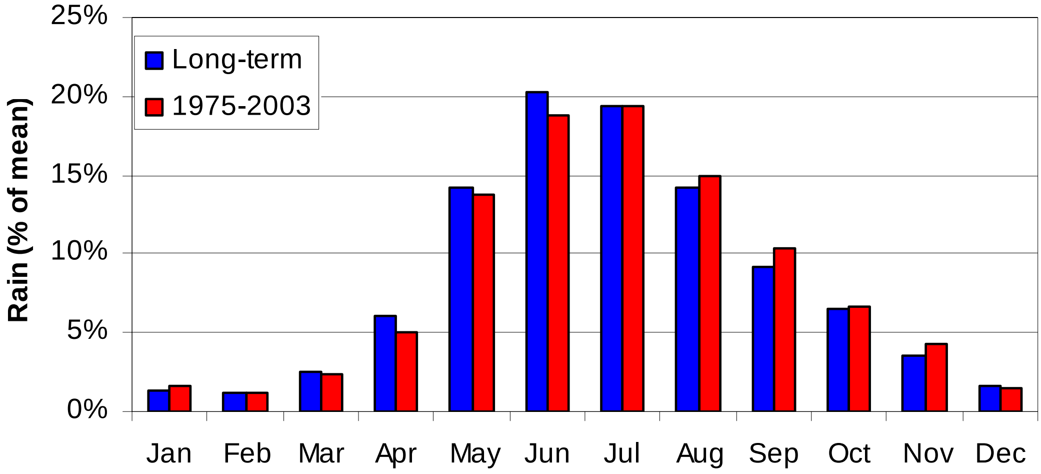


Figure 2-10. Monthly rainfall distribution for Margaret River (009574)

2.5 Streamflow

Streamflow in the Cape-to-Cape region has been summarised for three distinct periods:

- 1962-2004
- 1975-2003
- 1962-1995

The period 1962-2004 represents the long-term period for streamflow, as most of the long-term stations commenced in the 1960s. The period 1975-2003 is representative of a drying climate, while the 1962-1995 period was used in developing the REG6 regional yield estimation model. (REG6 is the tool currently used to determine the mean annual flow (MAF) for ungauged catchments in the south-west of Western Australia). As this model used a period of record of 1962 to 1995, it requires modifications for it to be compatible with the new standard period. The Water Resource Assessment Branch has developed a simple regional flow model that provides an estimate of mean annual flow from a catchment, for 1975 to 2003, based on revised flow, rainfall and land use data. This new model, REG75, will replace the widely used REG6 model. Comparisons between flow statistics for the 1962-1995 and 1975-2003 periods for the Cape-to-Cape region present likely impacts on allocation decisions, as a result of using the drier (1975-2003) period.

Annual and daily streamflow has been analysed in detail and is described in the individual sections for each of the sub-areas that have at least four years of streamflow data.

Monthly flow

Monthly flow data was analysed for the three streamflow gauging stations in the Cape-to-Cape region that have a long-term flow record since the 1960s (Table 2-3):

- Barlee Brook – Upper Iffley extended (608148/001)
- Blackwood River – Hut Pool extended (609025/019)
- Margaret River – Willmots Farm extended (610128/001).

Table 2-3. Monthly flow data stations

	Long-term Station			Station used for Extending		
Station	**Station Number**	**Period of Record**	**Area (km^2)**	**Station Number**	**Period of Record**	**Area (km^2)**
Barlee Brook – Upper Iffley	608001	1972-2000	159	608148	1961-1974	159
Blackwood River – Hut Pool	609019	1983-present	12,400	609025	1956-2000	11,600
Margaret River – Willmots Farm	610001	1970-present	443	610128	1958-1968	392

Monthly flow for the long-term streamflow gauging stations was extended to cover the period 1962 to 2004 by areally scaling monthly flow data from the stations used for extending in Table 2-3 (Equation 2-1):

$$Q_S = Q_{LT}\left(A_S / A_{LT}\right) \qquad \textit{Equation 2-1}$$

where Q_S, A_S = flow and catchment area for the station to be extended
Q_{LT}, A_{LT} = flow and catchment area for the long-term station

Monthly flow from March 2000 at Upper Iffley was estimated using regression with flow data from Donnelly River at Strickland (608151), because flow data ceased for Barlee Brook in 2000.

Like rainfall, streamflow in the Cape-to-Cape region is highly seasonal with 90 per cent of the annual flow occurring from June to October, inclusive (Figure 2-11 to Figure 2-13). The monthly flow plots also indicate a shift in the flow distribution during the year. For Barlee Brook and Margaret River, flow as a percentage of the mean increased in August to October from 1975 to 2003 compared to 1962-2004, and has decreased for the other months. For the Blackwood River, flow as a percentage of the mean has increased for the months of September to May, for the period 1975 to 2003 compared to the period 1962-2004, and has decreased for June to August. This shift could be also be due to land use impacts for the Blackwood and Margaret rivers.

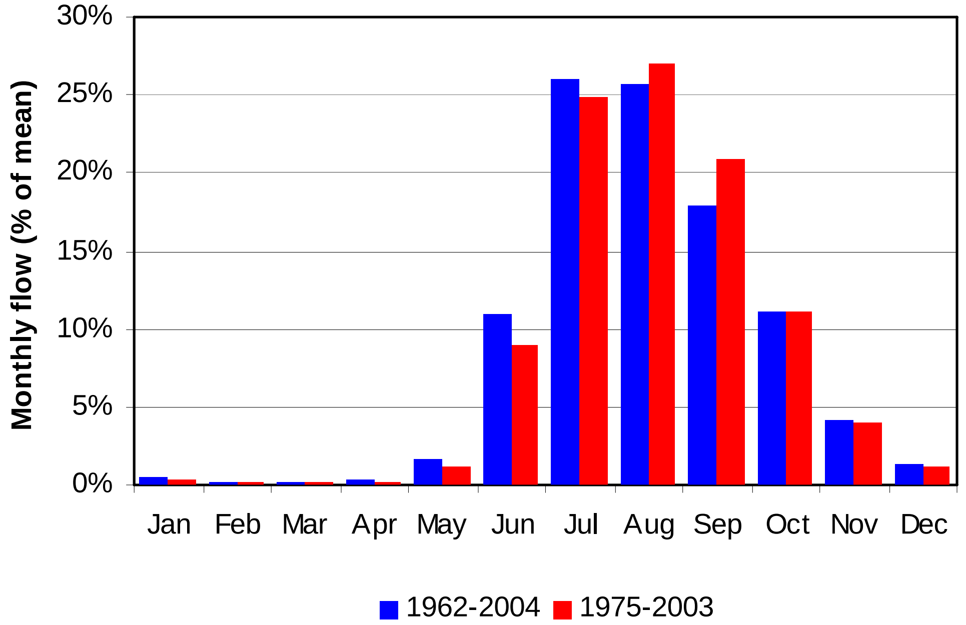


Figure 2-11. Monthly flow distribution for Barlee Brook at Upper Iffley extended (608148/001)

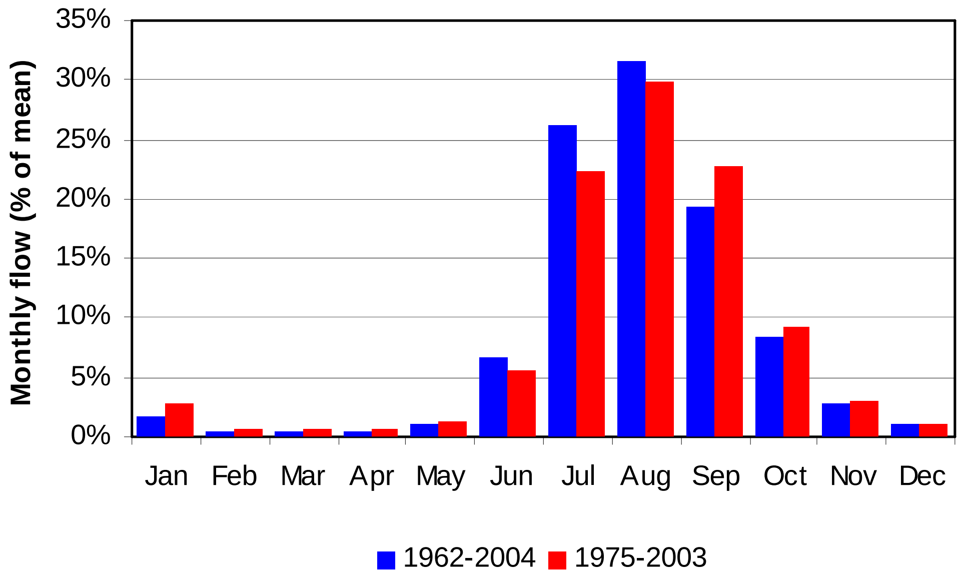


Figure 2-12. Monthly flow distribution for Blackwood River at Hut Pool extended (609025/019)

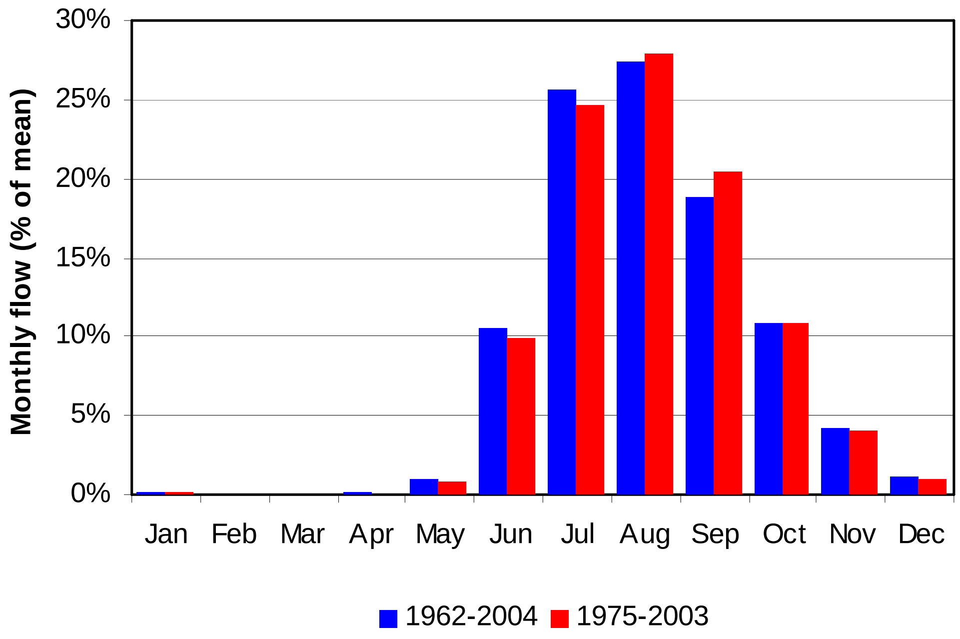


Figure 2-13. Monthly flow distribution for Margaret River at Willmots Farm extended (610128/001)

Annual flow

Streamflow yield

Observed annual calendar year flow records were extended to cover the period 1962 to 2004, based on a correlation with a hydrologically similar catchment to estimate annual flow for each year (for example, Figure 4-1). This also enabled flow statistics to be determined for each of the Cape-to-Cape region streamflow gauging stations for the periods outlined in Section 2.5. Commonly used flow statistics include the following:

- mean annual flow (MAF): the average flow over a particular period
- median annual flow (Q_{50}): the flow for which 50 per cent of years have greater flow (or the probability of exceedance is 50%)
- 90^{th} percentile flow (Q_{90}): a measure of low flow – the flow for which 90 per cent of years have greater flow (or the probability of exceedance is 90%). *Note: this has been referred to as Q_{10} in regional models such as REG6*
- coefficient of variation (CV): a measure of the variability of flow from year to year (ratio of the standard deviation to the mean).

The variability of annual flows in the Cape-to-Cape region is large with coefficients of variation (CVs) ranging from 0.30 for the Carbunup River at Lennox Vineyard (610015) to 0.98 for the Ludlow River at Happy Valley (610005) for the period 1975-2003. Mean annual flow (MAF) decreased for the 1975-2003 period compared to either the 1962-1995 or 1962-2004 periods (Figure 2-14 and Figure 2-15). The decrease in MAF from the 1962-1995 period to the 1975-2003 period ranges from eight per cent for the Vasse River at Chapman Hill (610003) to 36 per cent for the Abba River at Wonnerup Siding (610016), with an average of 20 per cent.

The median annual flow (Q_{50}) has also decreased for all gauging stations, ranging from a decrease of four per cent for the Ludlow River at Ludlow (610009) to a decrease of 34 per cent for the Ludlow River at Claymore (610007). For each station, Q_{50} has decreased less than the MAF, except for 610007, for which the change in MAF and Q_{50} are similar. This is reflected in the annual flow data for most stations (for example, Figure 5-2), which show that high flows have decreased since 1975. The change in Q_{90} has been highly variable, ranging from an increase of two per cent to a decrease of 31 per cent.

A mean annual flow (MAF) figure has been estimated for each surface water management sub-area (and the Whicher catchment which forms part of a sub-area) with streamflow gauging data. Where the gauging station is located upstream of the sub-area or Whicher catchment boundary, the MAF at the gauging station has been scaled areally to produce the MAF estimate for the sub-area (Equation 2-1).

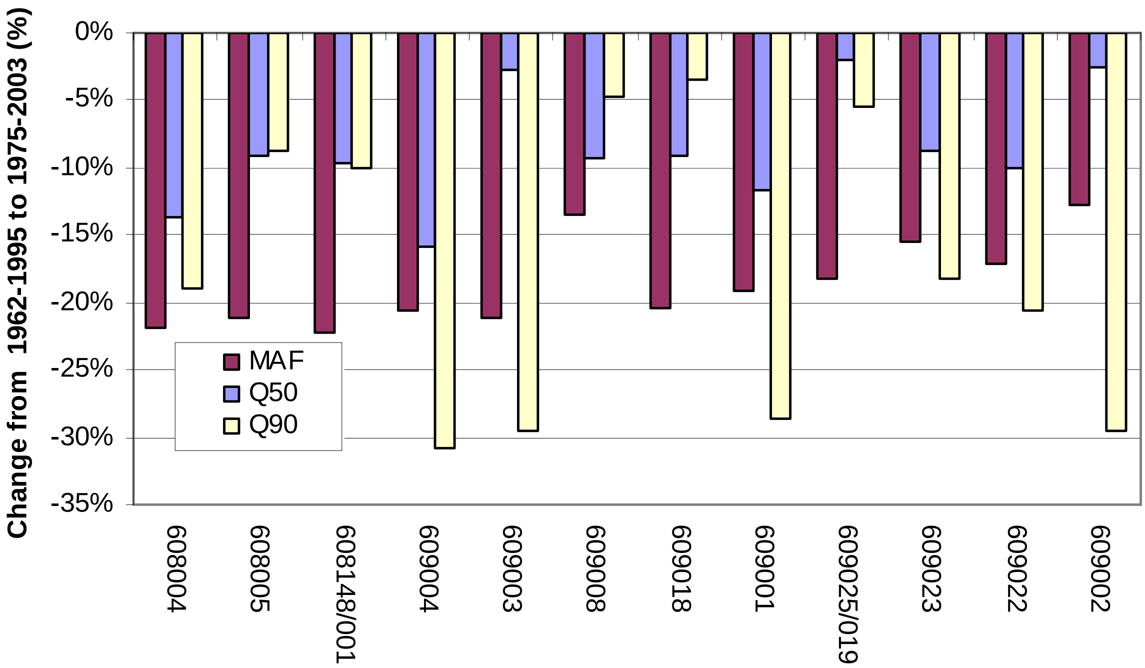


Figure 2-14. Changes in MAF, Q_{50} and Q_{90} for basins 608 and 609 from 1962-1995 to 1975-2003

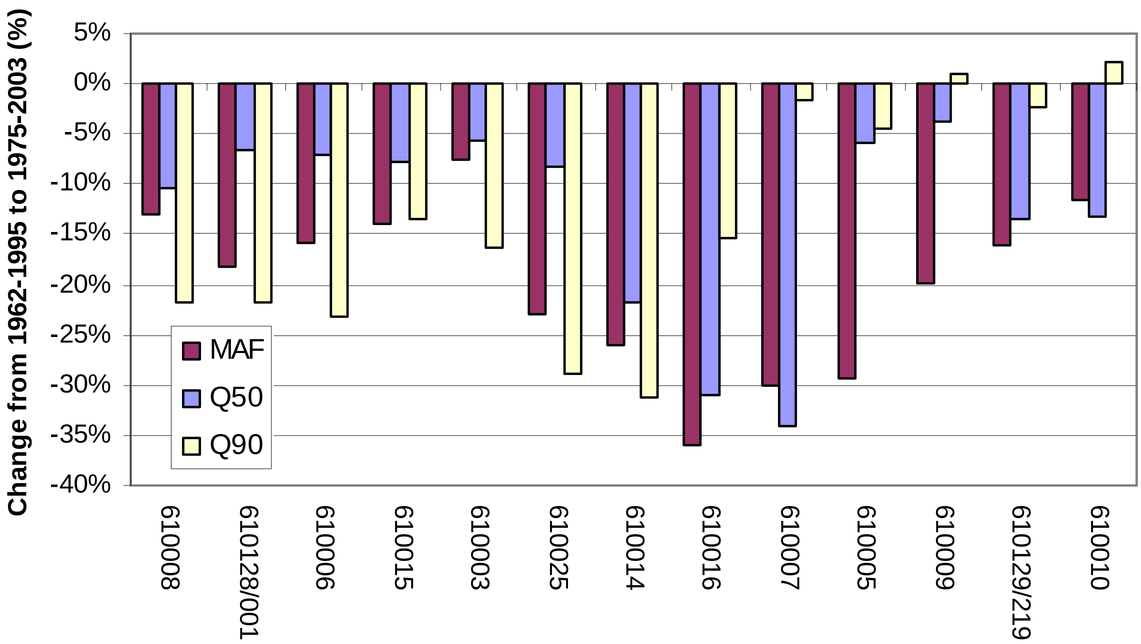


Figure 2-15. Changes in MAF, Q_{50} and Q_{90} for basin 610 from 1962-1995 to 1975-2003

Flood hydrology

There have not been widespread flood events in the Cape-to-Cape region since the 1960s. Flooding occurred in the Blackwood River as a result of heavy rainfall in the upper parts of the catchment from the January 1982 cyclone. Localised flooding occurred on the Vasse River in 1999.

A flood frequency analysis was undertaken for the three long-term streamflow gauging stations on Barlee Brook, Blackwood River and Margaret River. The annual flood peaks for the three streamflow gauging stations were extended to cover the period 1962 to 2004 by areally scaling the flow data from the long-term stations in Table 2-3 (Equation 2-2):

$$Q_S = Q_{LT} \left(A_S / A_{LT} \right)^{0.7} \qquad \textit{Equation 2-2}$$

where Q_S, A_S = flow and catchment area for the station to be extended
Q_{LT}, A_{LT} = flow and catchment area for the long-term station

Peak annual flow from 2000 to 2004 at Upper Iffley was estimated using regression with flow data from the Donnelly River at Strickland (608151), as flow data ceased for Barlee Brook in 2000.

A Log-Pearson type III (LPIII) distribution was fitted to the extended peak annual flow series for the three stations (Figure 2-16 to Figure 2-18 and Table 2-4).

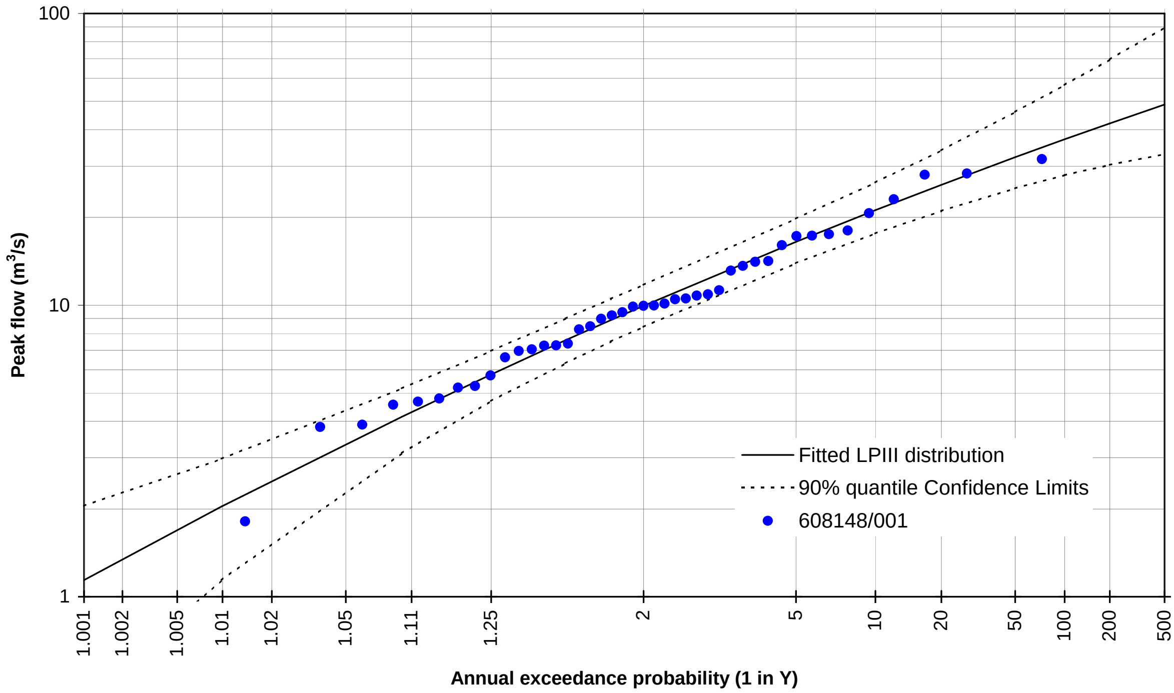


Figure 2-16. Annual series flood frequency for Barlee Brook at Upper Iffley extended (608148/001)

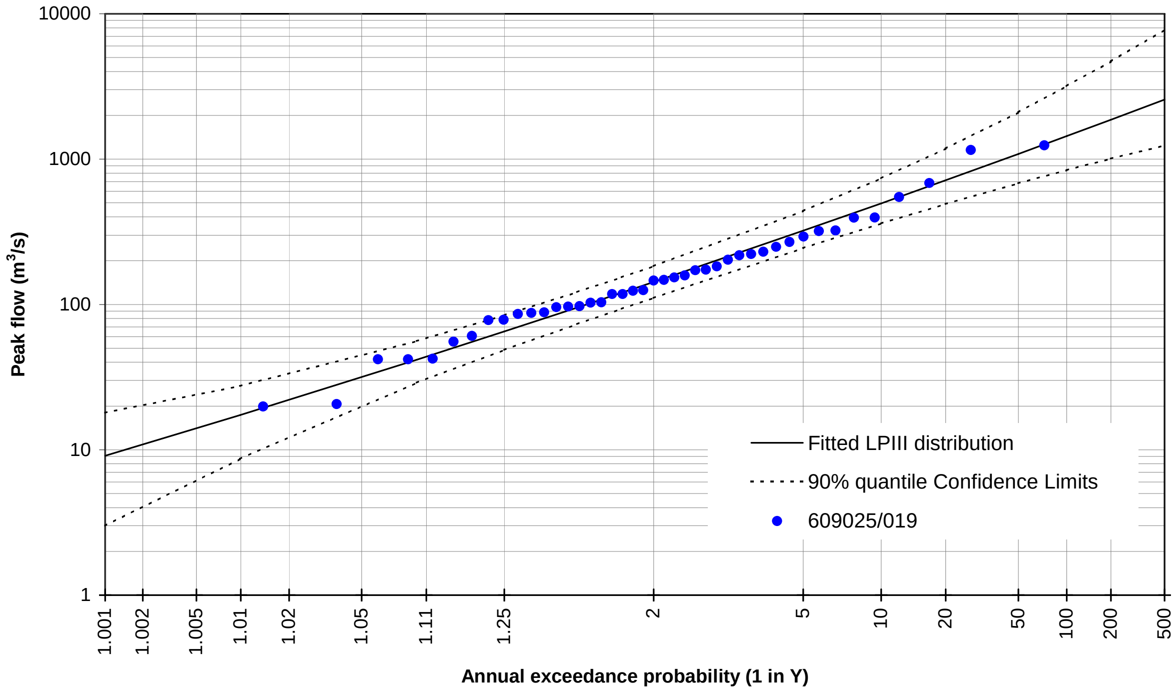


Figure 2-17. Annual series flood frequency for Blackwood River at Hut Pool extended (609025/019)

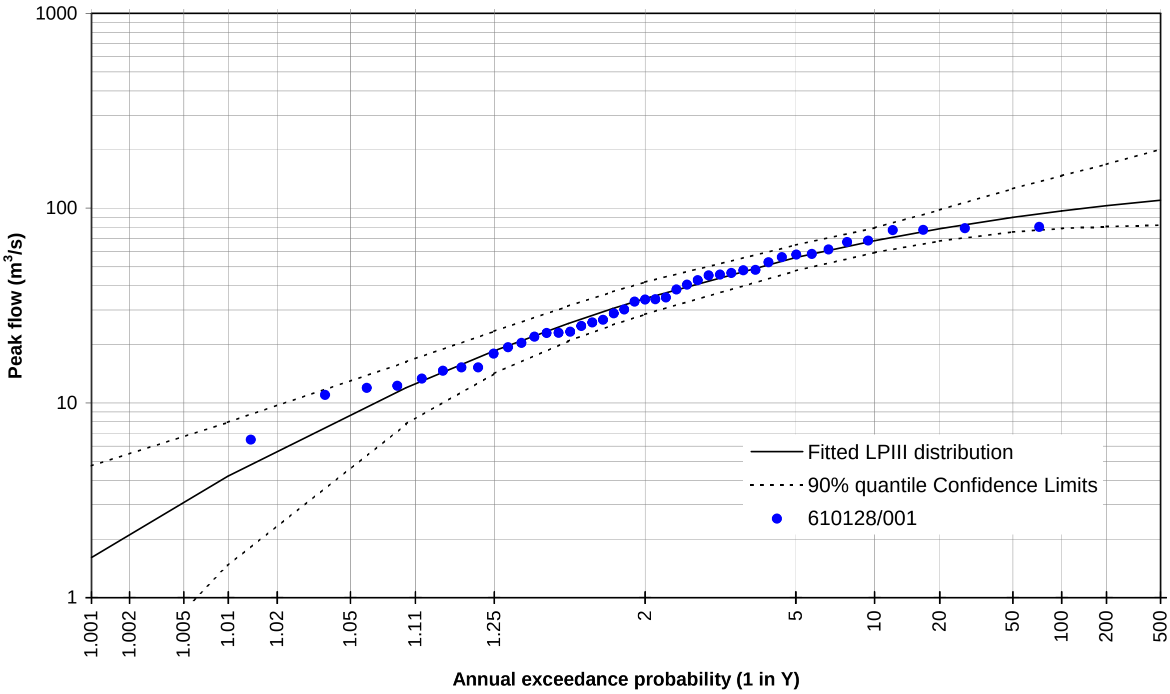


Figure 2-18. Annual series flood frequency for Margaret River at Willmots Farm extended (610128/001)

Table 2-4. Annual series flood frequency results

Annual exceedance probability	Peak annual flow					
	608148/001		609025/019		610128/001	
(1 in Y)	(m^3/s)	factor	(m^3/s)	factor	(m^3/s)	factor
1.1	4.15		41.6		12.0	
2	9.95	1.00	143	1.00	34.4	1.00
5	16.5	1.66	321	2.24	55.7	1.62
10	21.2	2.13	497	3.48	68.0	1.98
20	25.9	2.60	715	5.00	78.4	2.28
50	32.2	3.24	1090	7.62	89.7	2.61
100	37.0	3.72	1440	10.07	96.8	2.81
Peak recorded flow	31.7		1240		79.9	
(year)	(1962)		(1982)		(1965)	

Note: 'factor' is the 1 in 2 year annual exceedance probability growth factor

Daily flow

The following individual sub-area sections present a series of interpretations of daily flow, including plots showing continuous flow periods, flow duration curves and baseflow indices.

Continuous flow period

Continuous flow periods have been determined for each calendar year for the period 1975 to 2004 (for example, Figure 4-3). The continuous flow period is defined as the main flow period where daily flow was greater than 0 ML.

Flow duration curves

Flow duration curves (FDCs) show the relationship between streamflow and the percentage of time it is exceeded (Gordon et al, 2004). FDCs are useful for investigating environmental flow requirements, and for assessing flow periods for licensing. Flow duration curves have been constructed using available daily flow data from 1975 to 2004.

Flow duration curves are sometimes criticised as, traditionally, their interpretation depends on the particular period of record on which they are based (Vogel and Fennessey, 2000). Mean or median annual flow duration curves are developed by obtaining flow duration curves for individual years, then plotting the mean or median (Q_{50}) for each rank or probability. Based on this procedure, curves for other quantiles, such as Q_{90} can also be developed. Vogel and Fennessey showed that mean and median annual FDCs tend to approximate the period of record FDC, except for low flows. Significant differences between the period of record FDC and the mean and median annual FDCs can occur as the period of record FDC is highly sensitive to the hydrologic extremes associated with the particular period chosen, whereas the mean and median annual FDCs are not nearly as sensitive (Vogel and Fennessey, 2000). The annual flow duration plots (for example, Figure 4-5) show three curves:

- Period of Record. This is obtained by ranking all the daily flows for the period of record and plotting against probability.
- Mean Annual. This is obtained by ranking the daily flows for each year, then calculating the average for each rank or probability.
- Median Annual. This is obtained by ranking the daily flows for each year, then calculating the median for each rank or probability.

The median annual FDC has been selected for analysis in the following sections as it represents the distribution of daily streamflow in a typical hypothetical year and its interpretation is not affected by abnormally wet or dry periods during the period of record (Vogel and Fennessey, 2000).

The slope of the flow duration curve reflects the catchment's response to geology and rainfall. The daily curve for a flashy stream will tend to have a steep slope at the high flow end whereas a flatter high flow end is characteristic of streams with large amounts of potential storage. If groundwater contributions are significant, the slope of the curve at the lower end tends to be flattened whereas a steep slope indicates minor baseflows (Gordon et al, 2004).

Similar to the annual flow analysis, the following statistics have been investigated:

- median daily flow (Q_{50}): the flow for which 50 per cent of days have greater flow (or the probability of exceedance is 50%)
- 10^{th} percentile flow (Q_{10}): a measure of high flow – the flow for which 10 per cent of days have greater flow (or the probability of exceedance is 10%)
- 90^{th} percentile flow (Q_{90}): a measure of low flow – the flow for which 90 per cent of days have greater flow (or the probability of exceedance is 90%).

Two statistics have been determined to help interpret the high-end and low-end slopes: Q_{50}/Q_{10} and Q_{90}/Q_{50} respectively (Appendix 4).

Monthly flow duration curves have also been constructed for each of the gauging stations (for example, Figure 4-7), to provide greater detail of the flow regime.

Baseflow

A streamflow hydrograph can be separated into two main components:

- Direct runoff (or quickflow) – the flow produced from rainfall
- Baseflow – the flow representing the groundwater and subsurface contribution

A digital baseflow separation filter was applied to the observed daily flow data for all gauging stations, using the Chapman and Maxwell Method, with a k parameter value of 0.985 (Grayson et al, 1996). Figure 2-19 shows the result of applying the technique at Chapman Brook – Forest Grove (609023) for daily flow during 1996.

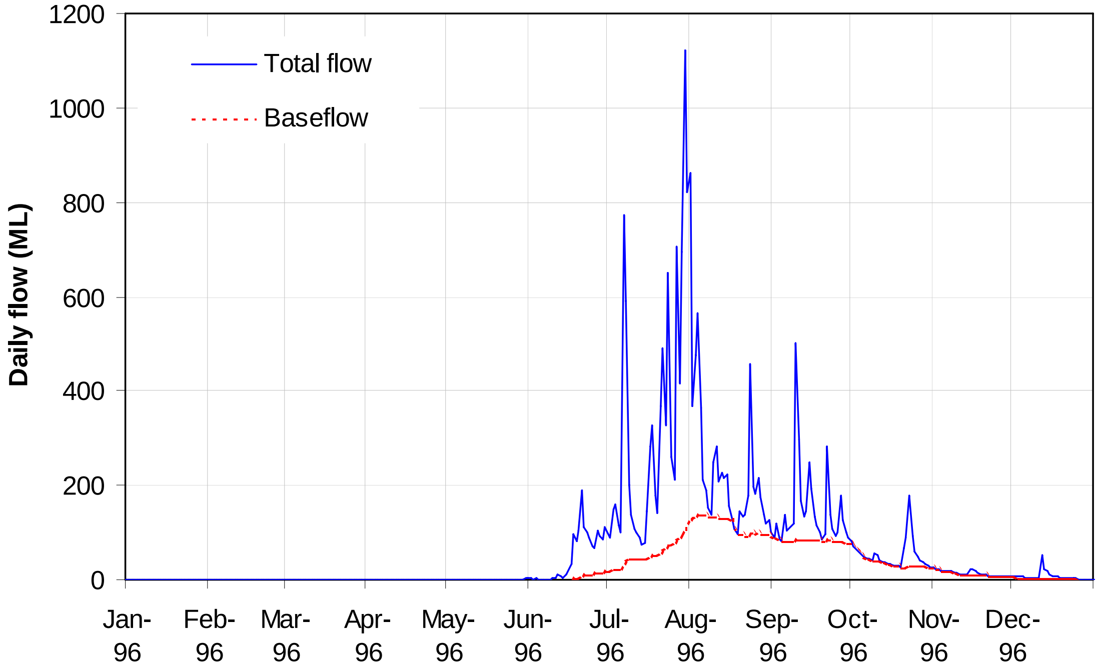


Figure 2-19. Chapman Brook at Forest Grove (609023) baseflow separation

Baseflow indices (BFIs) have been calculated for each year, as the ratio of the volume of baseflow to the volume of total flow. For example, a baseflow index of 40 per cent indicates that 40 per cent of flow is from groundwater/subsurface flow and 60 per cent of flow is from direct runoff. Plots of annual baseflow indices are presented in the following sections (for example, Figure 4-9). Although years with missing data are presented, only complete years of data are used to determine statistics such as the mean and range quoted in this report. The BFIs are also summarised in Appendix 4.

3 Lower Blackwood River

The Blackwood River is the largest river, by flow volume, in the south-west of Western Australia (Mayer et al, 2005) and is the major river in the Blackwood River Basin (609). There are currently two streamflow gauging stations operating in the Lower Blackwood Surface Water Management Area (Figure 2-2). Hut Pool (609019) is located eight kilometres downstream of the Adelaide Brook tributary, and was installed in 1983 following the January 1982 floods (Figure 2-6 and Figure 3-1). Old Nannup Caravan Park (609058) was installed in 2001 for flood warning purposes. Data from Darradup (609025) located downstream of Red Gully, operated from 1956 to 1998 and has been used to extend the record at 609019.

The Hut Pool catchment is approximately 64 per cent cleared. The water quality of the lower Blackwood River in the Cape-to-Cape region is highly brackish (1,500-3,000 mg/L TDS) for most of the year (Mayer et al, 2005) and therefore not suitable for most surface water resource uses.

3.1 Annual flow

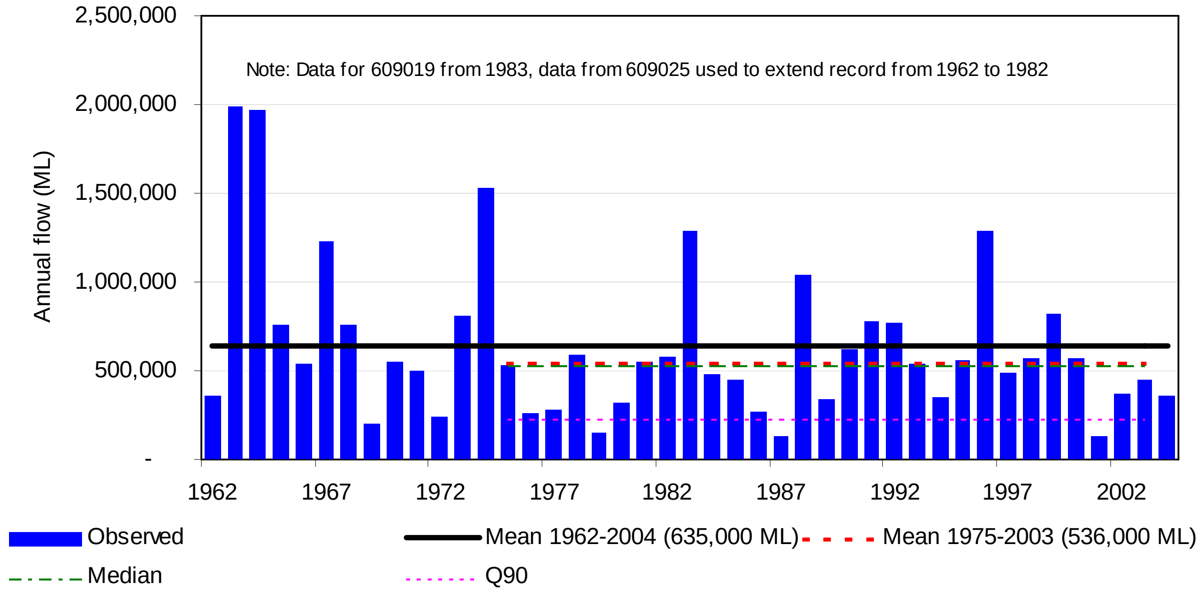


Figure 3-1. Blackwood River at Hut Pool extended (609025/019) annual flow

The observed coefficient of variation (CV) at Hut Pool extended (609025/019) is 0.69, however for the period 1975-2003 it is estimated to be 0.55. The lower CV for 1975-2003 compared to the observed period 1962-2004 indicates less variability in streamflow over the shorter period. The maximum and minimum recorded annual flows are 1,990,000 ML and 129,000 ML at Hut Pool (extended).

The mean annual flow (MAF) estimate for the Blackwood River – Hut Pool catchment for the period 1975 to 2003 is 536,000 ML (Table 4-1), a reduction of 18 per cent compared to the period 1962-1995.

Table 3-1. Blackwood River mean annual flows

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
609019	12,400	635,000	655,000	536,000

3.2 Daily flow

Continuous flow period

Figure 3-2 shows the observed continuous flow period for each calendar year since 1975 for the Blackwood River at Hut Pool. Flow has been perennial (continuous) for the entire period.

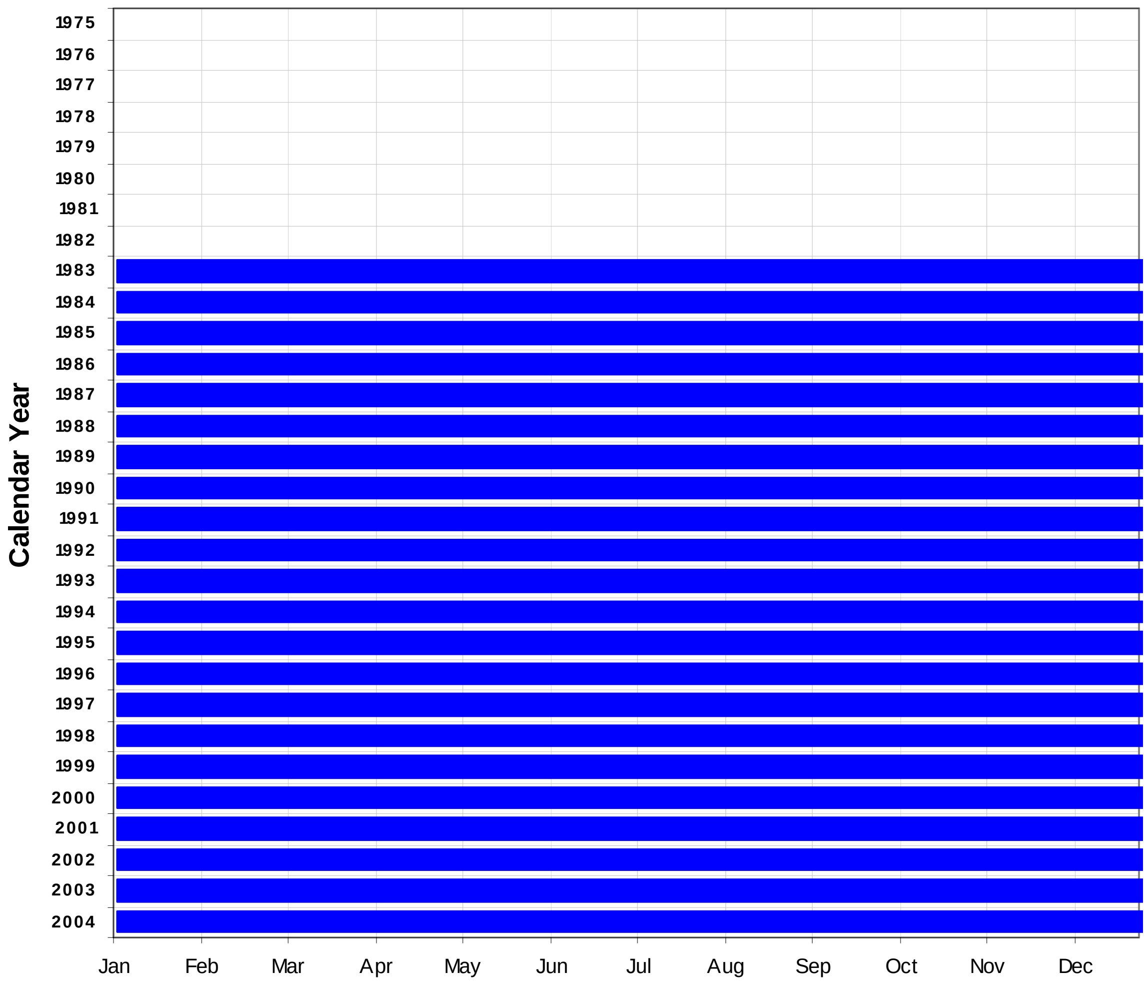


Figure 3-2. Blackwood River at Hut Pool (609019) continuous flow period

Flow duration curves

The annual flow duration curves (FDC) are similar for the Blackwood River at Hut Pool (Figure 3-3). The median FDC shows that the stream is perennial with a median daily flow of 350 ML. The high-flow end slope is relatively flat indicating a stable stream with large amounts of surface storage. The slope of the curve is very shallow at the low-flow end, indicating large groundwater contributions, which are from the Leederville and Yarragadee aquifers.

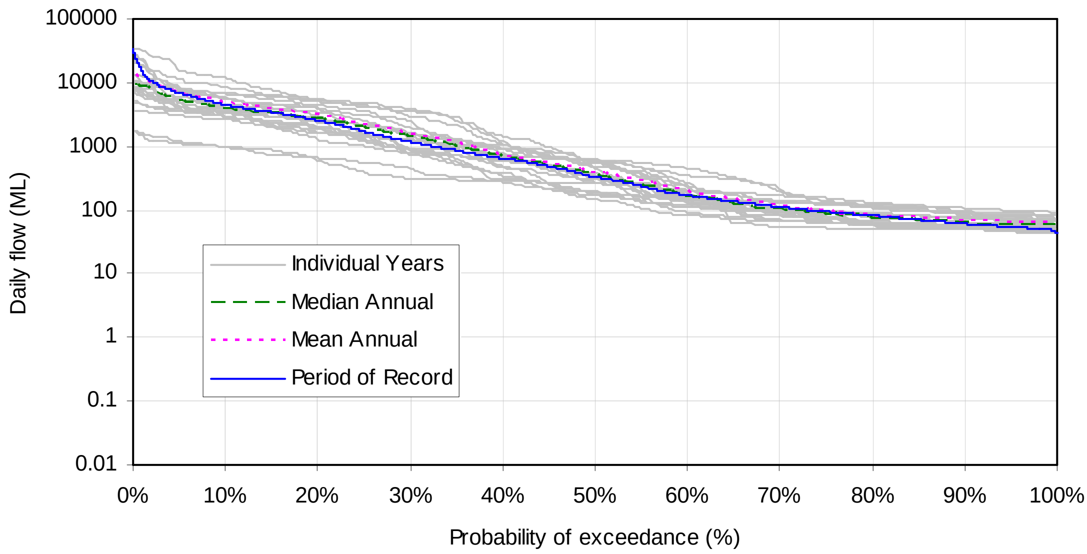


Figure 3-3. Blackwood River at Hut Pool (609019) annual flow duration curves

Monthly flow duration analysis for the Blackwood River at Hut Pool (Figure 3-4) shows that flow is continuous throughout the year and the corresponding median daily flow is greater than 64 ML. A minimum daily flow of 44 ML is maintained throughout the year. The curves for January through to March are very flat at the low end, indicating that groundwater contributions are the dominant flow source during these months.

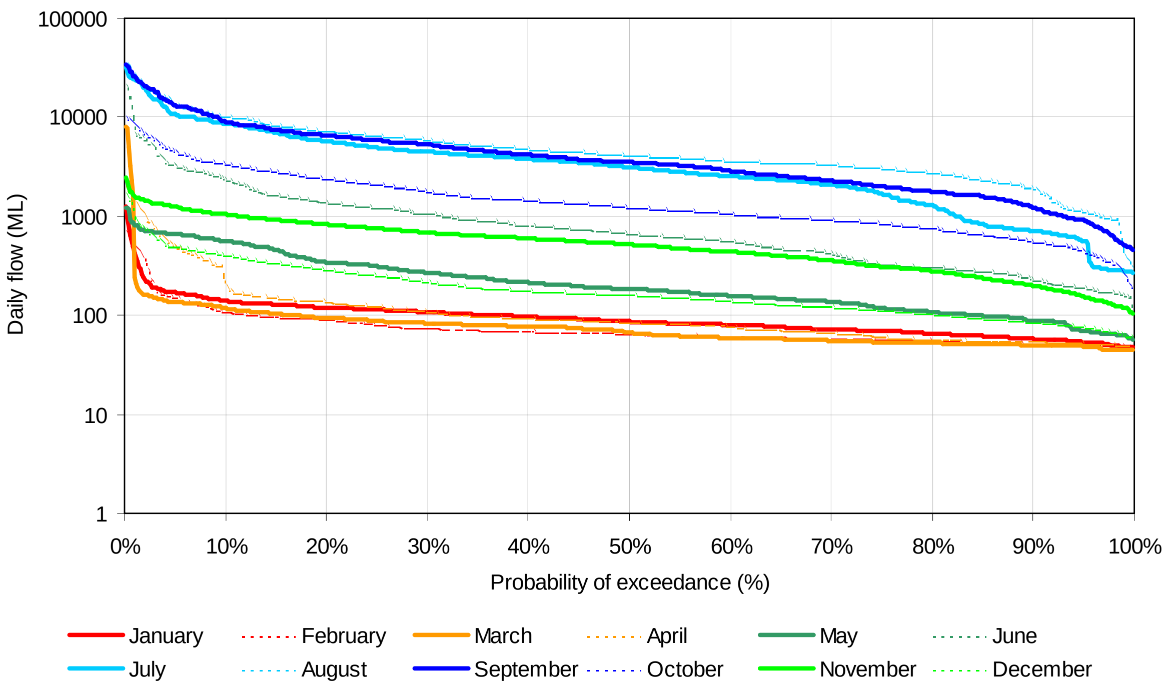


Figure 3-4. Blackwood River at Hut Pool (609019) monthly flow duration curves

Baseflow analysis

The baseflow analysis for the Blackwood River indicated that, on average, 41 per cent of the total annual flow at Darradup (609025) is derived from baseflow (ie a baseflow index of 41%) with a range of 25 to 45 per cent (Figure 3-5). Further downstream, Hut Pool (609019) has a higher baseflow index of 43 per cent and exhibits a similar variation.

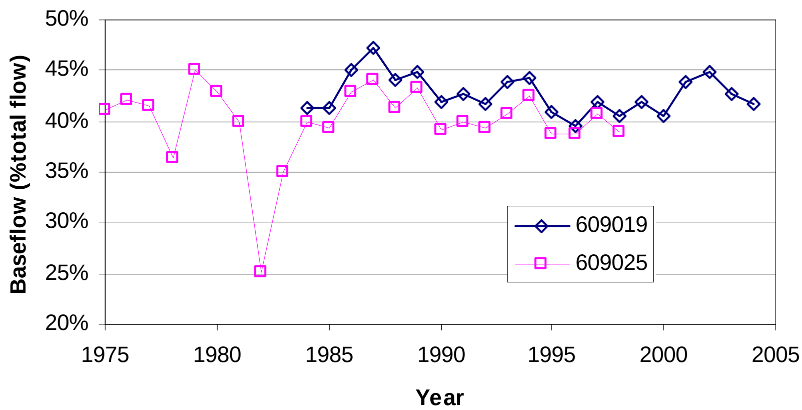


Figure 3-5. Lower Blackwood River baseflow indices

4 Chapman Brook

The Chapman Brook Surface Water Management Sub-area (Whicher catchment Chapman 5) (Figure 2-2 and Figure 2-3) has had two streamflow gauging stations operating since 1995: at Forest Grove (609023) upstream of the confluence of the Upper Chapman Brook and at White Elephant Bridge (609022) downstream of the confluence (Figure 2-6, Figure 4-1 and Figure 4-2). At the time of the development of REG6, these gauging stations had only just started operating, so flow statistics produced at these sites were estimates only. The gauging station at White Elephant Bridge also measures the contribution of flow from the Upper Chapman Brook Sub-area (Whicher catchment Upper Chapman 4); however, there have not been any gauging stations operating which measure flow from the Upper Chapman Brook only. The Forest Grove catchment is approximately 60 per cent cleared, while the White Elephant Bridge catchment is approximately 30 per cent cleared. The Upper Chapman and Chapman brooks are fresh (<500 mg/L TDS) (Mayer et al, 2005).

4.1 Annual flow

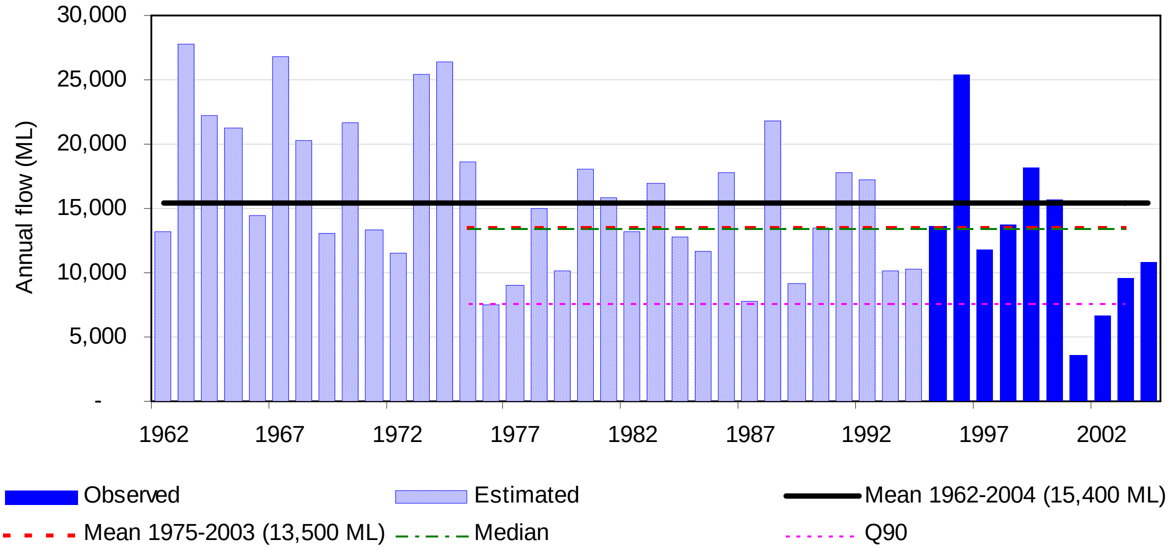


Figure 4-1. Chapman Brook at Forest Grove (609023) annual flow

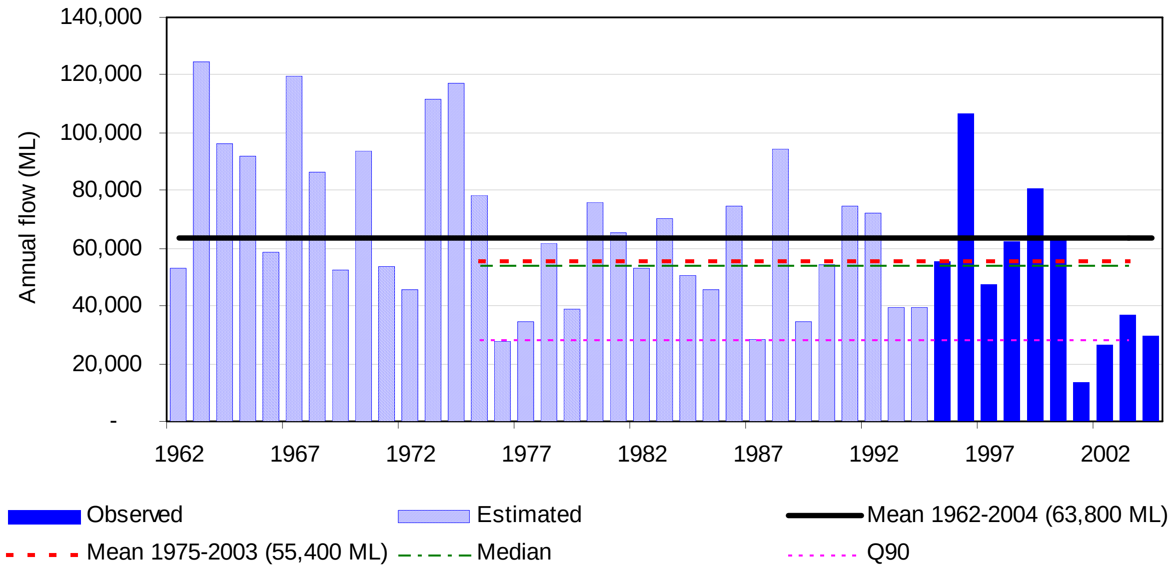


Figure 4-2. Chapman Brook at White Elephant Bridge (609022) annual flow

The observed coefficients of variation (CVs) at Forest Grove (609023) and White Elephant Bridge (609022) are 0.47 and 0.53; however, for the period 1975-2003 they are estimated to be 0.36 and 0.39 respectively. The lower CV for 1975-2003 compared to the observed period 1995-2004 indicates less variability in streamflow over the longer period. The maximum and minimum recorded annual flows are 25,500 ML and 3,620 ML respectively at Forest Grove and 107,000 ML and 13,800 ML respectively at White Elephant Bridge.

The mean annual flow (MAF) estimate for the period 1975 to 2003 is 13,500 ML at Forest Grove and 55,400 ML at White Elephant Bridge (Table 4-1), a reduction of 16 and 17 per cent respectively, compared to 1962-1995.

The estimated MAFs for the Upper Chapman and Chapman Surface Water Management Sub-areas are 36,400 ML and 20,100 ML respectively.

Table 4-1. Chapman Brook mean annual flows

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
609023	45.2	15,400	16,000	13,500
609022	180	63,800	66,900	55,400
Upper Chapman Sub-area	118	–	–	*36,400*
Chapman Sub-area	67.0	–	–	*20,100*

Note: Figures in *italics* have been derived from areal scaling (Equation 2-1)

4.2 Daily flow

Continuous flow period

Figure 4-3 and Figure 4-4 show the observed continuous flow period for each calendar year since 1975 for the Chapman River at Forest Grove and White Elephant Bridge respectively. Flow is ephemeral, generally starting in May and stopping in January, although the plot for Forest Grove shows that flow has ceased by the end of December for the last four years.

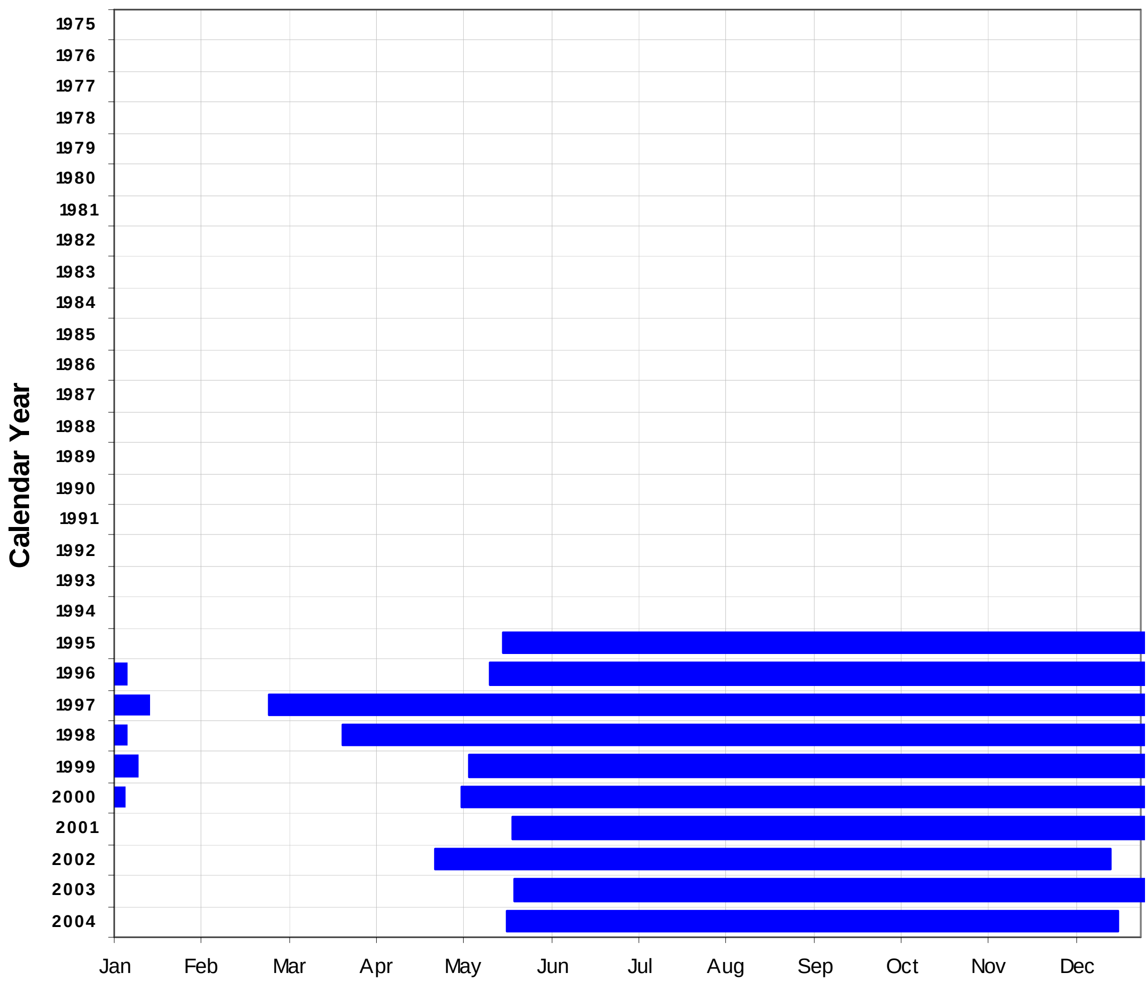


Figure 4-3. Chapman Brook at Forest Grove (609023) continuous flow period

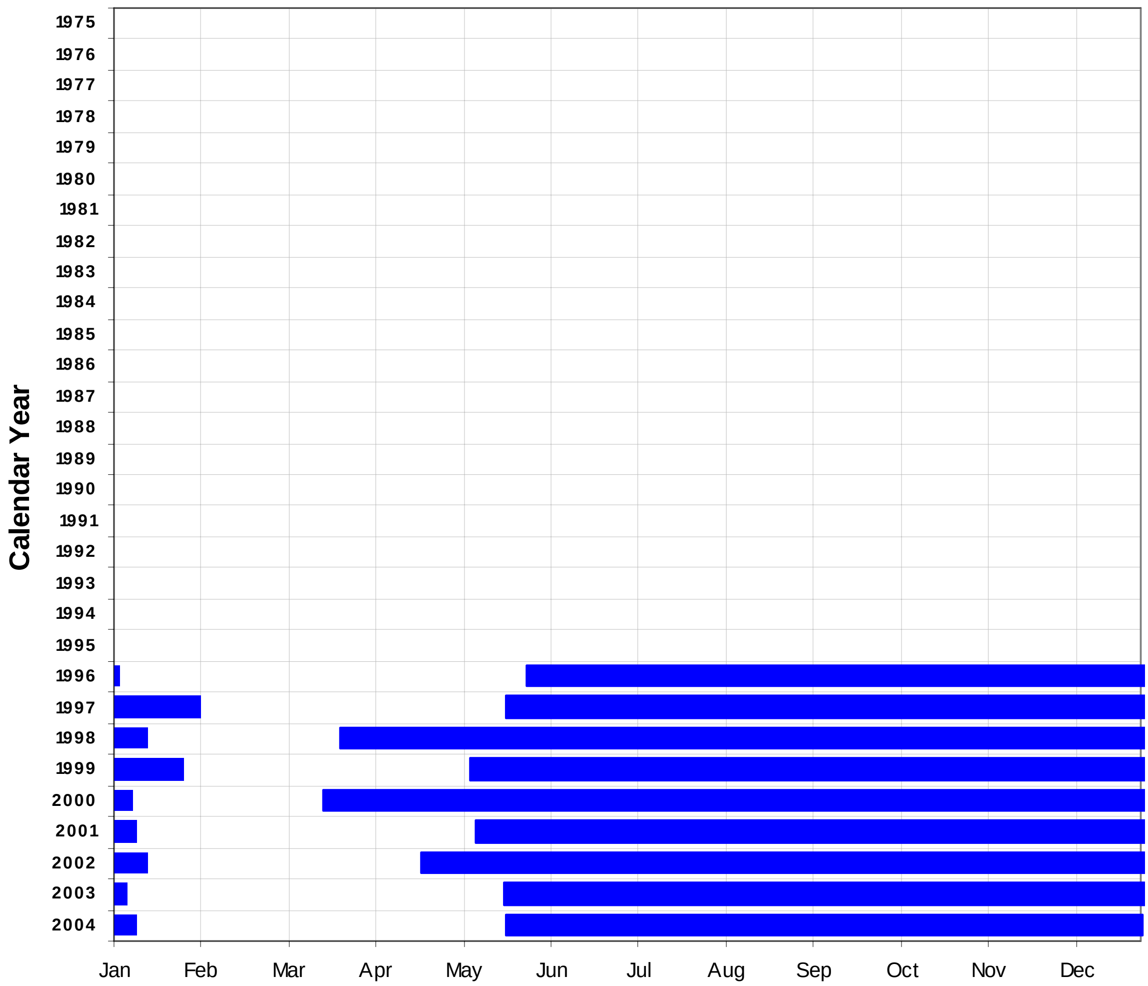


Figure 4-4. Chapman Brook at White Elephant Bridge (609022) continuous flow period

Flow duration curves

For the Chapman Brook, the median annual flow duration curve (FDC) indicates a lower reliability of flow for low flows. The median FDC shows that the stream is ephemeral with 63 per cent of days having flow at Forest Grove (Figure 4-5) and 70 per cent at White Elephant Bridge (Figure 4-6). The median daily flow is 4.6 ML at Forest Grove and 25 ML at White Elephant Bridge. The high-flow end slope is relatively flat for Forest Grove and White Elephant Bridge, indicating a stable stream with large amounts of surface storage.

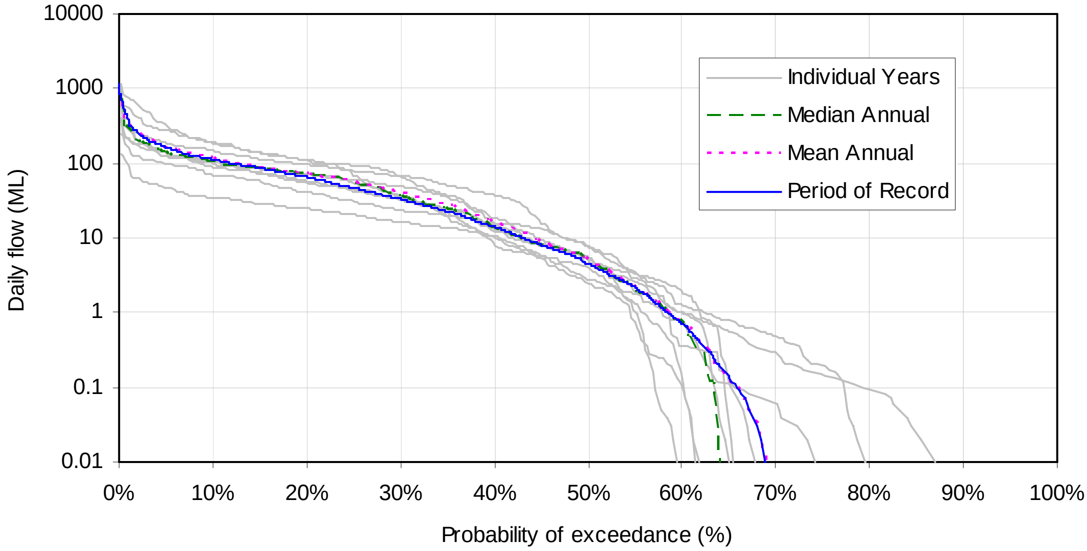


Figure 4-5. Chapman Brook at Forest Grove (609023) annual flow duration curves

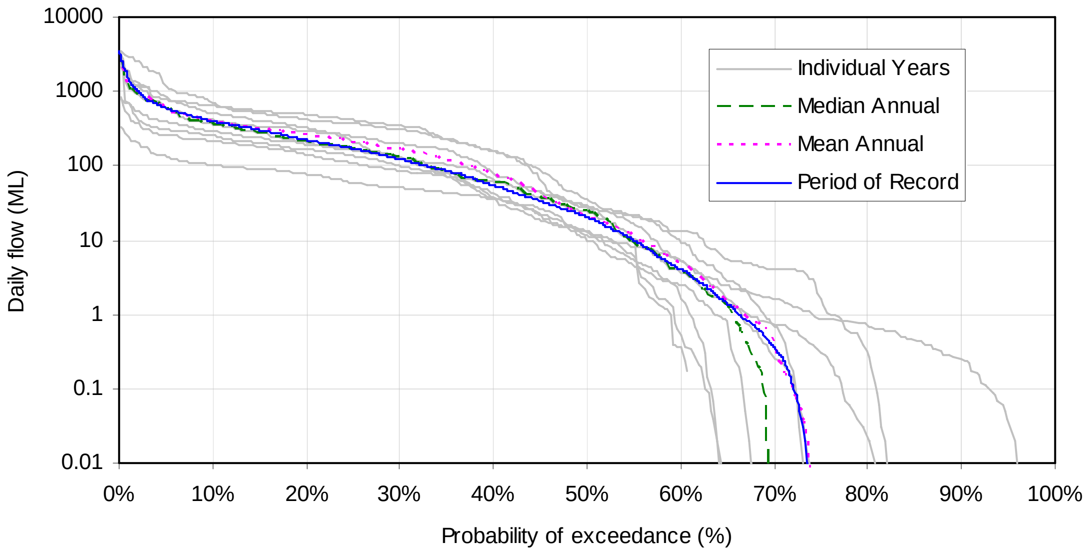


Figure 4-6. Chapman Brook at White Elephant Bridge (609022) annual flow duration curves

Monthly flow duration analysis for the Chapman Brook (Figure 4-7 and Figure 4-8) shows that flow is continuous between June and November and the corresponding median daily flow is greater than 6.7 ML at Forest Grove and 36 ML at White Elephant Bridge. Flow is not continuous for the other months and the median daily flow is less than 0.01 ML/day between January and April.

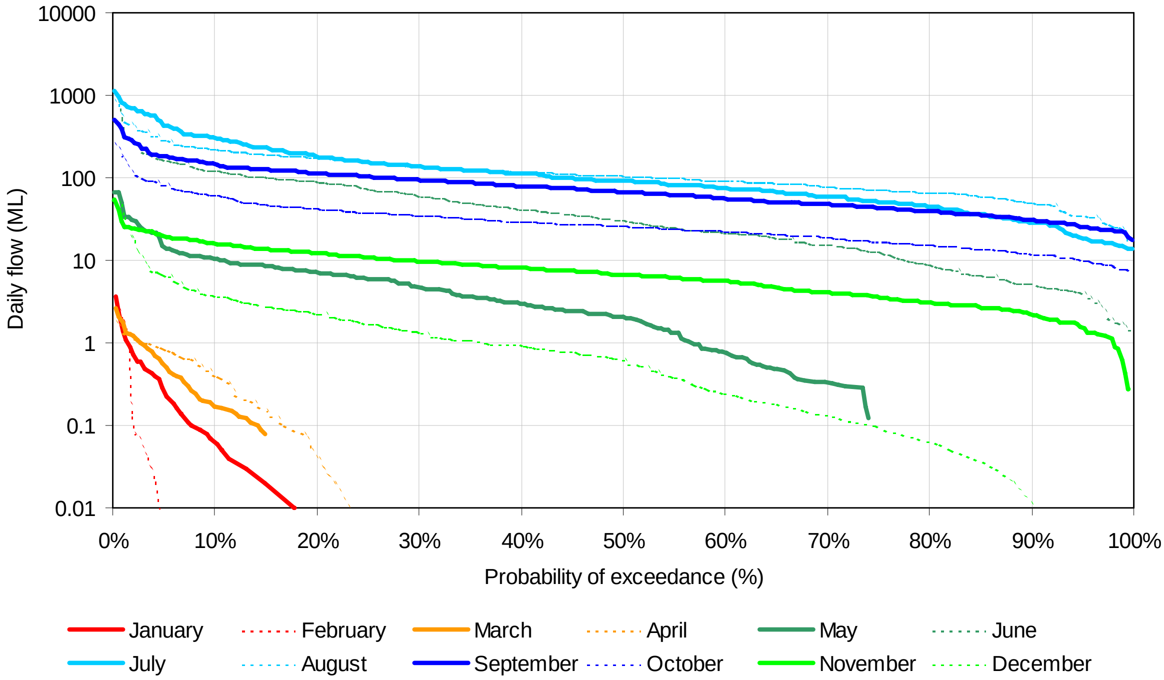


Figure 4-7. Chapman Brook at Forest Grove (609023) monthly flow duration curves

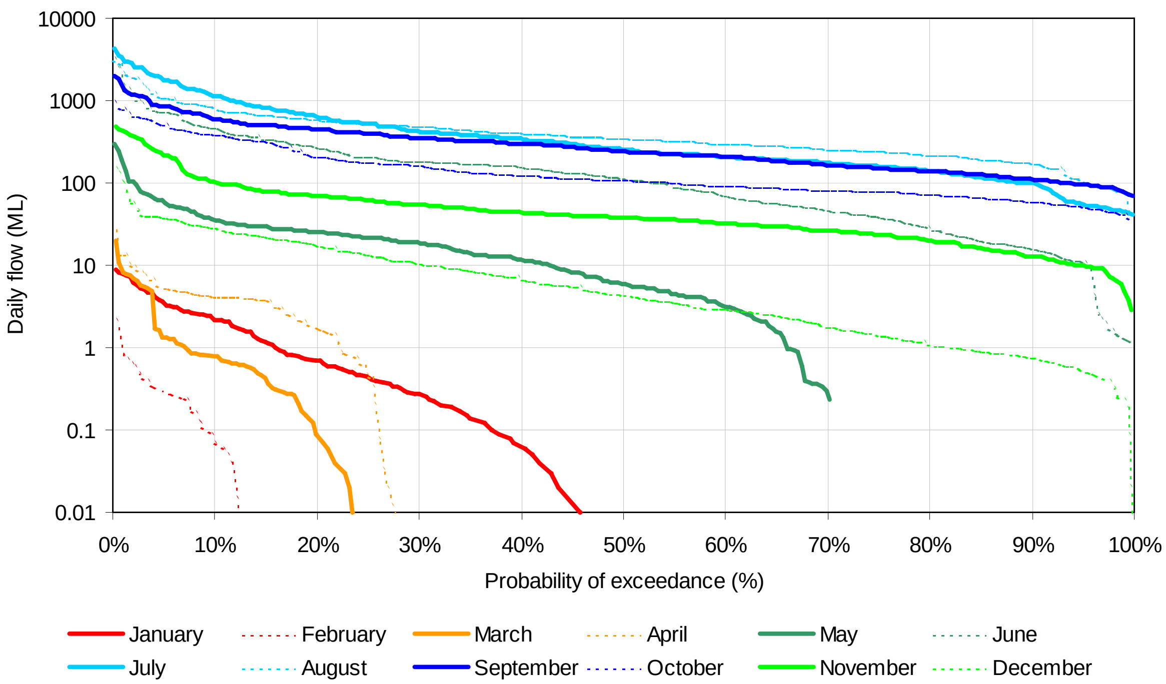


Figure 4-8. Chapman Brook at White Elephant Bridge (609022) monthly flow duration curves

Baseflow analysis

The baseflow analysis for Chapman Brook indicated that on average, 40 per cent of the total annual flow at Forest Grove (609023) is derived from baseflow (ie a baseflow index of 40%) with a range of 38 to 41 per cent (Figure 4-9). Further downstream, White Elephant Bridge (609022) has a slightly higher baseflow index of 41 per cent and exhibits more variation, with a range of 35 to 43 per cent.

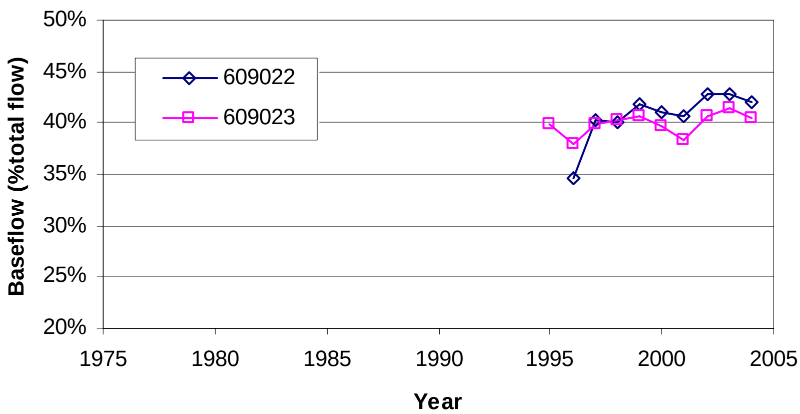


Figure 4-9. Chapman Brook baseflow indices

5 Margaret

The Margaret and Capel Rivers are the only rivers currently proclaimed in the Cape-to-Cape region for surface water licensing. The Margaret River catchment (Whicher catchment Margaret 13) has recently been further divided into five Surface Water Management Sub-areas (Figure 2-2 and Figure 2-3).

- Upper Margaret
- Middle Margaret
- Ten Mile Brook
- Margaret Town
- Lower Margaret.

Bramley Brook (Whicher catchment 15) is also a tributary of the Margaret River; however, it has been defined as a separate Surface Water Management Sub-area.

The Margaret River currently has one streamflow gauging station operating: at Willmots Farm (610001), located in the Margaret Town Sub-area, which has been operating since 1970 (Figure 2-6 and Figure 5-2). Data from Lower Town Weir (610128), which operated from 1958 to 1968, has been used to extend the record at 610001. A gauging station at Margaret River North – Whicher Range, a tributary in the Upper Margaret Sub-area, operated from 1977 to 1999 (Figure 5-1). The Whicher Range catchment is located in State forest; whereas the Willmots Farm catchment includes contribution from agricultural areas and is approximately 20 per cent cleared. The Margaret River and its tributaries are fresh (Mayer et al, 2005).

5.1 Annual flow

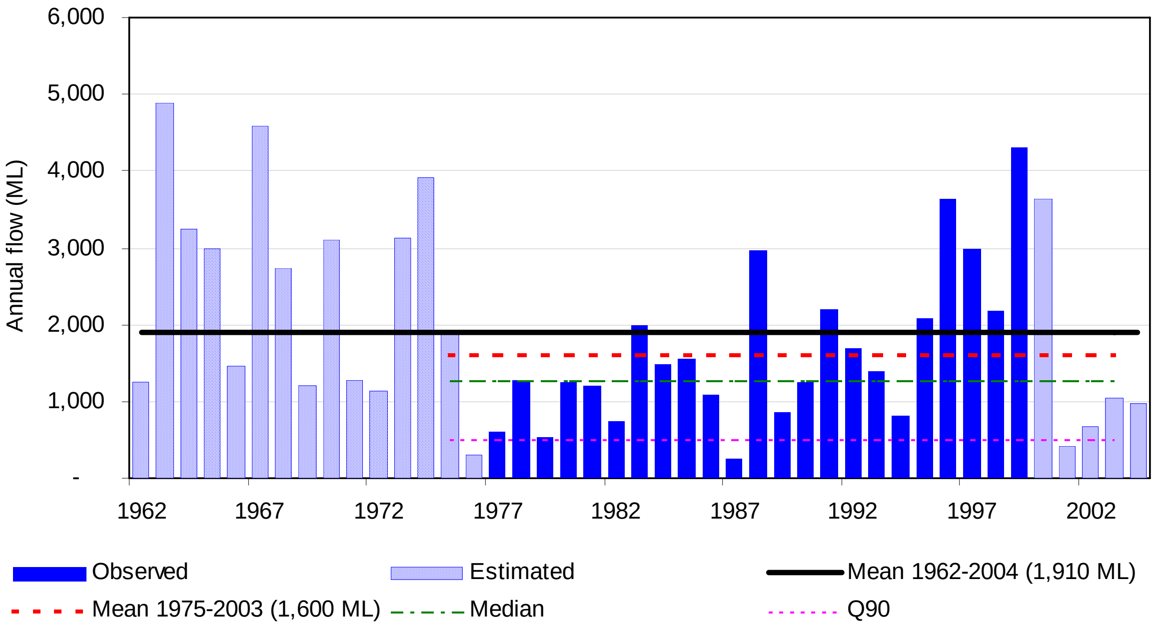


Figure 5-1. Margaret River North at Whicher Range (610008) annual flow

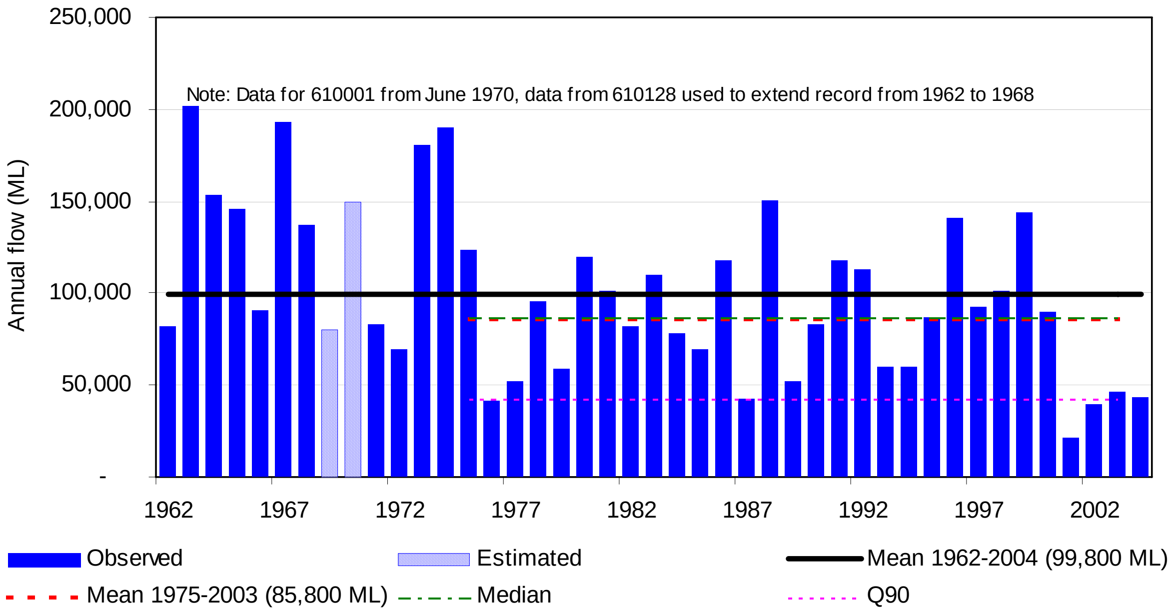


Figure 5-2. Margaret River at Willmots Farm extended (610128/001) annual flow

Annual flow in the Margaret River is quite variable, especially in the upper reaches. The observed coefficients of variation (CVs) at Whicher Range (610008) and Willmots Farm (610001) are 0.61 and 0.47; however, for the period 1975-2003 they are estimated to be 0.67 and 0.40 respectively. The high variability in flow at Whicher Range is reflected in the large CV and the large difference in the 1975-2003 period median and mean (Figure 5-1). The maximum and minimum recorded annual flows are 4,310 ML and 244 ML respectively at Whicher Range and 202,000 ML and 20,900 ML respectively at Willmots Farm.

The mean annual flow (MAF) estimate for the period 1975 to 2003 is 1,600 ML at Whicher Range and 85,800 ML at Willmots Farm (Table 5-1), a reduction of 13 and 18 per cent respectively, compared to 1962-1995.

Table 5-1. Margaret River mean annual flows

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
610008	15.5	1,910	1,830	1,600
610001	443	99,800	105,000	85,800
Upper Margaret Sub-area	274			*39,200*
Middle Margaret Sub-area	85.9			*25,800*
Ten Mile Brook Sub-area	4.9			*1,200*
Margaret Town Sub-area	31.8			*9,300*
Lower Margaret Sub-area	49.2			*14,100*
Bramley Sub-area	46.9	–	–	*14,900*

Note: Figures in *italics* have been derived from a regional relationship (REG75)

5.2 Daily flow

Continuous flow period

Figure 5-3 and Figure 5-4 show the observed continuous flow period for each calendar year since 1975 for the Margaret River North at Whicher Range and for the Margaret River at Willmots Farm respectively. Flow is ephemeral at Whicher Range, generally starting in late June or early July and stopping in December. This is typical of forested catchments with large soil water storage capacities. At Willmots Farm further downstream, it appears that flow was perennial until the 1980s. Since then, there have been some years where it has flowed continuously; however, the continuous flow period appears to be decreasing. For example, since 1995, flow at Willmots Farm has generally commenced in May and ceased in January. This could be due to a combination of low rainfall and pumping from river pools.

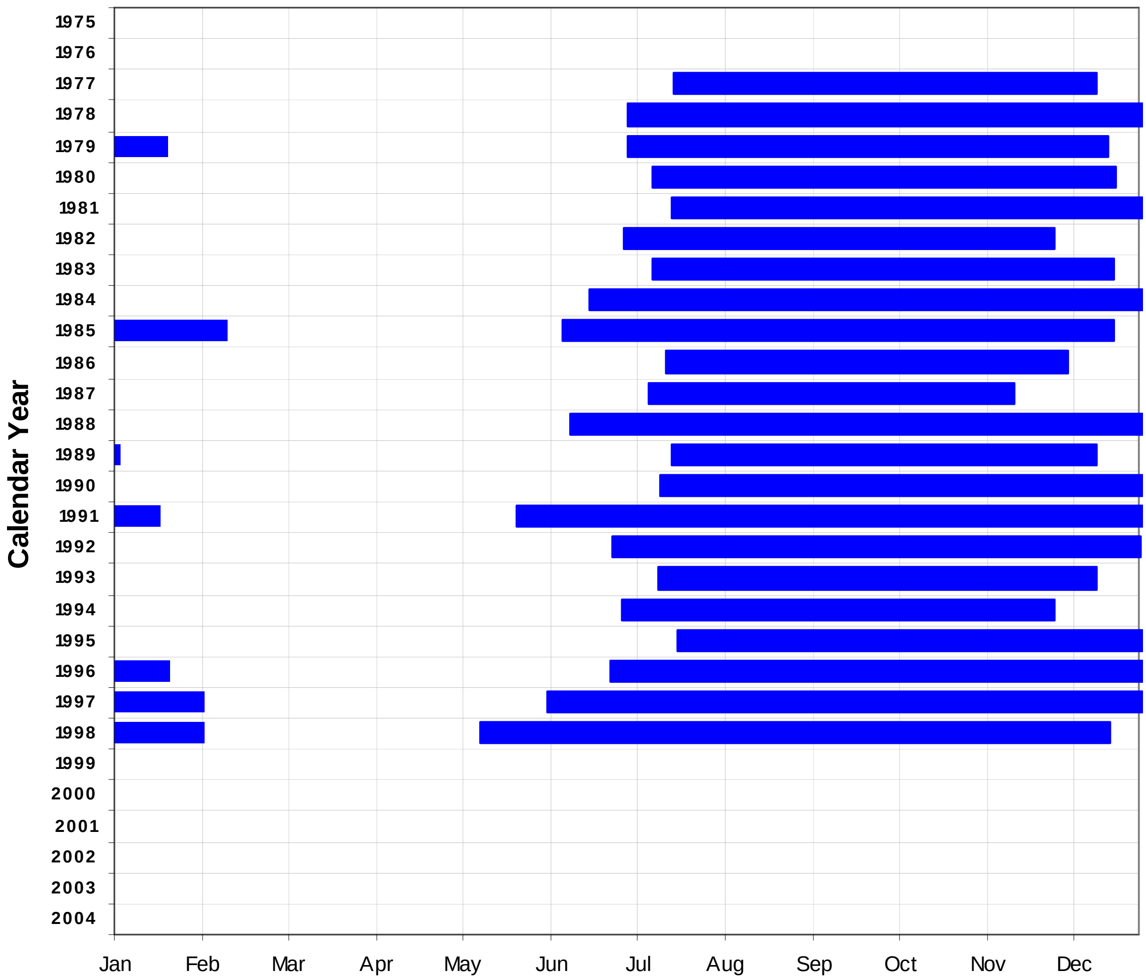


Figure 5-3. Margaret River North at Whicher Range (610008) continuous flow period

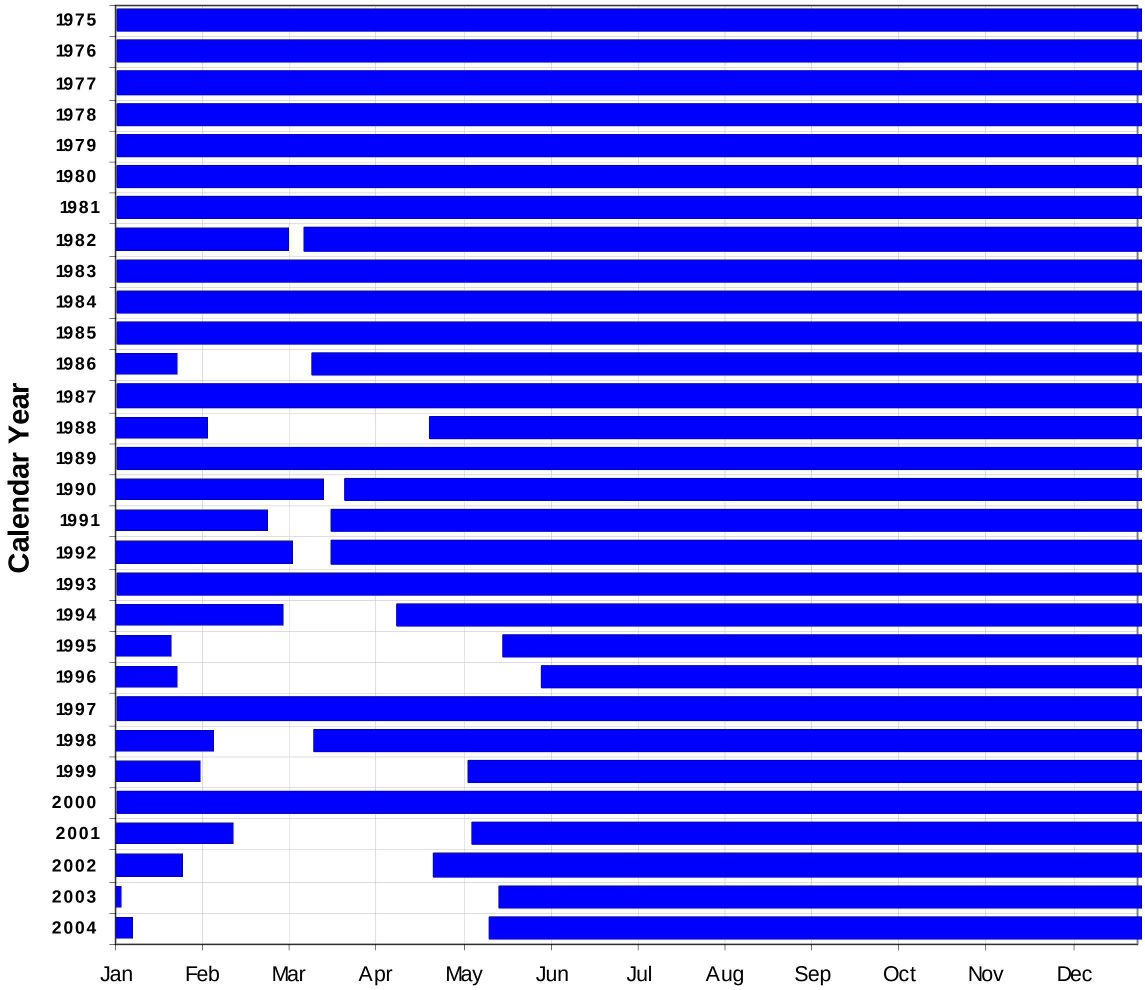


Figure 5-4. Margaret River at Willmots Farm (610001) continuous flow period

Flow duration curves

For the Margaret River, the median annual flow duration curve (FDC) indicates a slightly lower reliability of flow for low flows. The median FDC for Margaret River North at Whicher Range (Figure 5-5) shows that the stream is ephemeral with 46 per cent of days having flow and therefore a median daily flow of 0 ML. This steepness of the curve at the low-flow end is typical of most forested catchments in the region. Flow for the Margaret River at Willmots Farm is also ephemeral, with 89 per cent of days having flow and a median daily flow of 49 ML (Figure 5-6). The curve is much flatter at the high-flow end, indicating a stream with large amounts of potential storage.

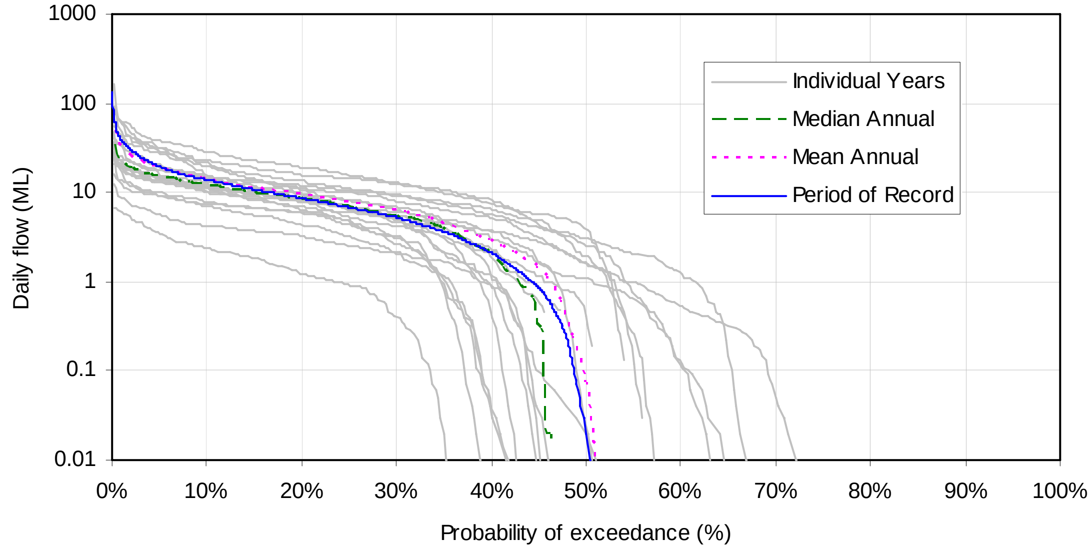


Figure 5-5. Margaret River North at Whicher Range (610008) annual flow duration curves

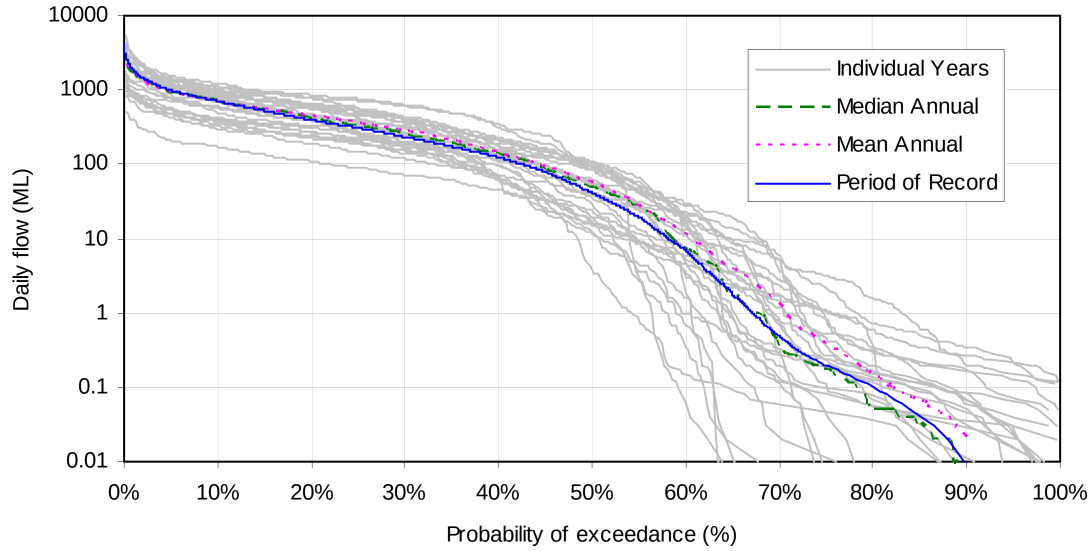


Figure 5-6. Margaret River at Willmots Farm (610001) annual flow duration curves

Monthly flow duration analysis for the Margaret River North at Whicher Range (Figure 5-7) shows that flow is continuous between August and October and the corresponding median daily flow is greater than 7.0 ML. Flow is not continuous for the other months and occurs less than 30 per cent of the time between January and June.

Monthly flow duration analysis for the Margaret River at Willmots Farm (Figure 5-8) shows that flow is much more widespread throughout the year than at Whicher Range. Flow is continuous between June and December and the corresponding median daily flow is greater than 16 ML (greater than 100 ML between June and November). Flow is not continuous for the other months; however, the median daily flow during this period is greater than 0.02 ML.

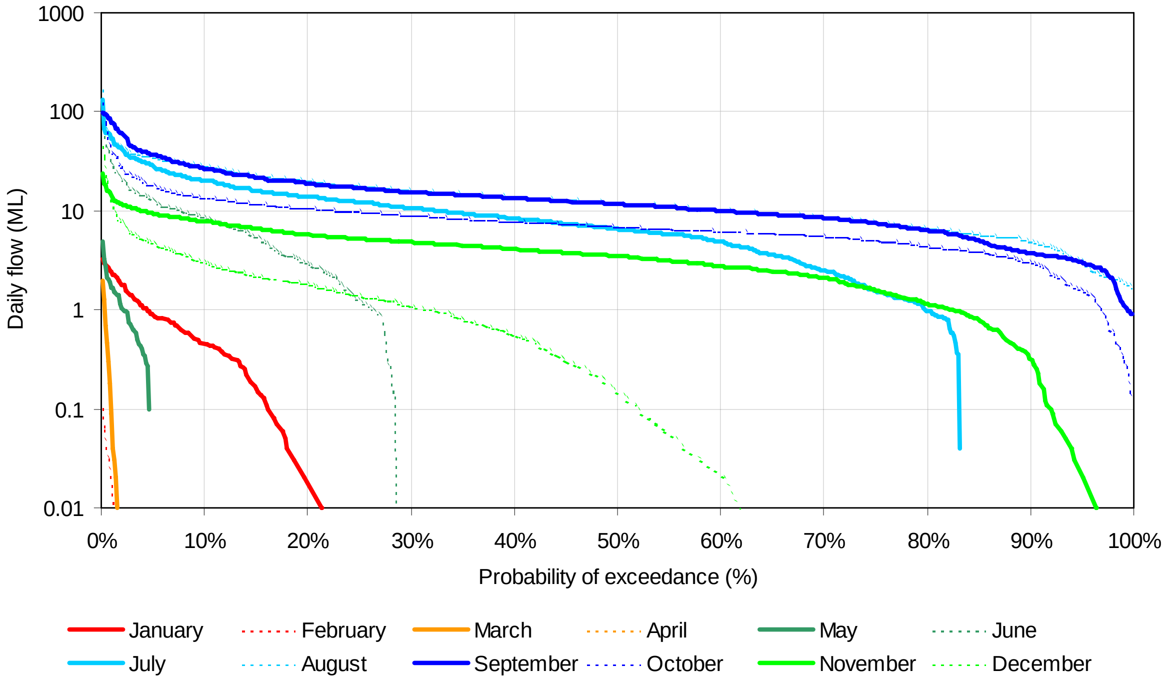


Figure 5-7. Margaret River North at Whicher Range (610008) monthly flow duration curves

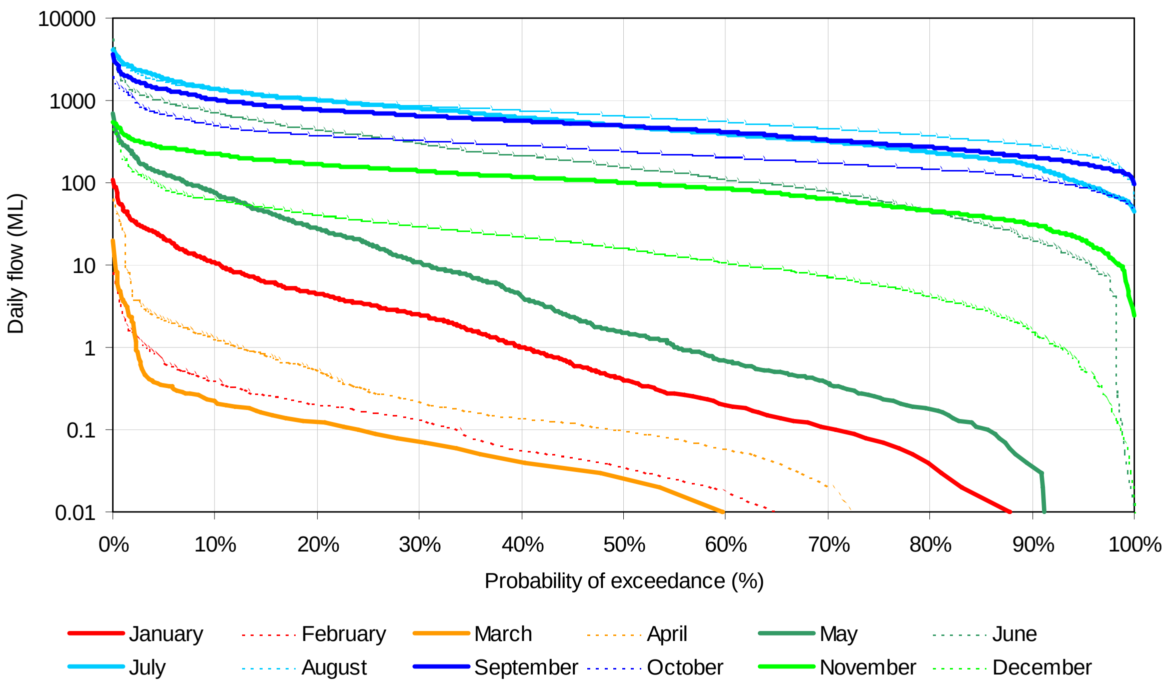


Figure 5-8. Margaret River at Willmots Farm (610001) monthly flow duration curves

Baseflow analysis

The baseflow analysis indicated that on average, 41 per cent of the total annual flow at Whicher Range (610008) is derived from baseflow (ie a baseflow index of 41%) with a range of 36 to 45 per cent (Figure 3–10). Further downstream, Willmots Farm (610001) has a slightly higher baseflow index of 42 per cent and exhibits less variation, with a range of 40 to 44 per cent.

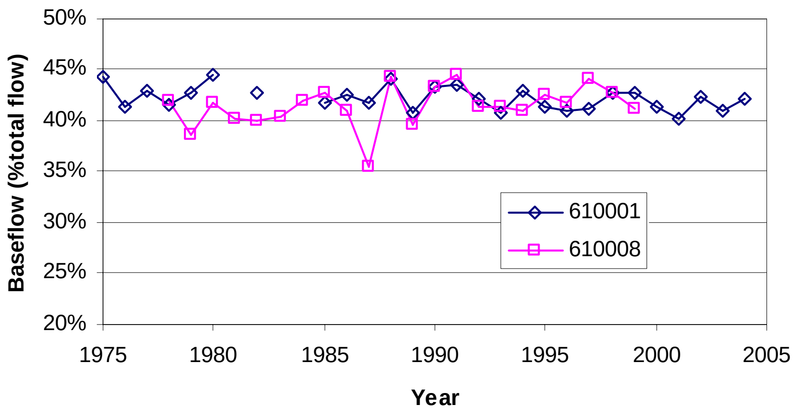


Figure 5-9. Margaret River baseflow indices

6 Cowaramup

Cowaramup Brook is located in the Cowaramup Surface Water Management Sub-area (Whicher catchment Cowaramup 16) (Figure 2-2 and Figure 2-3). Historically, there has not been any gauging of flow on Cowaramup Brook. A gauging station was installed recently at Gracetown (610029), which has been operating since November 2004. Until sufficient streamflow data is available, a regional yield estimation model such as REG75 will be used to estimate streamflow yield. The water quality of Cowaramup Brook is marginal (500-1,000 mg/L TDS) (Mayer et al, 2005).

Table 6-1. Cowaramup Brook mean annual flows

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
610029	21.5	–	–	–
Cowaramup Sub-area	26.4			*7,800*

Note: Figures in *italics* have been derived from a regional relationship (REG75)

7 Wilyabrup

The Wilyabrup Brook Surface Water Management Sub-area (Whicher catchment Wilyabrup 18) (Figure 2-2 and Figure 2-3) currently has two streamflow gauging stations operating. Woodlands (610006) at the downstream end of the catchment has been operating since 1973 (Figure 2-6 and Figure 7-1). A gauging station further upstream was installed recently at Juniper (610028), which has been operating since November 2004. The Sub-area has a very high level of clearing at approximately 70 per cent, mostly for viticulture. Wilyabrup Brook is fresh (Mayer et al, 2005).

7.1 Annual flow

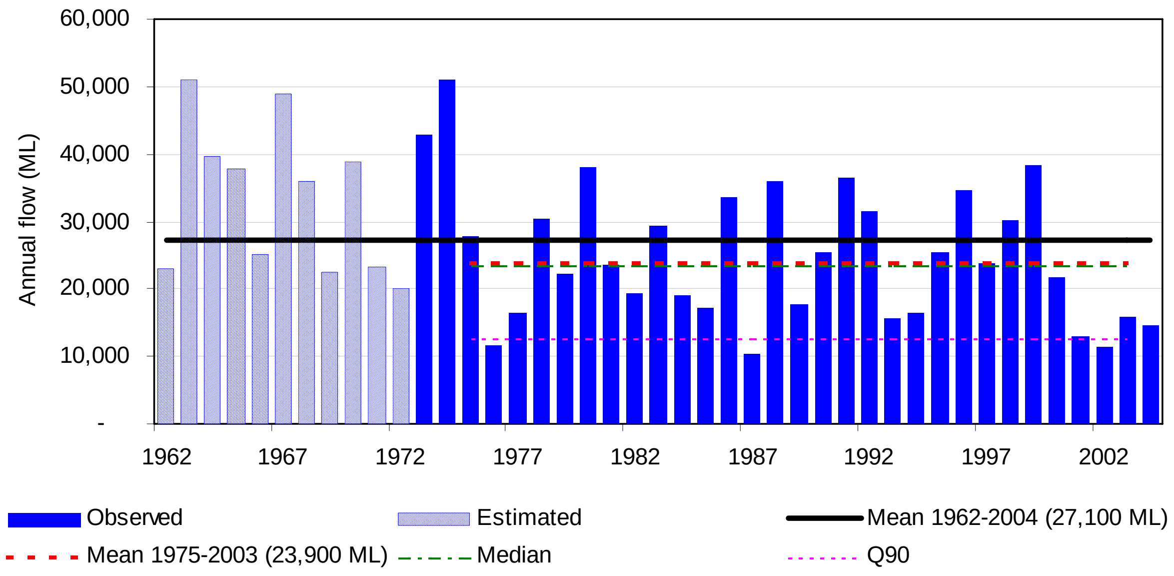


Figure 7-1. Wilyabrup Brook at Woodlands (610006) annual flow

The observed coefficient of variation (CV) at Woodlands (610006) is 0.41, and for the period 1975-2003 it is 0.36, indicating a relatively low variability in annual flow in Wilyabrup Brook. The maximum and minimum recorded annual flows are 51,000 ML and 10,400 ML respectively. The mean annual flow (MAF) estimate for the period 1975 to 2003 is 23,900 ML (Table 7-1), a reduction of 16 per cent compared to 1962 to 1995.

The estimated MAF for the Wilyabrup Surface Water Management Sub-area is 25,900 ML.

Table 7-1. Wilyabrup Sub-area mean annual flows

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
610006	82.3	27,100	28,300	23,900
Wilyabrup Sub-area	89.1	–	–	*25,900*

Note: Figures in *italics* have been derived from areal scaling

7.2 Daily flow

Continuous flow period

Figure 7-2 shows the observed continuous flow period for each calendar year since 1975 for Wilyabrup Brook at Woodlands. Flow is ephemeral, although the continuous flow period appears to be increasing. Prior to 1989, flow was ephemeral and generally commenced in May and ceased in January, with flow commencing before May only six times. Since 1989, flow has generally started in May and stopped in February, with flow commencing before May 11 times (including six continuous flow years). This is possibly due to irrigation return water over summer.

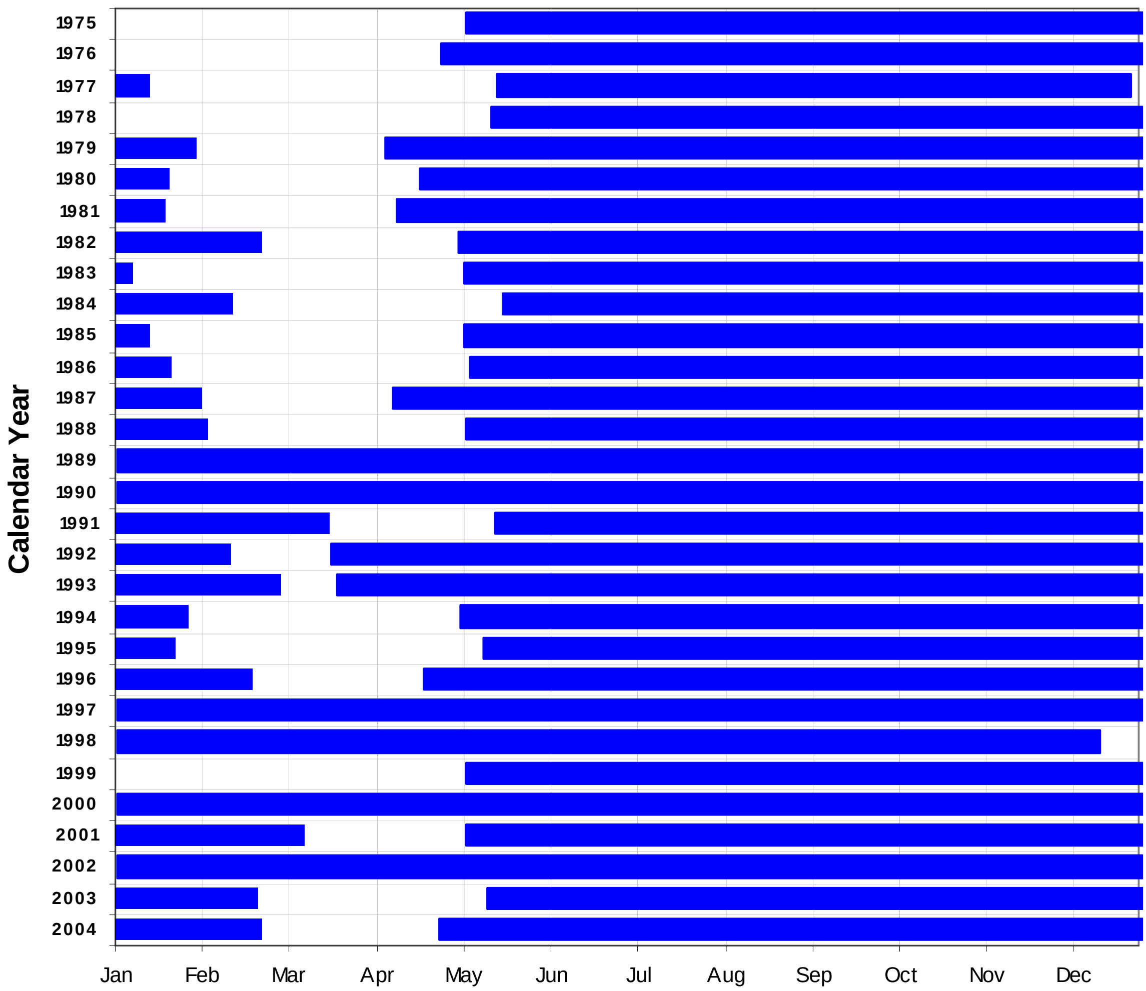


Figure 7-2. Wilyabrup Brook at Woodlands (610006) continuous flow period

Flow duration curves

For Wilyabrup Brook, the median annual flow duration curve (FDC) indicates a slightly lower reliability of flow for low flows. The median FDC shows that the stream is ephemeral with 77 per cent of days having flow. The median daily flow is 1.8 ML at Woodlands (Figure 7-3).

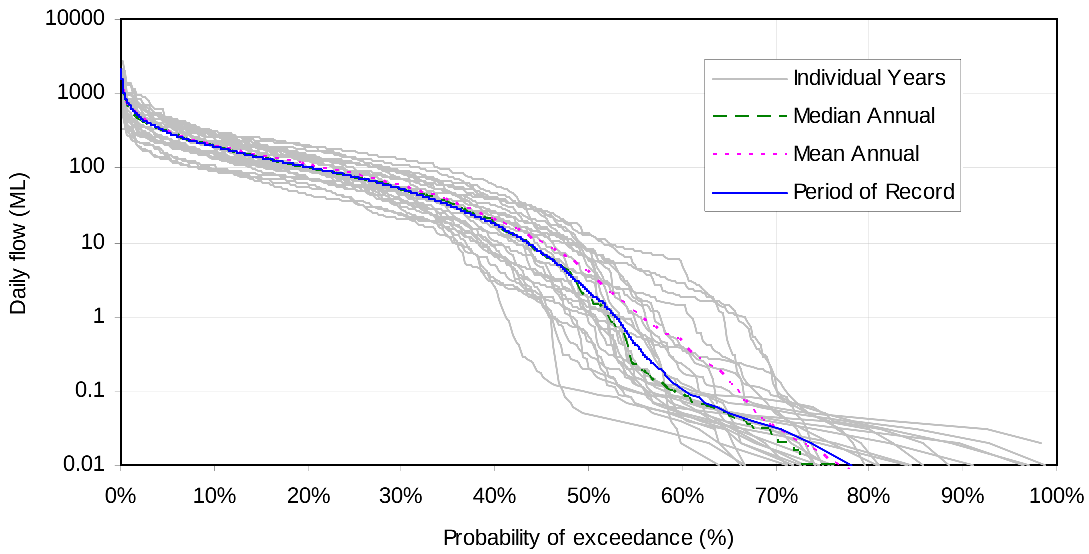


Figure 7-3. Wilyabrup Brook at Woodlands (610006) annual flow duration curves

Monthly flow duration analysis for the Wilyabrup Brook (Figure 7-4) shows that flow is continuous between June and November and the corresponding median daily flow is greater than 5.7 ML. Flow is not continuous for the other months and the median daily flow is less than 0.01 ML/day between February and April.

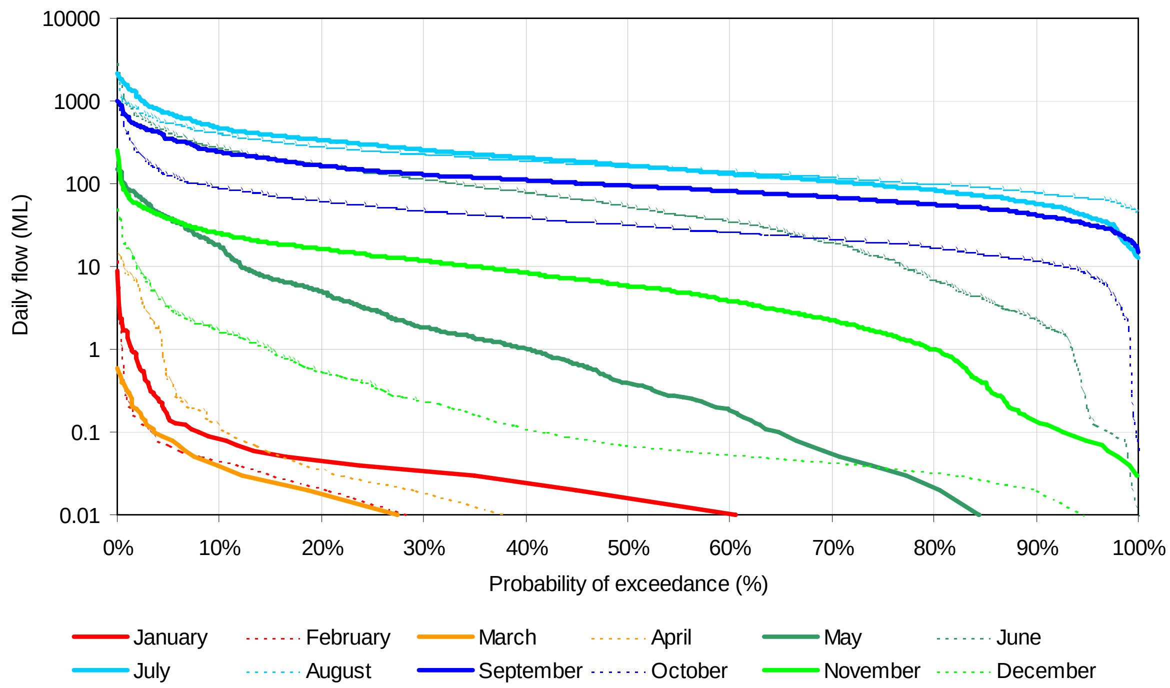


Figure 7-4. Wilyabrup Brook at Woodlands (610006) monthly flow duration curves

Baseflow analysis

The baseflow analysis indicated that on average, 37 per cent of the total annual flow at Woodlands (610006) is derived from baseflow (ie a baseflow index of 37%) with a range of 34 to 40 per cent (Figure 7-5). The analysis also indicates that annual baseflow, as a proportion of total flow, has been relatively constant throughout the period 1975 to 2003.

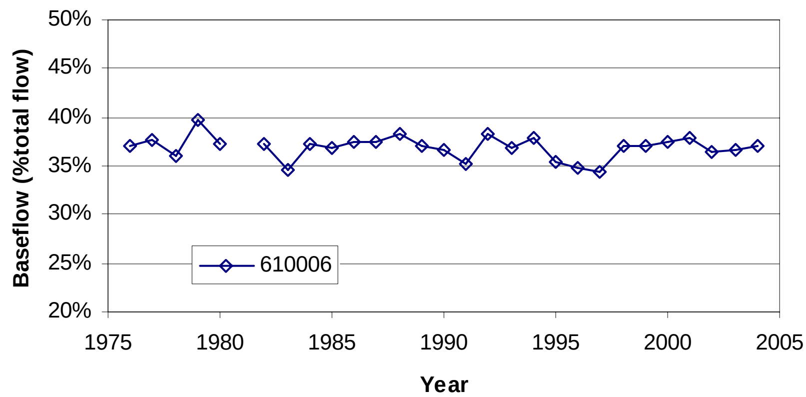


Figure 7-5. Wilyabrup Brook baseflow indices

8 Carbunup

The Carbunup River Surface Water Management Sub-area (including Whicher catchment Carbunup 23) (Figure 2-2 and Figure 2-3) has one streamflow gauging station operating. Lennox Vineyard (610015) is located at the downstream boundary of the Whicher catchment and has been operating since 1995 (Figure 2-6 and Figure 8-1). The Carbunup River Sub-area extends further than the Whicher catchment, to the coast. The sub-area has a high level of clearing at approximately 55 per cent and the river is fresh (Mayer et al, 2005).

8.1 Annual flow

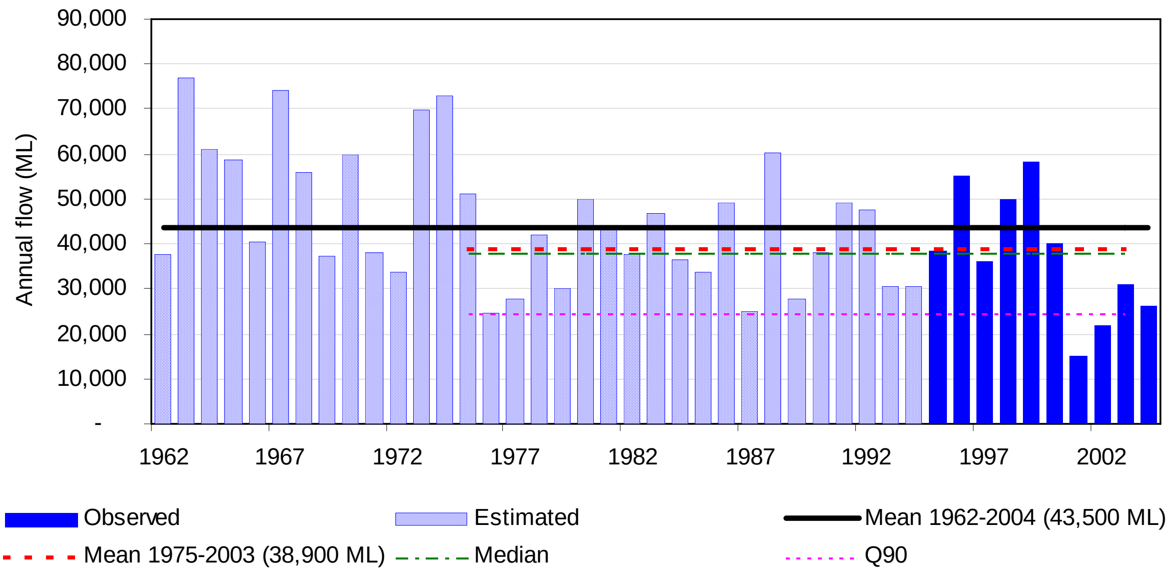


Figure 8-1. Annual flow at Carbunup River – Lennox Vineyard (610015)

Variability in annual flow in the Carbunup River is relatively low, with an observed coefficient of variation (CV) at Lennox Vineyard (610015) of 0.38, and of 0.30 for the period 1975-2003. The maximum and minimum recorded annual flows are 58,300 ML and 15,200 ML respectively. The mean annual flow (MAF) estimate for the period 1975 to 2003 is 38,900 ML (Table 8-1), a reduction of 14 per cent compared to 1962-1995.

The estimated MAF for the Carbunup Surface Water Management Sub-area is 40,300 ML.

Table 8-1. Carbunup Sub-area mean annual flows

Location	Area (km^2)	Mean Annual Flow (ML) 1962-2004	1962-1995	1975-2003
Carbunup Catchment (610015)	159	43,500	45,200	38,900
Carbunup Sub-area	165	–	–	*40,300*

Note: Figures in *italics* have been derived from areal scaling

8.2 Daily flow

Continuous flow period

Figure 8-2 shows the observed continuous flow period for each calendar year since 1975 for the Carbunup River at Lennox Vineyard. Flow is ephemeral, generally starting in May and stopping in December.

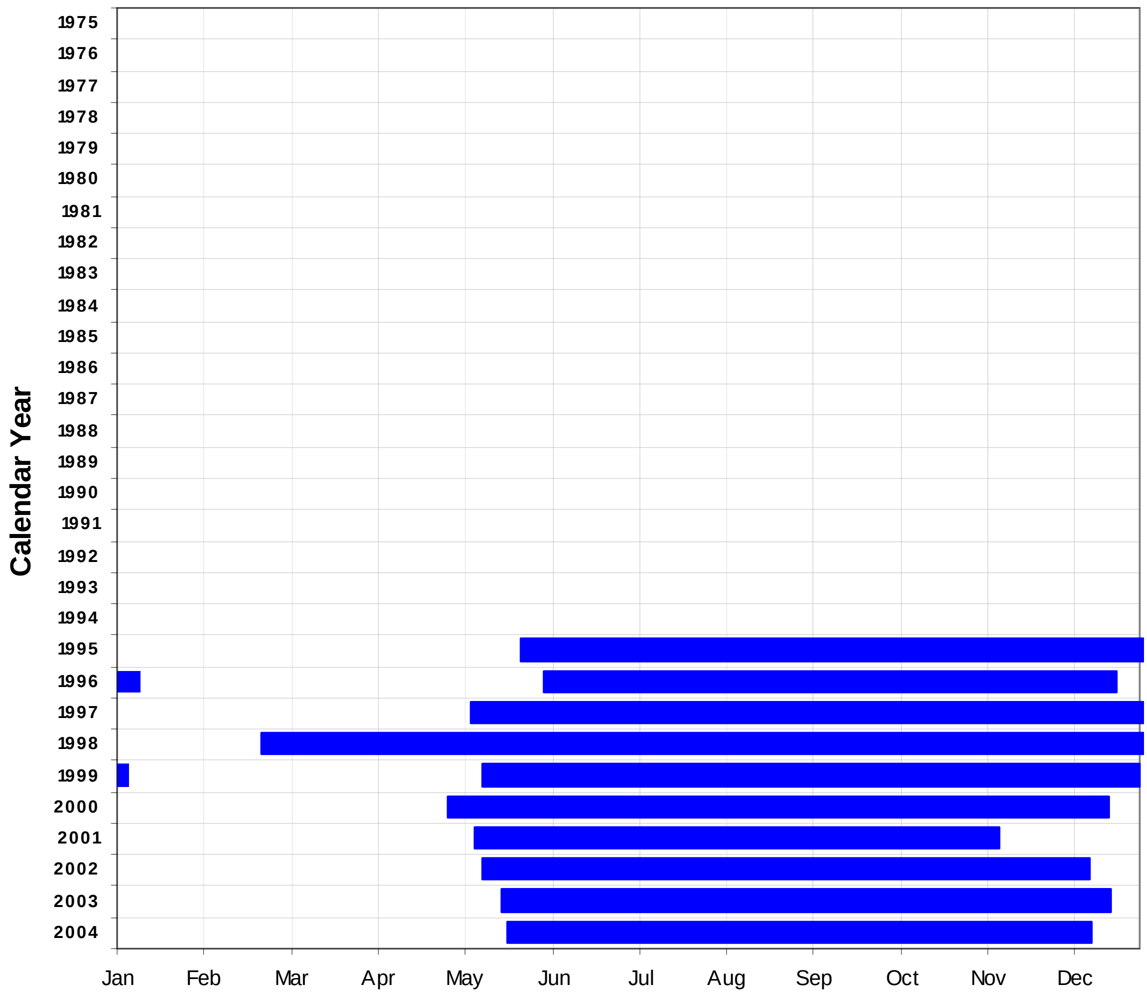


Figure 8-2. Carbunup River at Lennox Vineyard (610015) continuous flow period

Flow duration curves

For the Carbunup River, the median annual flow duration curve (FDC) indicates a lower reliability of flow for low flows. The median FDC at Lennox Vineyard (Figure 8-3) shows that the stream is ephemeral with 62 per cent of days having flow and a median daily flow of 21 ML. The curve has a relatively flat slope at the high-flow end. The river is highly regulated with pumping from groundwater into excavations in the river bed.

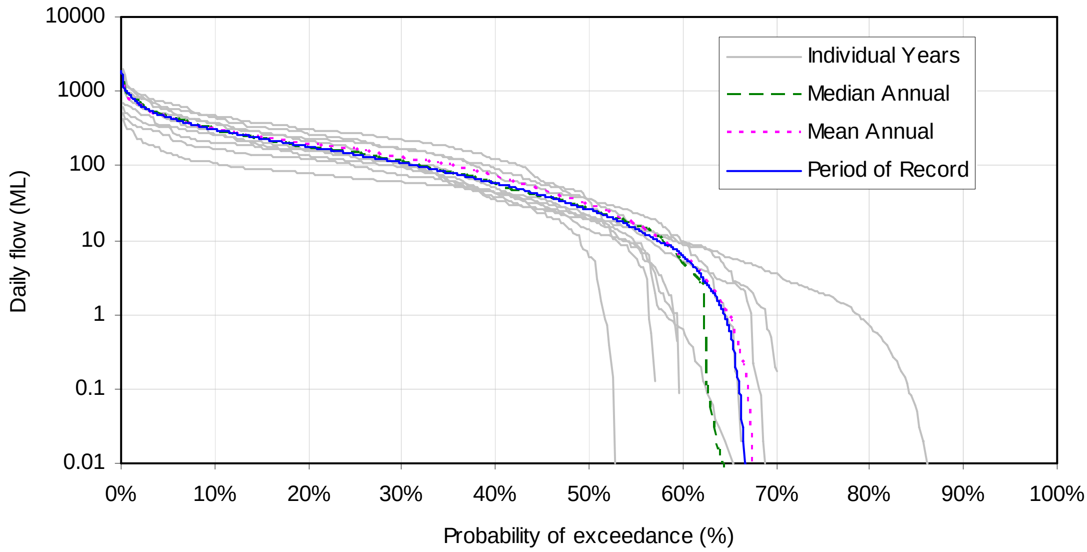


Figure 8-3. Carbunup River — Lennox Vineyard (610015) annual flow duration curves

Monthly flow duration analysis for the Carbunup River (Figure 8-4) shows that flow is continuous between June and November and the corresponding median daily flow is greater than 81 ML. Flow is not continuous for the other months and the flow occurs less than 20 per cent of the time between January and April.

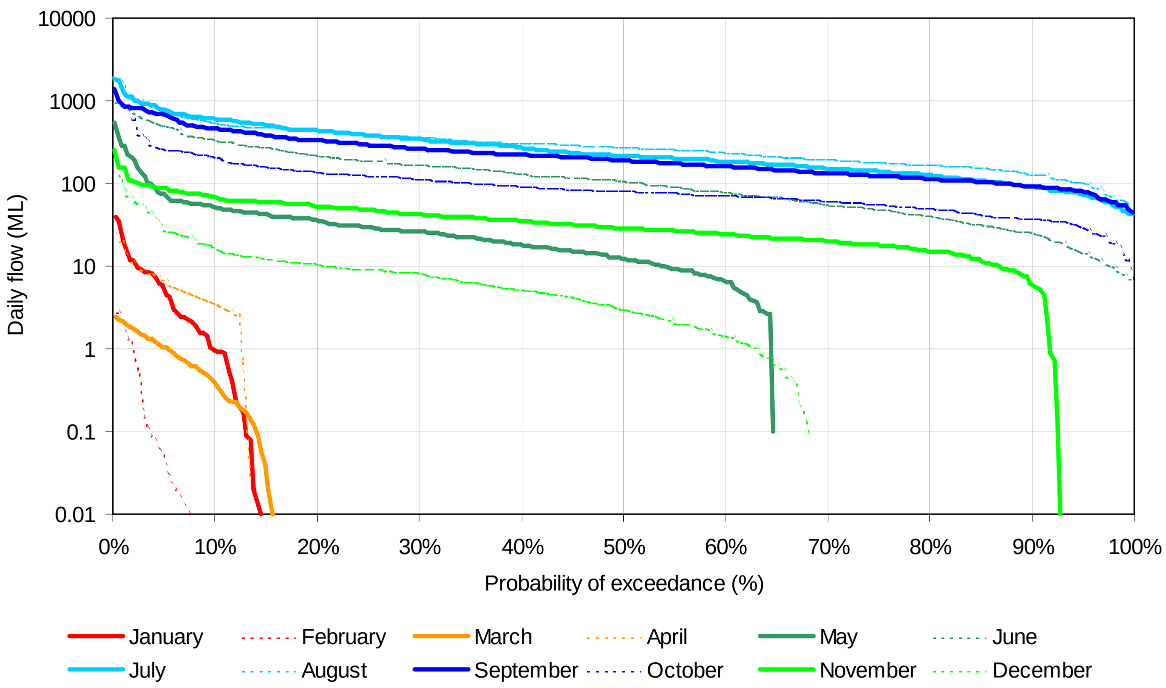


Figure 8-4. Carbunup River - Lennox Vineyard (610015) monthly flow duration curves

Baseflow analysis

The baseflow analysis for the Carbunup River indicated that on average, 41 per cent of the total annual flow at Lennox Vineyard (610015) is derived from baseflow (ie a baseflow index of 41%) with a range of 38 to 43 per cent (Figure 8-5).

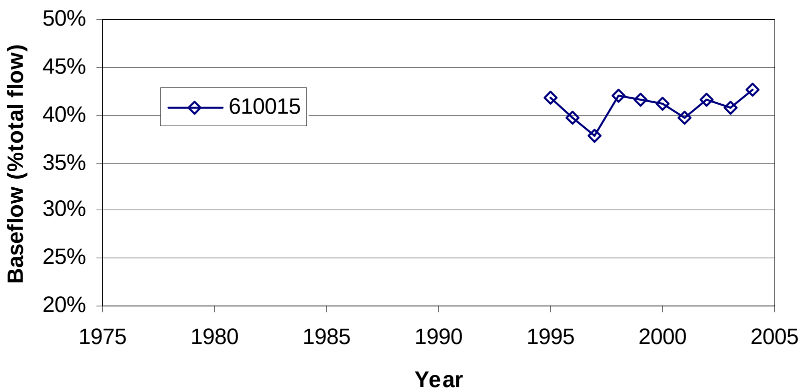


Figure 8-5. Carbunup River baseflow indices

9 Vasse

The Vasse Surface Water Management Sub-area includes the Whicher catchments Vasse 25 and Sabina 26 and extends to the coast (Figure 2-2 and Figure 2-3). The downstream section of the sub-area is drained artificially and includes the Vasse and Sabina diversion drains. There are currently two streamflow gauging stations operating on the Vasse River. Chapman Hill (610003) is located at the downstream boundary of the Vasse catchment and has been operating since 1972 (Figure 2-6 and Figure 9-1). D/S Hill Rd on the Vasse Diversion Drain (610014) has been operating since 1995 (Figure 9-3). The Sabina River has one streamflow gauging station operating: Sabina Diversion at Wonnerup East Road (610025) is located at the downstream boundary of the Sabina catchment and has been operating since 2000 (Figure 9-2).

The Vasse River – Chapman Hill catchment has a high level of clearing at approximately 50 per cent and the Sabina is approximately 30 per cent cleared. The sub-area has a very high level of clearing at approximately 70 per cent. The Vasse and Sabina rivers are fresh except for the natural channel sections downstream of the diversion drains, where the water quality is marginal (500-1,000 mg/L TDS) (Mayer et al, 2005).

9.1 Annual flow

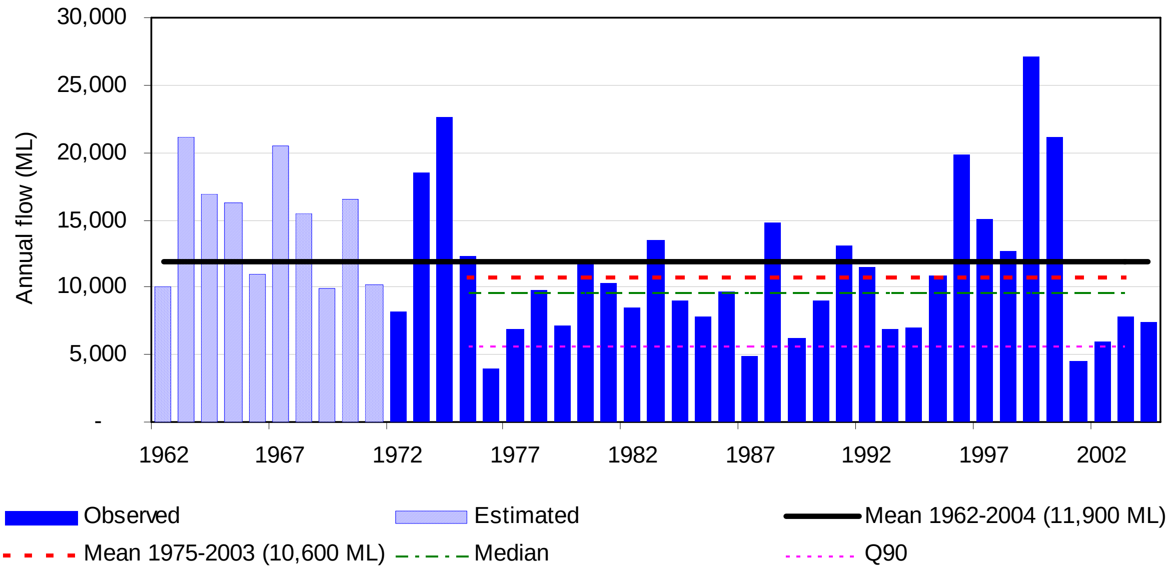


Figure 9-1. Vasse River at Chapman Hill (610003) annual flow

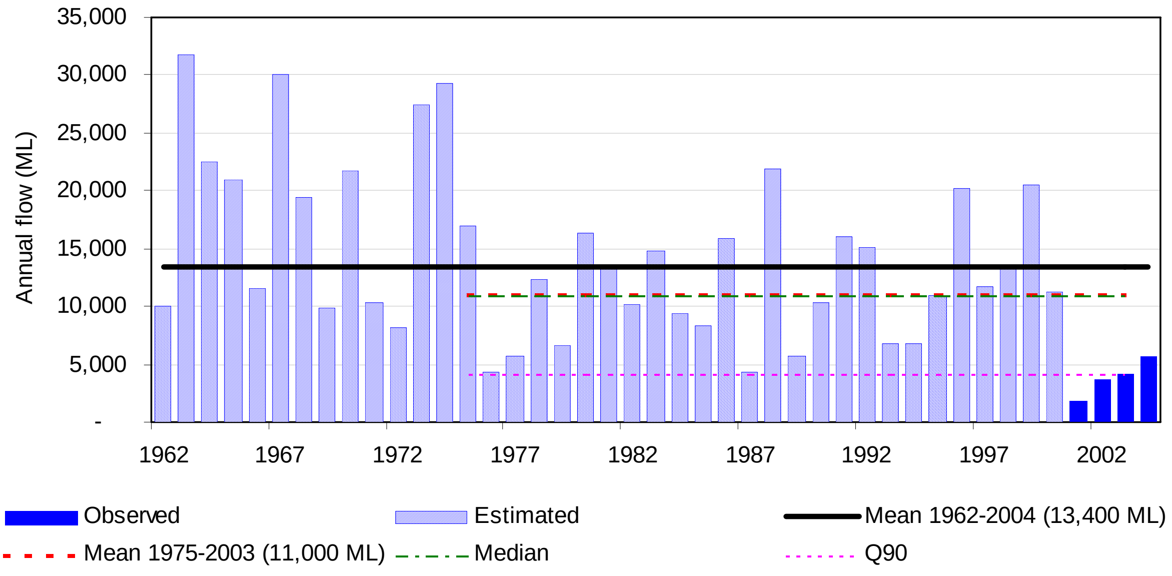


Figure 9-2. Sabina Diversion at Wonnerup East Road (610025) annual flow

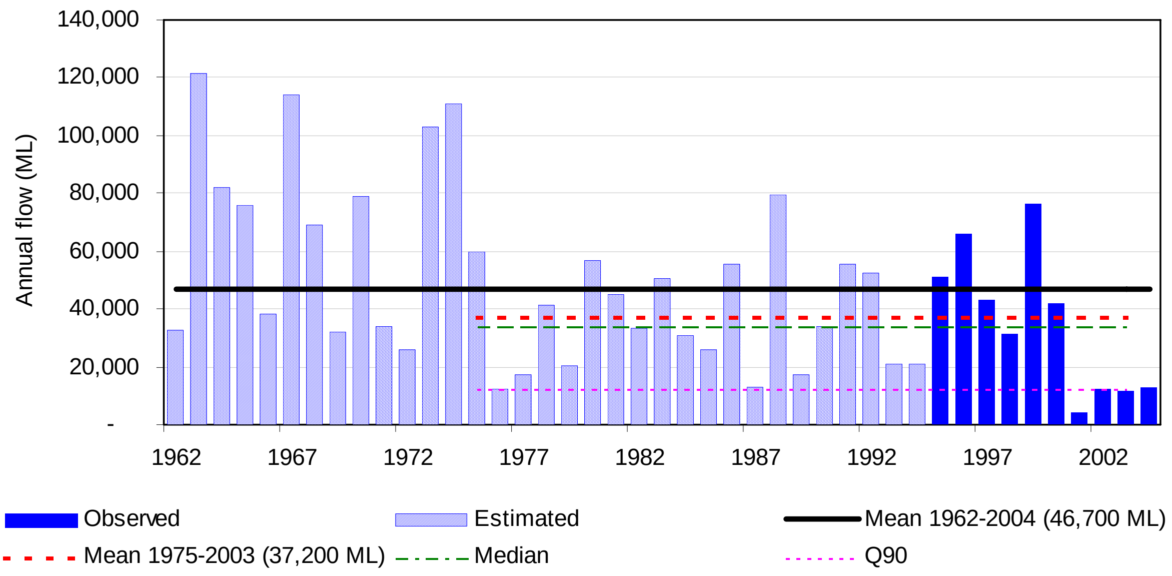


Figure 9-3. Vasse Diversion at D/S Hill Rd (610014) annual flow

The following statistics for the Sabina Diversion are estimates as there has only been four years of complete streamflow record at Wonnerup East Road (610025).

Variability in annual flow in the Vasse Sub-area is relatively high, with an observed coefficient of variation (CV) at Chapman Hill (610003) of 0.50 and 0.49 for the period 1975-2003. The CVs for the Sabina and Vasse diversion are also similar for 1975-2003 at 0.50 and 0.55 respectively. The observed CV for the Vasse diversion is high at 0.70; however, it has a relatively short record (10 years). The flow record for the Sabina Diversion is too short (four years) for a meaningful observed CV.

The maximum and minimum recorded annual flows for the Sabina Diversion are 5,670 ML and 1,780 ML respectively; however, all four years of record have had low flow. The maximum and minimum recorded annual flows for the Vasse are 27,100 ML and 3,980 ML respectively at Chapman Hill and 76,300 ML and 4,610 ML respectively at D/S Hill Rd.

The mean annual flow (MAF) estimate for the period 1975 to 2003 is 10,600 ML at Chapman Hill (Table 9-1), a reduction of eight per cent compared to 1962-1995. The mean annual flow estimates for the period 1975 to 2003 for the Sabina and Vasse diversions are 11,000 ML and 37,200 ML respectively, a reduction of 23 and 26 per cent compared to 1962-1995. The change at Chapman Hill is the smallest change evident at any of the Cape-to-Cape streamflow gauging stations, while the change for the Vasse Diversion at D/S Hill Rd is one of the largest.

The estimated MAFs for the Vasse and Sabina River catchments are 10,600ML and 11,000 ML respectively. The estimated MAF for the Vasse Surface Water Management Sub-area is 40,000 ML.

Table 9-1. Vasse Sub-area mean annual flows

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
Vasse Catchment (610003)	47.7	11,900	11,500	10,600
Sabina Catchment (610025)	77.6	13,400	14,300	11,000
610014	265	46,700	50,300	37,200
Vasse Sub-area	283	–	–	*39,700*

Note: Figures in *italics* have been derived from areal scaling

9.2 Daily flow

Continuous flow period

Figure 9-4 to Figure 9-6 show the observed continuous flow period for each calendar year since 1975 for the Vasse Sub-area. Flow is ephemeral for the Vasse River at Chapman Hill, generally starting in May and stopping in December, with a relatively constant period of continuous flow. The period of continuous flow is highly variable at the Sabina and Vasse diversions (Figure 9-5 and Figure 9-6), and it is not possible to discern when flow generally commences and ceases from the short flow records. This variability is possibly due to regulation of the drainage network within the catchment.

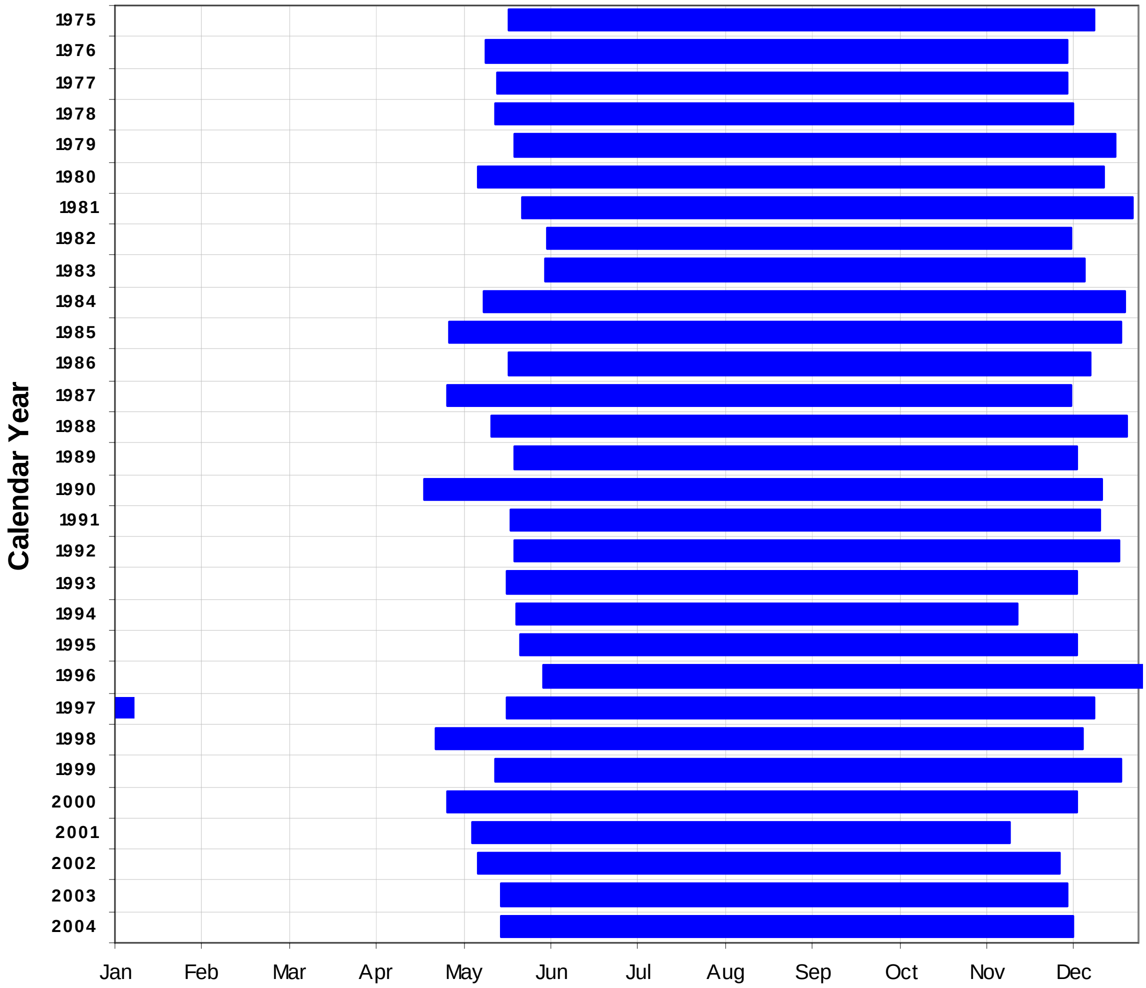


Figure 9-4. Vasse River at Chapman Hill (610003) continuous flow period

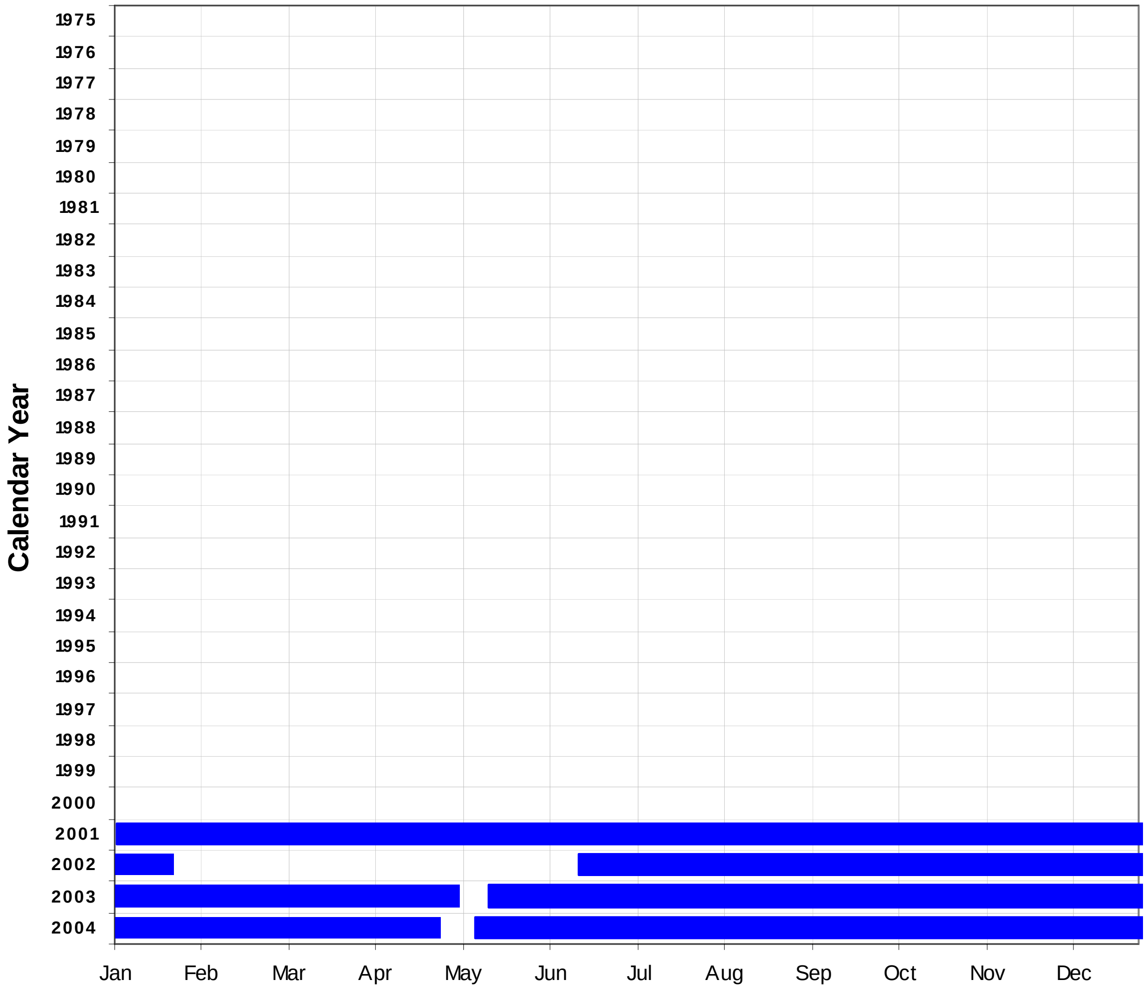


Figure 9-5. Sabina Diversion at Wonnerup East Road (610025) continuous flow period

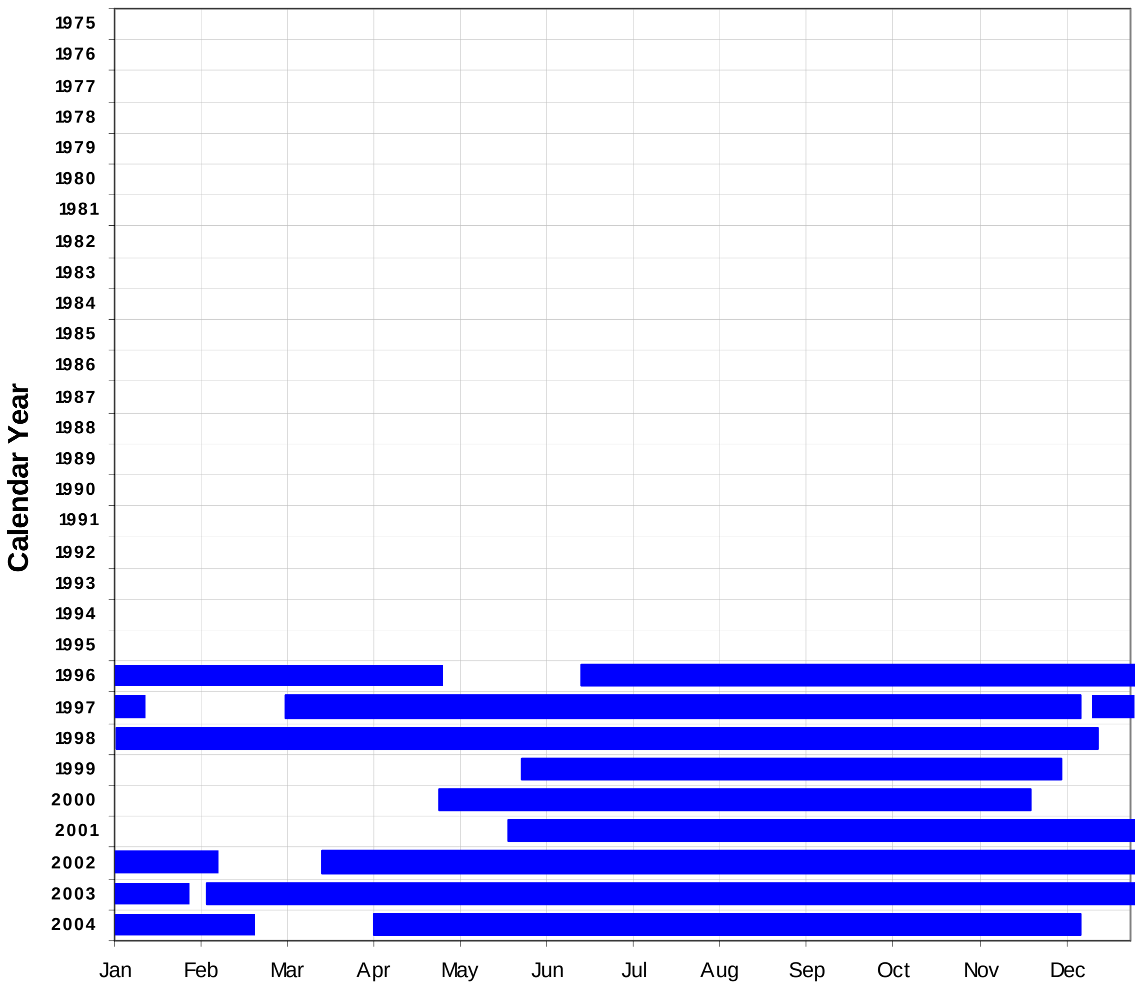


Figure 9-6. Vasse Diversion at D/S Hill Rd (610014) continuous flow period

Flow duration curves

For the Vasse Sub-area, the median annual flow duration curve (FDC) indicates a slightly lower reliability of flow for low flows. The median FDC for Chapman Hill (Figure 9-7) shows that the stream is ephemeral with 58 per cent of days having flow and a median daily flow of 4.5 ML. Flow for the Sabina Diversion is also ephemeral; however, 89 per cent of days have flow and the median daily flow is 1.2 ML (Figure 9-8).

The median annual FDC for the Vasse Diversion at D/S Hill Rd (Figure 9-9) is very different to the Sabina FDC. A FDC was produced for the period 2001 to 2004 for the Vasse Diversion (observed flow period for the Sabina Diversion) to ensure this difference was not due to the very short flow period for the Sabina Diversion. However, there was very little change to the Vasse Diversion curves, especially at the low flow end. Although 82 per cent of days have flow, the curve is very steep at the high flow end and flattens at the low flow end, with a median daily flow of less than 0.1 ML.

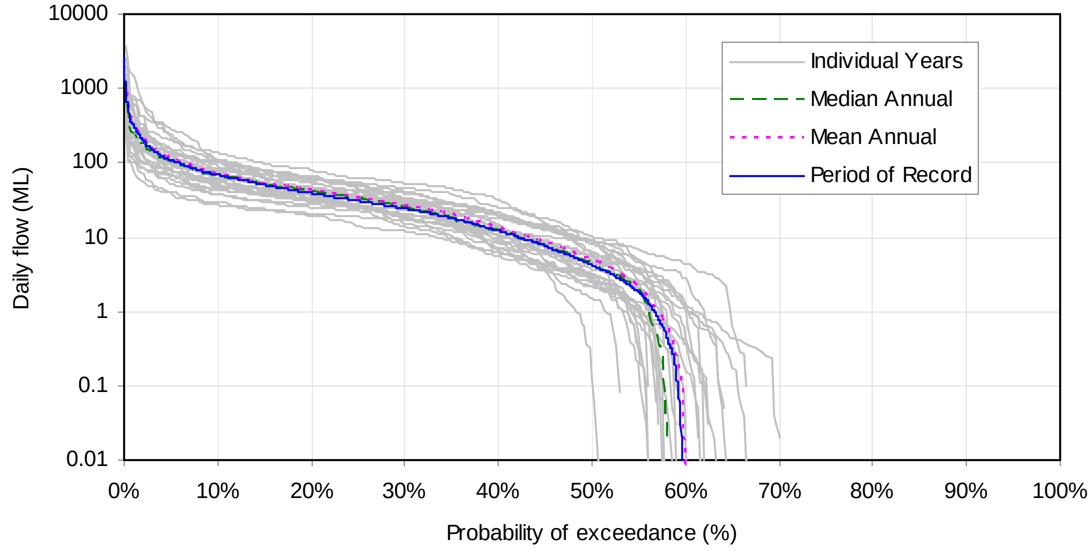


Figure 9-7. Vasse River at Chapman Hill (610003) annual flow duration curves

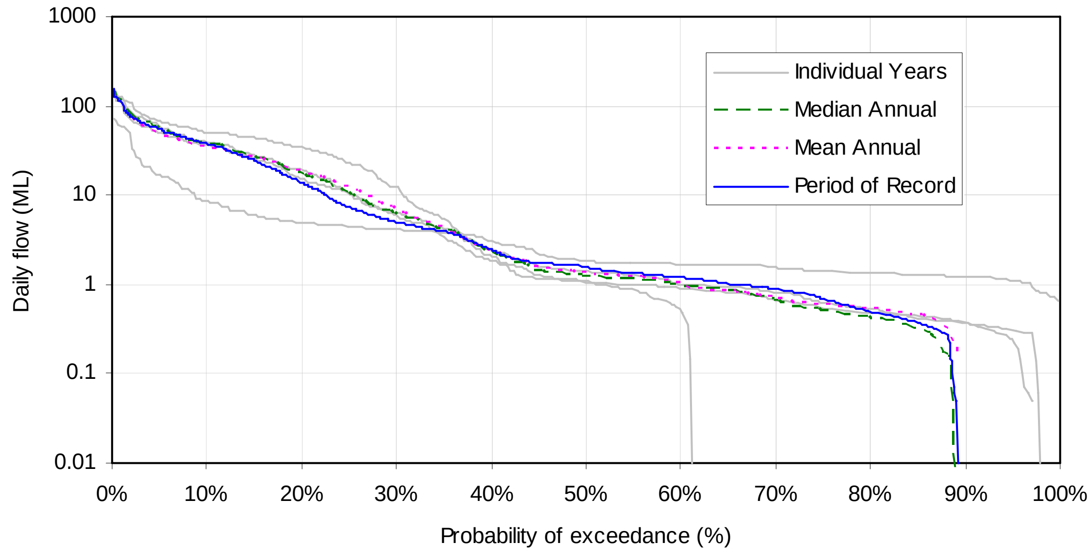


Figure 9-8. Sabina Diversion at Wonnerup East Road (610025) annual flow duration curves

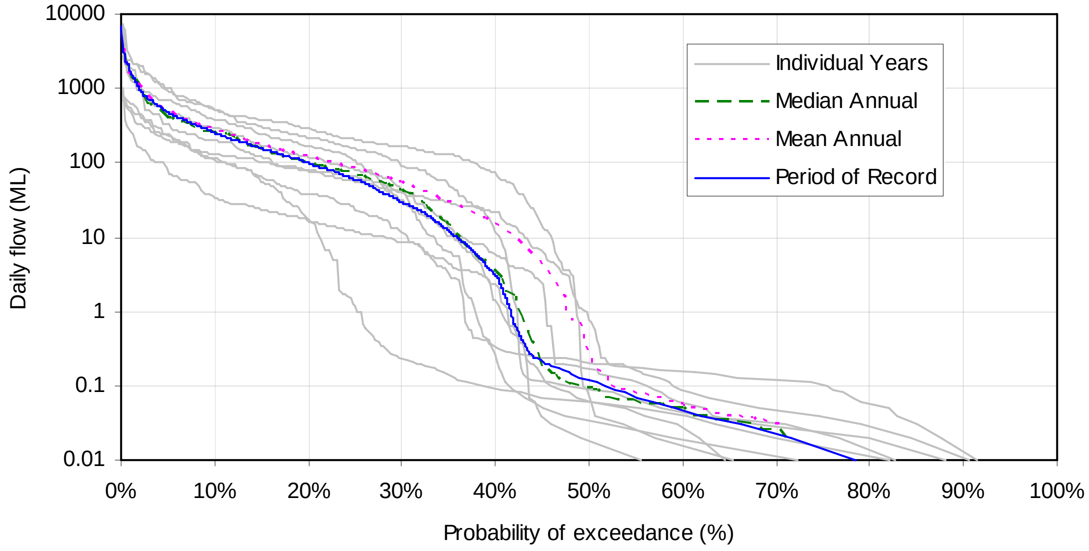


Figure 9-9. Vasse Diversion at D/S Hill Rd (610014) annual flow duration curves

Monthly flow duration analysis for the Vasse River at Chapman Hill (Figure 9-10) shows that flow is generally continuous between June and October and the corresponding median daily flow is greater than 17 ML (one day in June has had no flow). Flow is not continuous for the other months and occurs less than 10 per cent of the time between January and April. Historically, there has been no flow in February.

Monthly flow duration analysis (2001 to 2004) for the Sabina Diversion (Figure 9-11) shows that flow is continuous between June and December and the corresponding median daily flow is greater than 1.9 ML. Flow is not continuous for the other months; however, the median daily flow during this period is relatively high at 0.45 ML.

Monthly flow duration analysis for the Vasse Diversion at D/S Hill Rd (Figure 9-12) shows that flow is much more widespread throughout the year than at Chapman Hill. Flow is continuous between July and October and the corresponding median daily flow is greater than 6.4 ML. Flow is not continuous for the other months; however, the median daily flow during this period is greater than 0.01 ML.

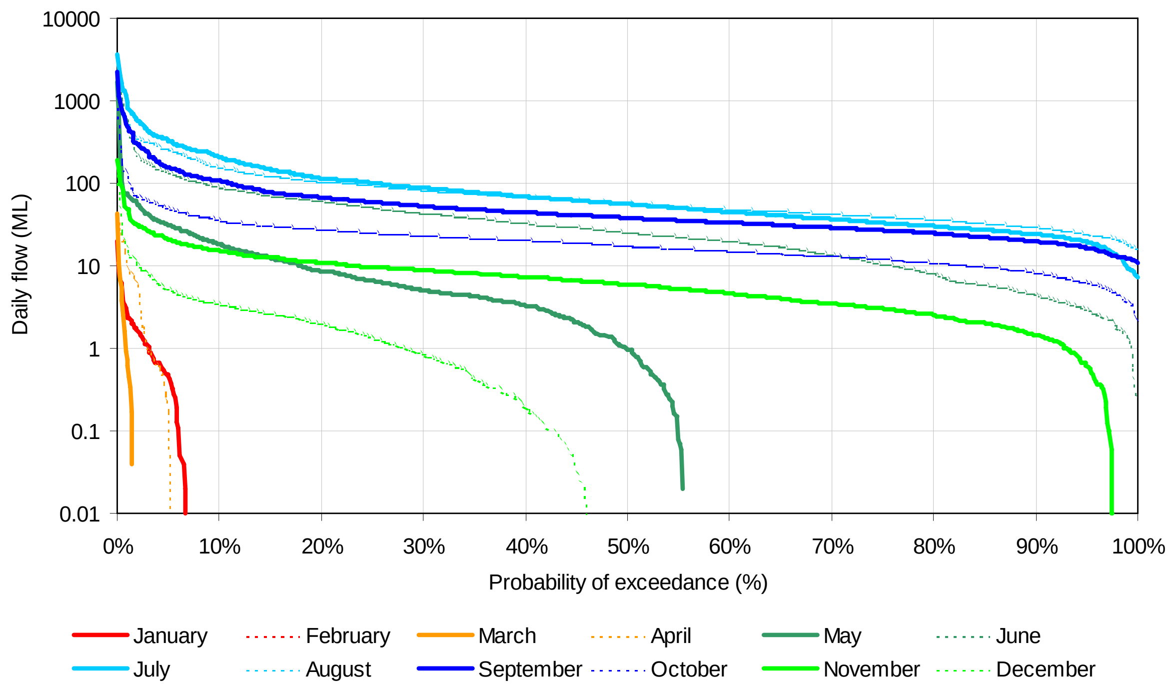


Figure 9-10. Vasse River at Chapman Hill (610003) monthly flow duration curves

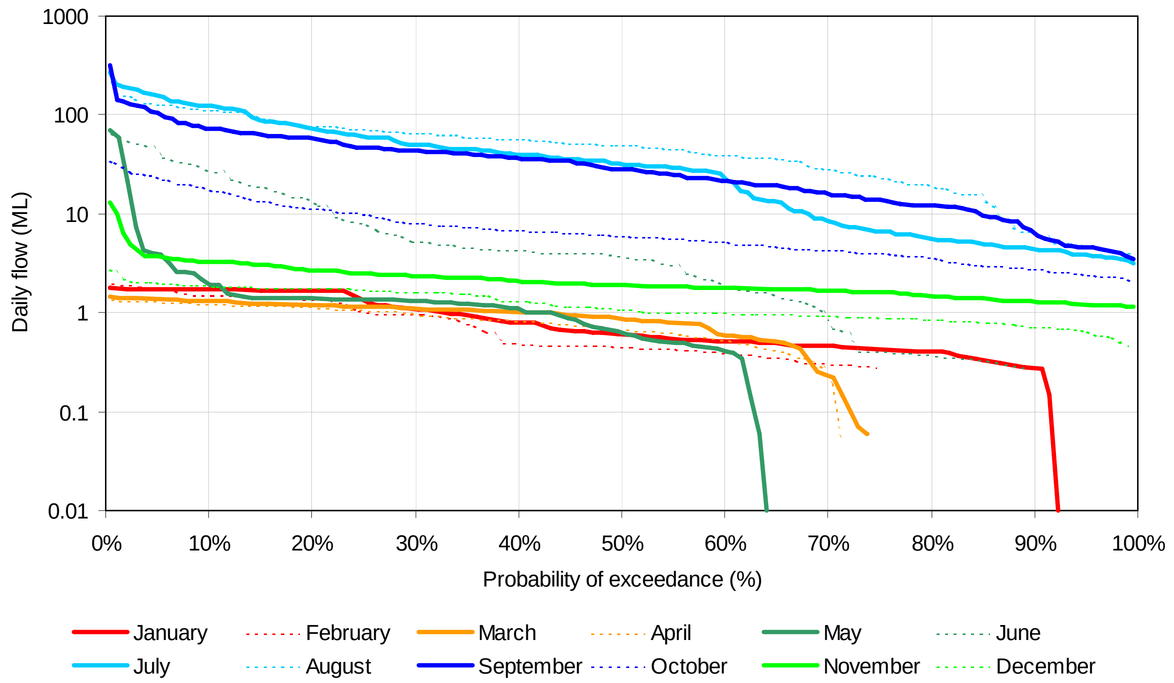


Figure 9-11. Sabina Diversion at Wonnerup East Road (610025) monthly flow duration curves

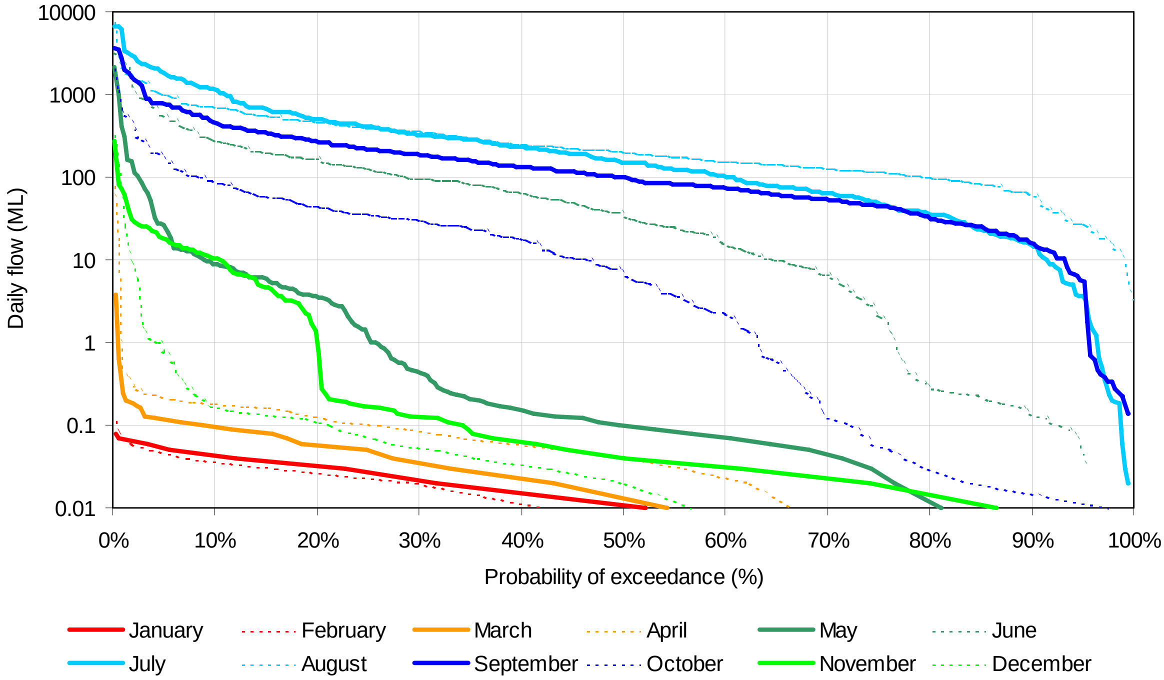


Figure 9-12. Vasse Diversion at D/S Hill Rd (610014) monthly flow duration curves

Baseflow analysis

The baseflow analysis for the Vasse Sub-area indicated that on average, 38 per cent of the total annual flow for the Vasse River at Chapman Hill (610003) is derived from baseflow (ie a baseflow index of 38%) with a range of 30 to 43 per cent (Figure 9-13). The wide range in baseflow indices has been particularly evident since 1995. The baseflow analysis for the Sabina Diversion (610025) also shows a wide range (34% to 44%) with an average baseflow index of 39 per cent. Further downstream, Vasse Diversion at D/S Hill Rd (610014) has a low baseflow index of 26 per cent and exhibits a large variation, with a range of 17 to 38 per cent – the largest in the Cape-to-Cape region.

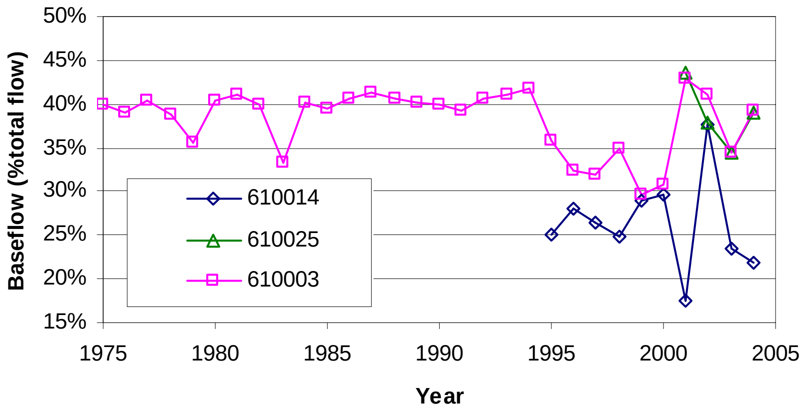


Figure 9-13. Vasse Sub-area baseflow indices

10 Wonnerup

The Wonnerup Surface Water Management Sub-area includes the Whicher catchments Abba 27 and Ludlow 28 and extends to the coast (Figure 2-2 and Figure 2-3). The Abba River does not have any streamflow gauging stations within the Whicher catchment. However, a station at Wonnerup Siding (610016), located downstream of the catchment, operated from 1995 to 2001 (Figure 2-6 and Figure 10-1). The Ludlow River currently has one gauging station operating: at Ludlow (610009) at the downstream boundary of the catchment, which has been operating since 1991 (Figure 10-4). Two other stations on the Ludlow that operated from the 1970s were closed in 1999: Claymore (610007) in the upper reaches (Figure 10-2) and Happy Valley (610005) in the middle of the catchment (Figure 10-3).

The Abba catchment (Abba 27) is approximately 10 per cent cleared, while the Abba River (Wonnerup Siding) catchment has a very high level of clearing at approximately 80 per cent. The Ludlow River catchments at Claymore and Happy Valley have negligible clearing (0% and 1% respectively), while the Ludlow catchment is approximately 25 per cent cleared. Both the Abba and Ludlow rivers are fresh (Mayer et al, 2005).

10.1 Annual flow

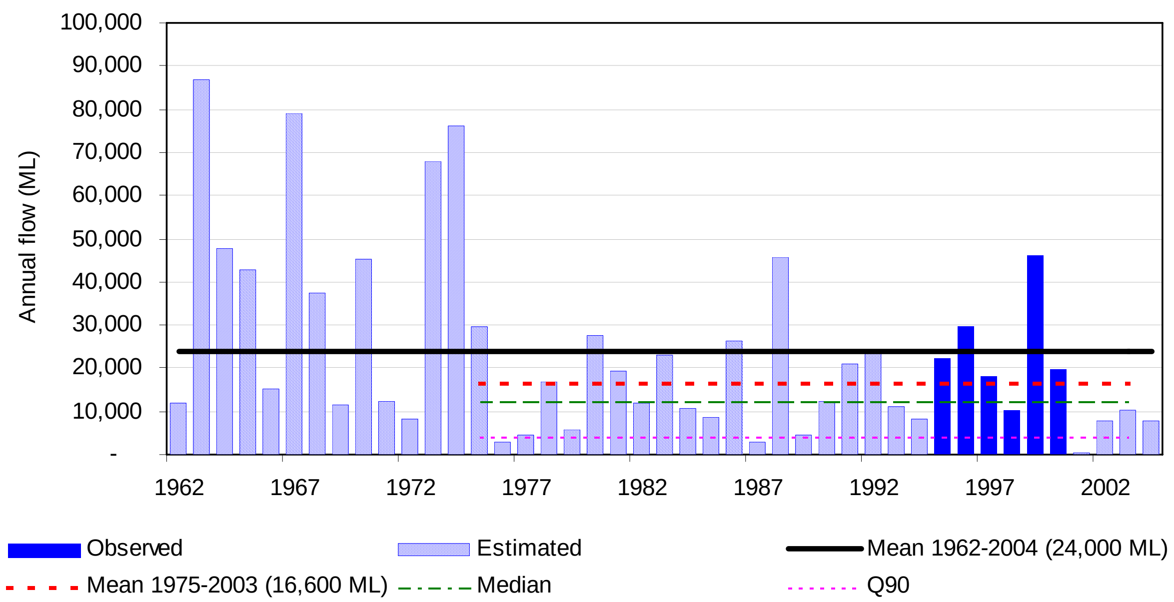


Figure 10-1. Abba River at Wonnerup Siding (610016) annual flow

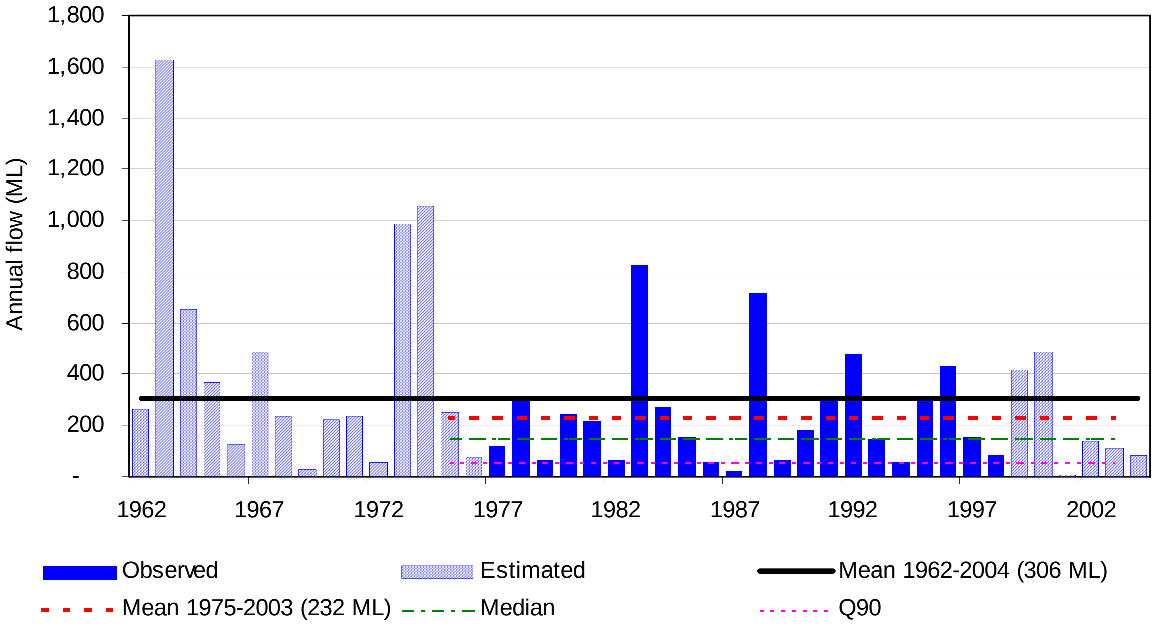


Figure 10-2. Ludlow River at Claymore (610007) annual flow

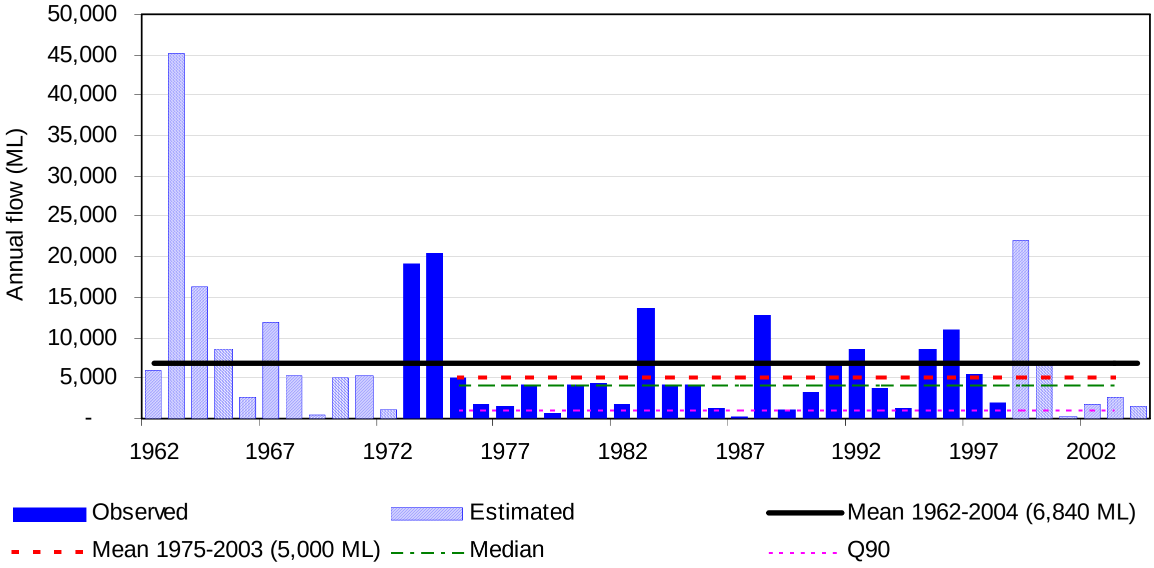


Figure 10-3. Ludlow River at Happy Valley (610005) annual flow

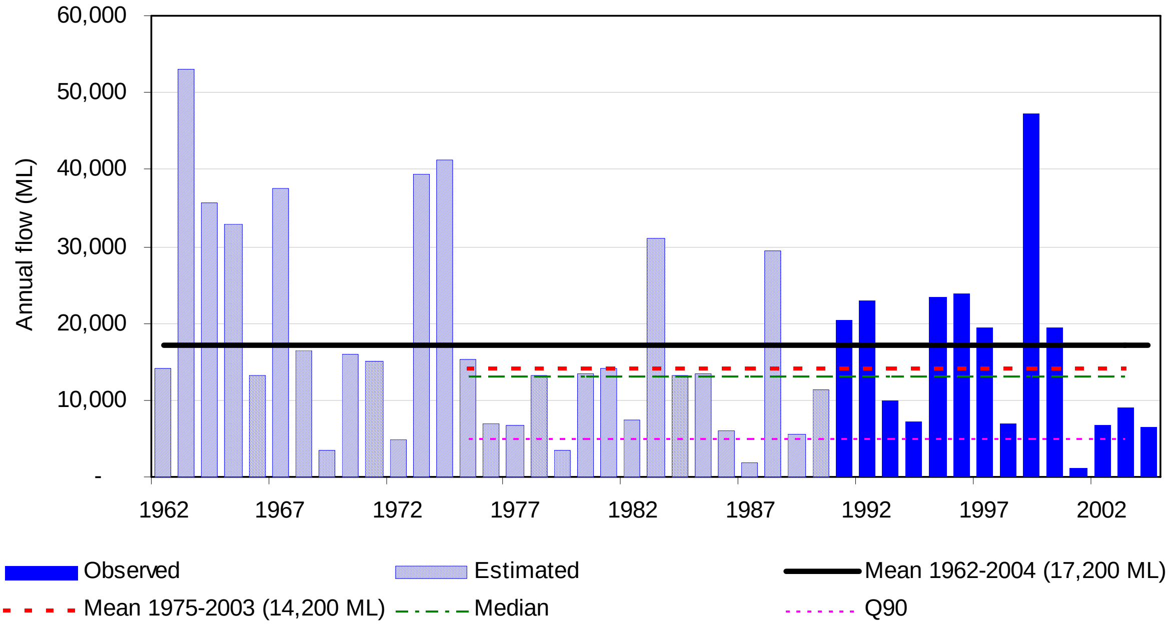


Figure 10-4. Ludlow River at Ludlow (610009) annual flow

Annual flow in the Wonnerup Sub-area is highly variable, especially in the upper reaches of the Ludlow River. The observed coefficients of variation (CVs) range from 0.69 to 0.95, and there is large difference between the minimum and maximum observed flows (Table 10-1). The mean annual flow estimate for the period 1975 to 2003 is 16,600 ML for the Abba River at Wonnerup Siding (Table 10-2); a reduction of 36 per cent compared to the period 1962-1995.

The mean annual flow (MAF) estimates for the period 1975 to 2003 are 232 ML, 5,000 ML and 14,200 ML at Claymore, Happy Valley and Ludlow (Table 10-2), a reduction of 30, 29 and 20 per cent respectively, compared to 1962-1995. The reductions for the Abba River at Wonnerup Siding, and the Ludlow River at Claymore and Happy Valley are the highest for the region. The hydrology of the upper reaches of the Ludlow River (Claymore and Happy Valley) is very different to the lower reaches of the Ludlow River (Ludlow) due to different geology, which could explain the variations in the reductions in streamflow.

The estimated MAFs for the Abba River (Wonnerup Siding) and Ludlow River catchments are 16,600 ML and 14,200 ML respectively. A MAF has not been estimated for Abba River catchment (Abba 27) based on the Wonnerup Siding MAF, as the Whicher catchment is much further upstream, has less clearing and is therefore likely to have different hydrological properties.

Table 10-1. Wonnerup Sub-area CVs, and minimum and maximum flows

		Coeff. of Variability		Observed Flow (ML/a)	
River	**Station**	**Observed**	**1975-2003**	**Min**	**Max**
Abba	Wonnerup Siding (610016)	0.69	0.71	543	46,000
Ludlow	Claymore (610007)	0.90	0.88	17.9	830
Ludlow	Happy Valley (610005)	0.95	0.98	263	20,500
Ludlow	Ludlow (610009)	0.74	0.72	1,140	47,200

Table 10-2. Wonnerup Sub-area mean annual flows

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
610016	128	24,000	25,900	16,600
610007	9.5	306	332	232
610005	109	6,840	7,080	5,000
Ludlow Catchment (610009)	208	17,200	17,600	14,200
Wonnerup Sub-area	477			*32,700*

Note: Figures in *italics* have been derived from a regional relationship (REG75)

10.2 Daily flow

Continuous flow period

Figure 10-5 to Figure 10-8 show the observed continuous flow period for each calendar year since 1975 in the Wonnerup Sub-area. Flow is ephemeral in the Abba River at Wonnerup Siding; however, it is not possible to discern a trend due to the short flow record. Flow is ephemeral in the Ludlow River at Claymore and Happy Valley generally starting in June and stopping in November, although the flow period appears to be decreasing, particularly at Claymore. At Ludlow further downstream, the flow period is more variable, but also appears to be decreasing. The flow period for the Ludlow River appears to be related to annual flow with shorter flow periods evident following low flow years.

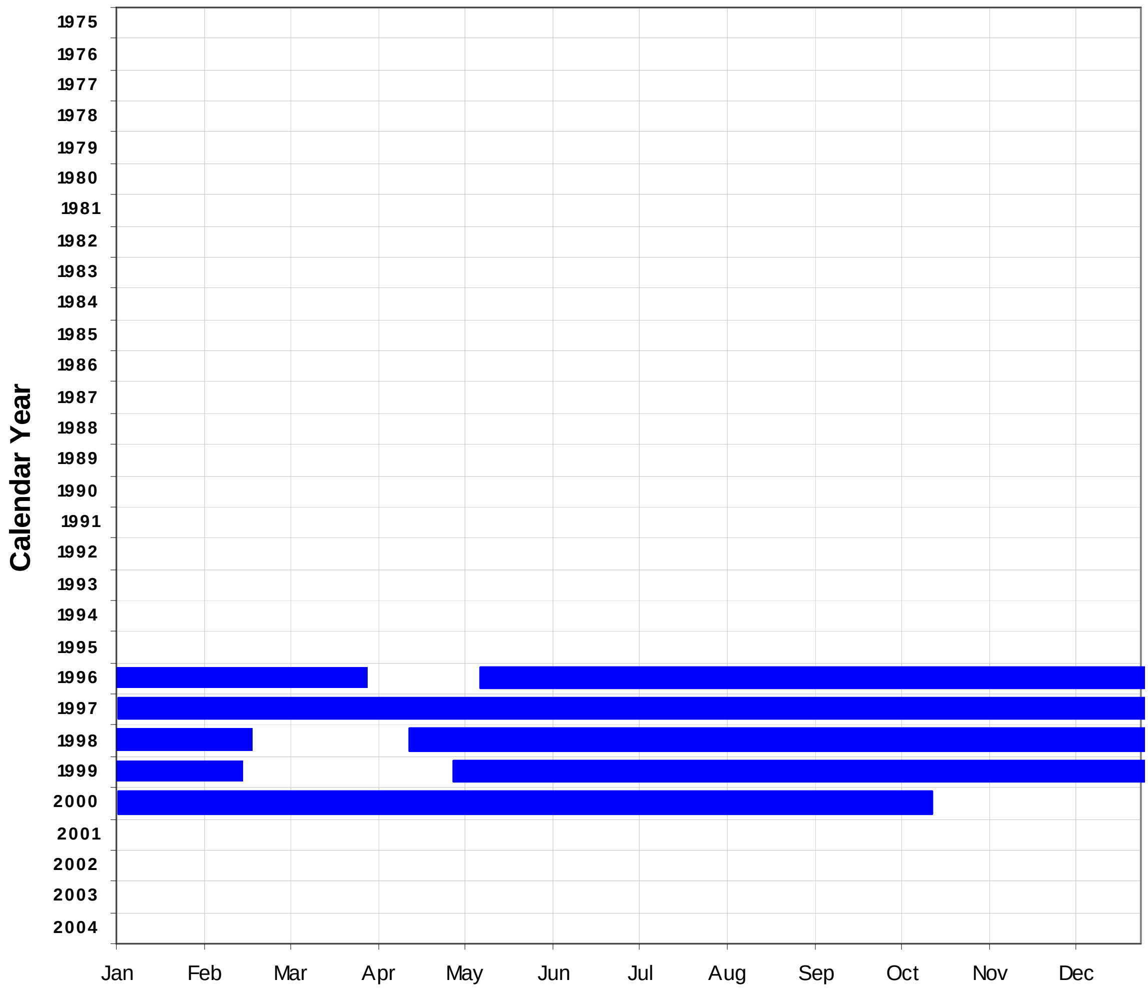


Figure 10-5. Abba River at Wonnerup Siding (610016) continuous flow period

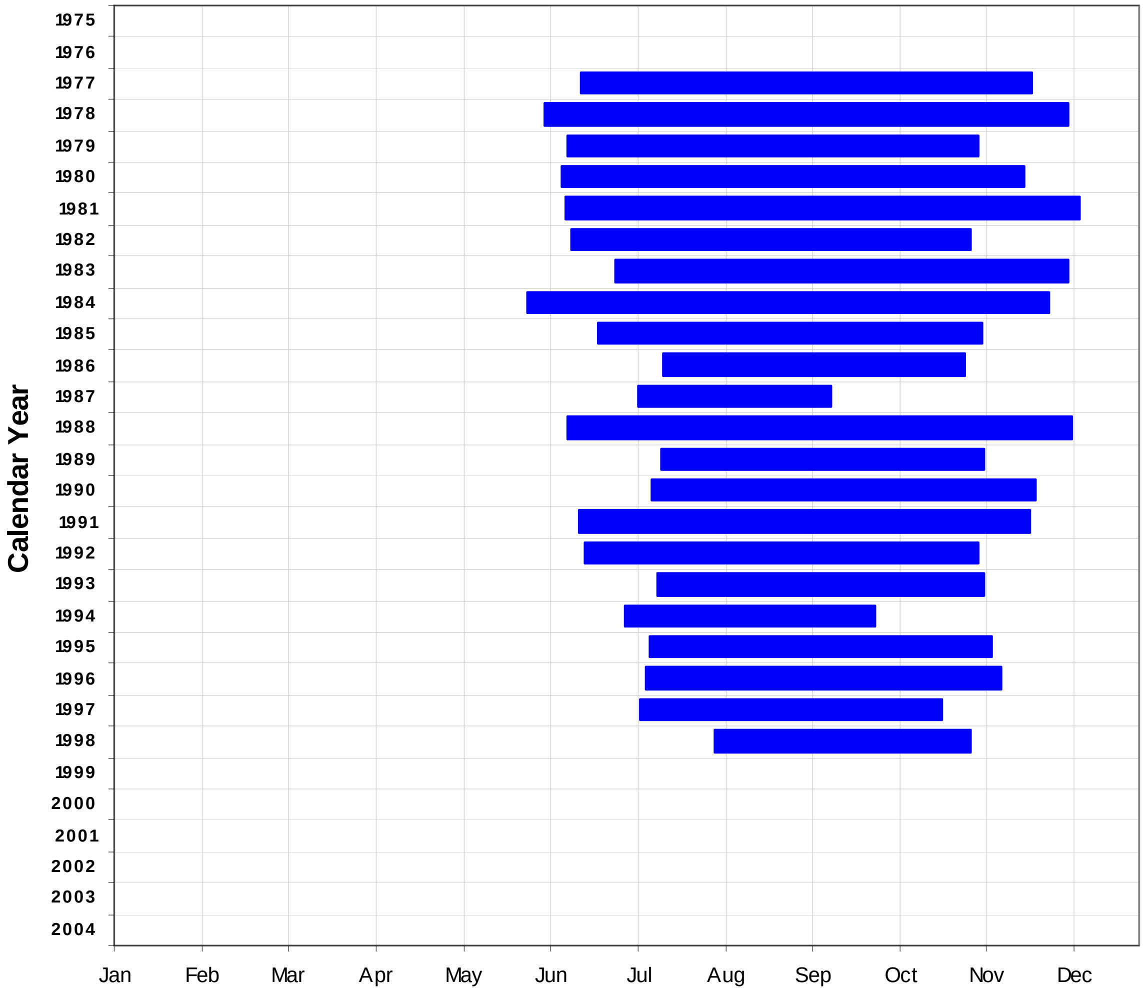


Figure 10-6. Ludlow River at Claymore (610007) continuous flow period

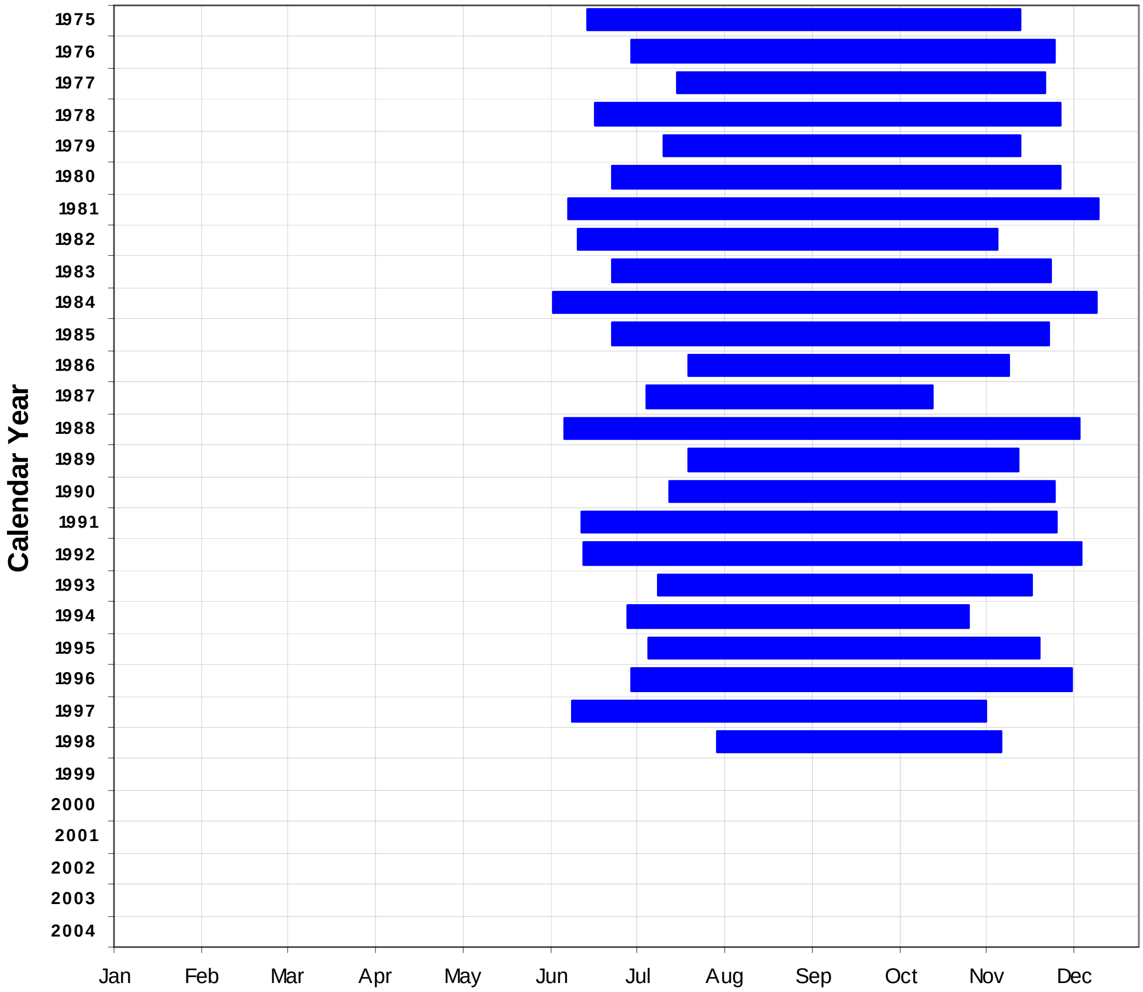


Figure 10-7. Ludlow River at Happy Valley (610005) continuous flow period

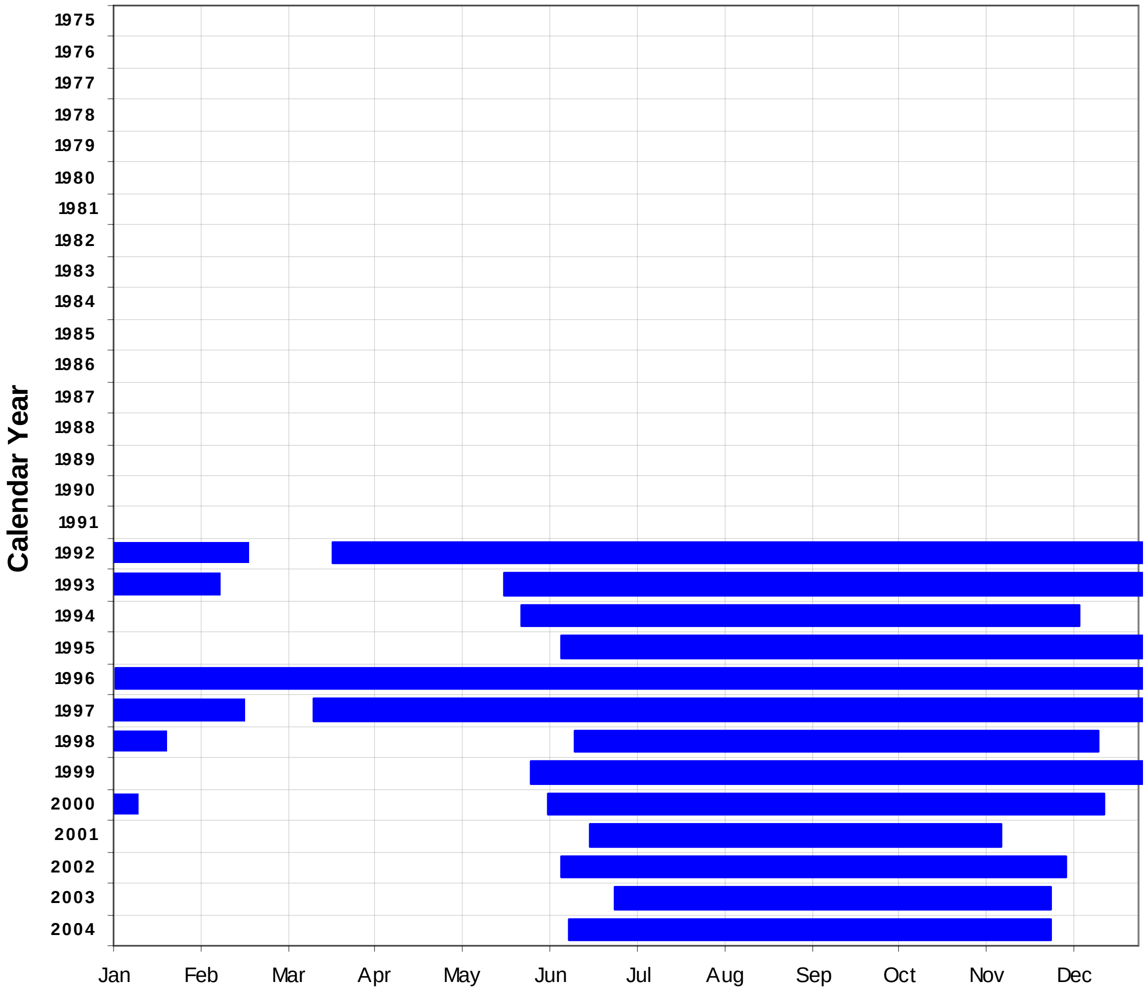


Figure 10-8. Ludlow River at Ludlow (610009) continuous flow period

Flow duration curves

The median annual flow duration curve (FDC) for the Abba River at Wonnerup Siding (Figure 10-9) is similar to the FDC for Vasse Diversion at D/S Hill Rd (Figure 9-9), also located on the Swan Coastal Plain. The curve shows that streamflow is ephemeral and although 87 per cent of days have flow, the curve is very steep at the high flow end and flattens at the low flow end, with a median daily flow 0.34 ML.

For the Ludlow River, the median annual flow duration curve (FDC) indicates a lower reliability of flow for low flows, especially at the downstream station at Ludlow (610009). The median FDCs for Claymore (Figure 10-10) and Happy Valley (Figure 10-11) show that streamflow at both locations is ephemeral with 38 per cent of days having flow and therefore the median daily flow is 0 ML. This steepness of the curve at the low-flow end is typical of most forested catchments in the region. Flow in the Ludlow River at Ludlow is also ephemeral, with 54 per cent of days having flow and a low median daily flow of 0.65 ML (Figure 10-12). The steepness of the curves at the low-flow end for the upper reaches of the Ludlow River is typical of forested catchments.

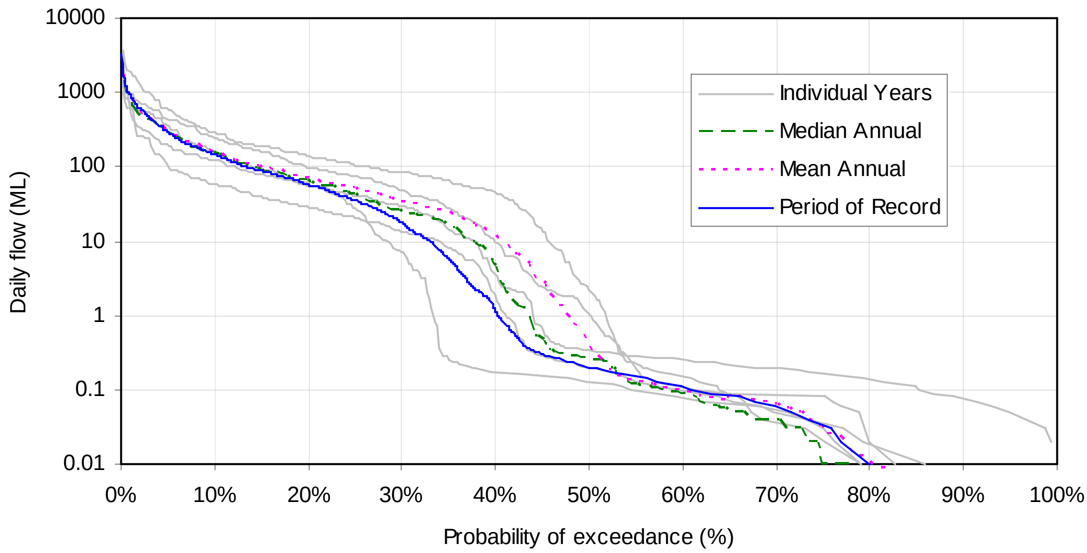


Figure 10-9. Abba River at Wonnerup Siding (610016) annual flow duration curves

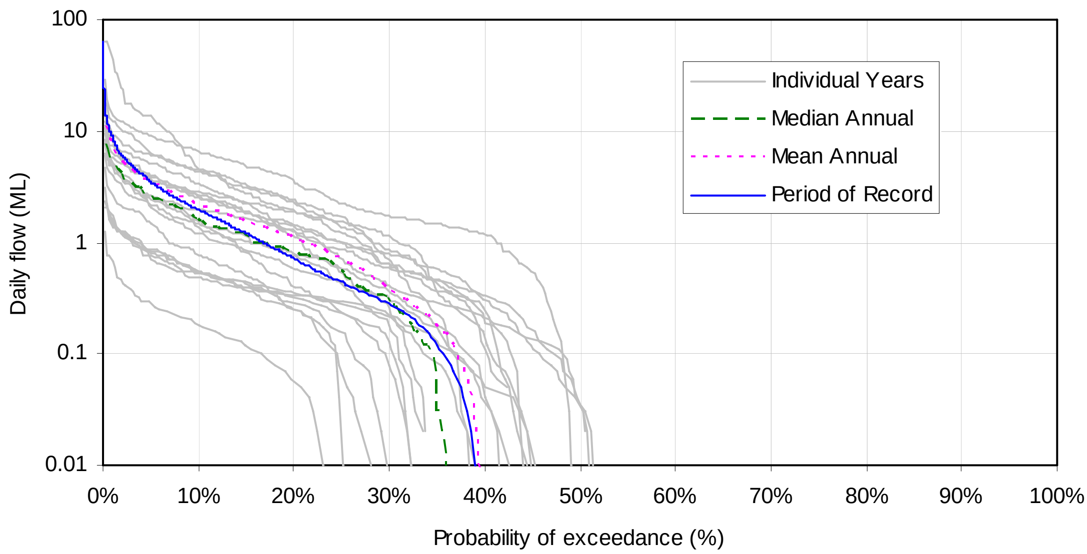


Figure 10-10. Ludlow River at Claymore (610007) annual flow duration curves

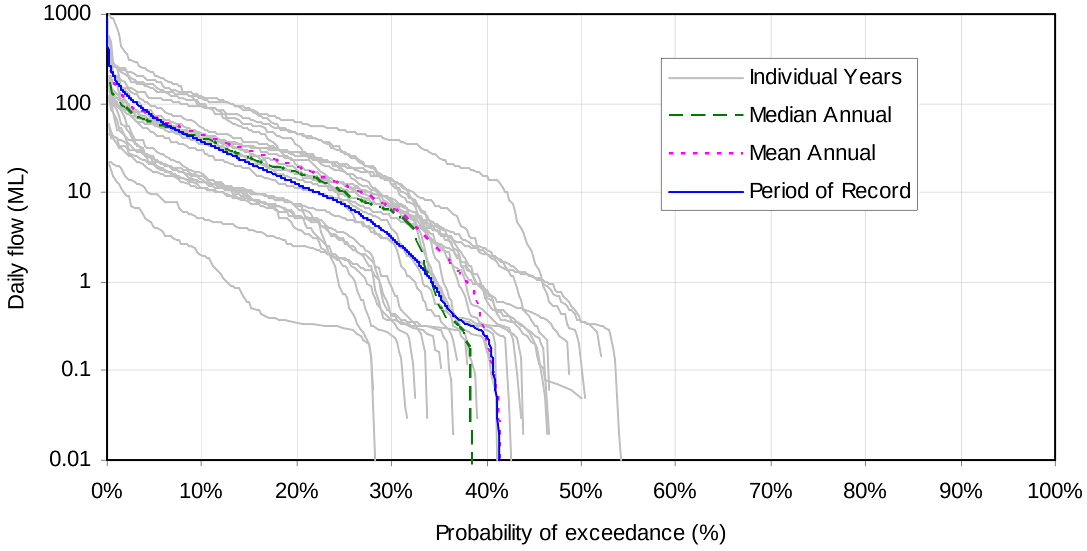


Figure 10-11. Ludlow River at Happy Valley (610005) annual flow duration curves

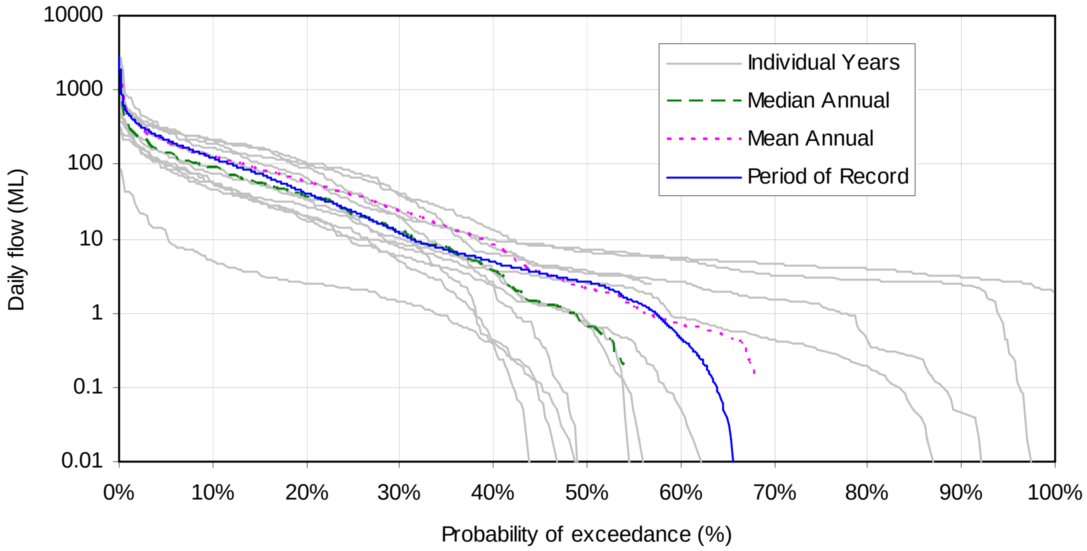


Figure 10-12. Ludlow River at Ludlow (610009) annual flow duration curves

Monthly flow duration analysis for the Abba River at Wonnerup Siding (Figure 10-13) shows that flow is much more widespread throughout the year than for the Ludlow River. Flow is continuous only during September, with a corresponding median daily flow of 53 ML. Flow is not continuous for the other months; however, the median daily flow during this period is greater than 0.01 ML, except for March where flow is greater than 0.01 ML for 40 per cent of the time.

Monthly flow duration analysis for the Ludlow River in the upper reaches (Figure 10-14 and Figure 10-15) shows that flow is highly ephemeral. Historically, at Claymore flow has been continuous only during August, with a median daily flow of 1.6 ML. Flow is not continuous for the other months and occurs less than five per cent of the time between January and May. Historically, there has been no flow from January through to April. At Happy Valley, further downstream, flow is continuous during August and September, with a corresponding median daily flow greater than 25 ML. Flow is not continuous for the other months and also occurs less than five per cent of the time between January and May. Historically, there has been no flow during February and March.

Monthly flow duration analysis for the Ludlow River at Ludlow in the downstream reaches (Figure 10-16) shows that flow is continuous between July and October and the corresponding median daily flow is greater than 13 ML. Flow is not continuous for the other months and occurs less than 50 per cent of the time between January and May.

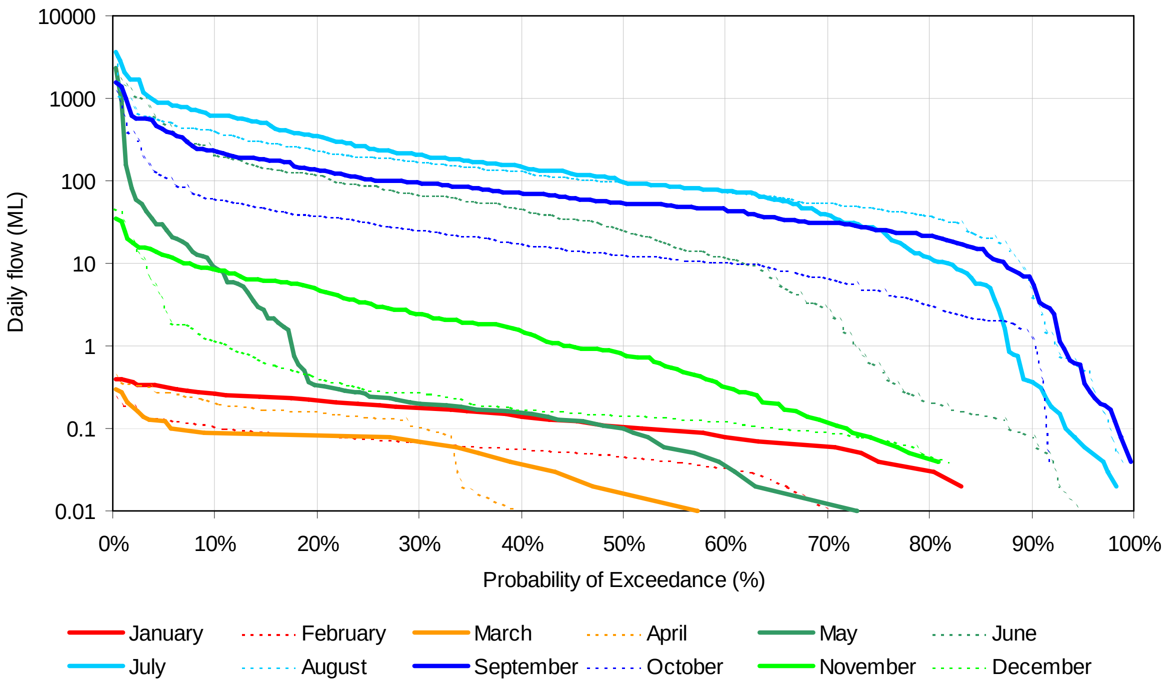


Figure 10-13. Abba River at Wonnerup Siding (610016) monthly flow duration curves

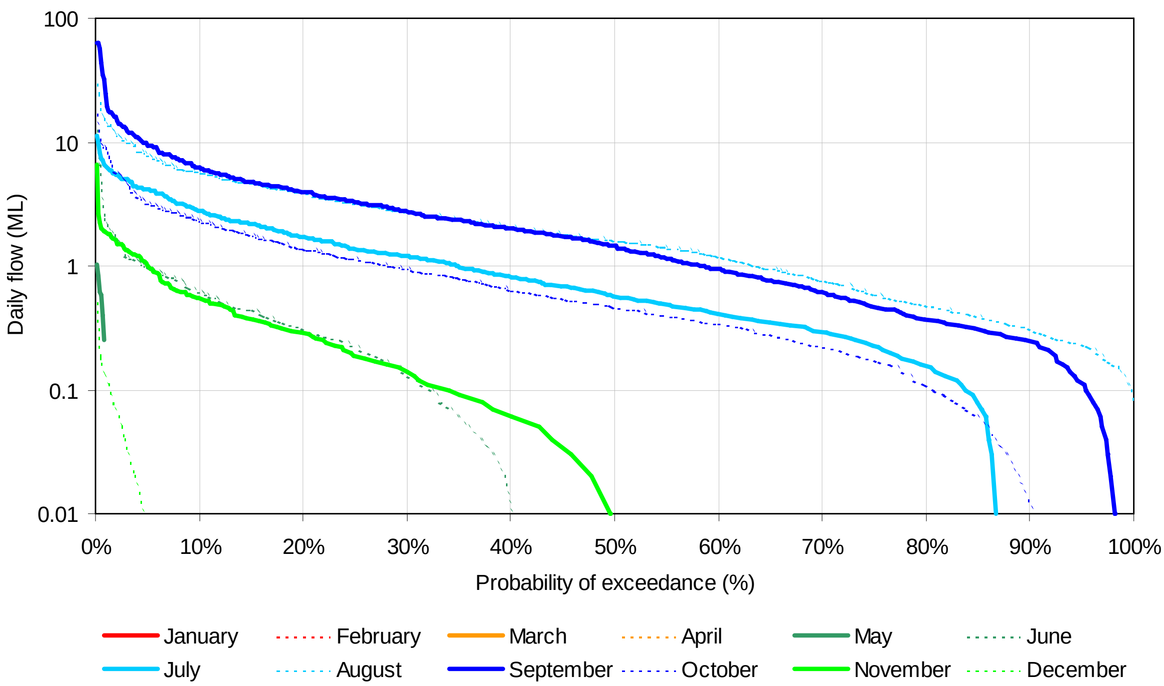


Figure 10-14. Ludlow River at Claymore (610007) monthly flow duration curves

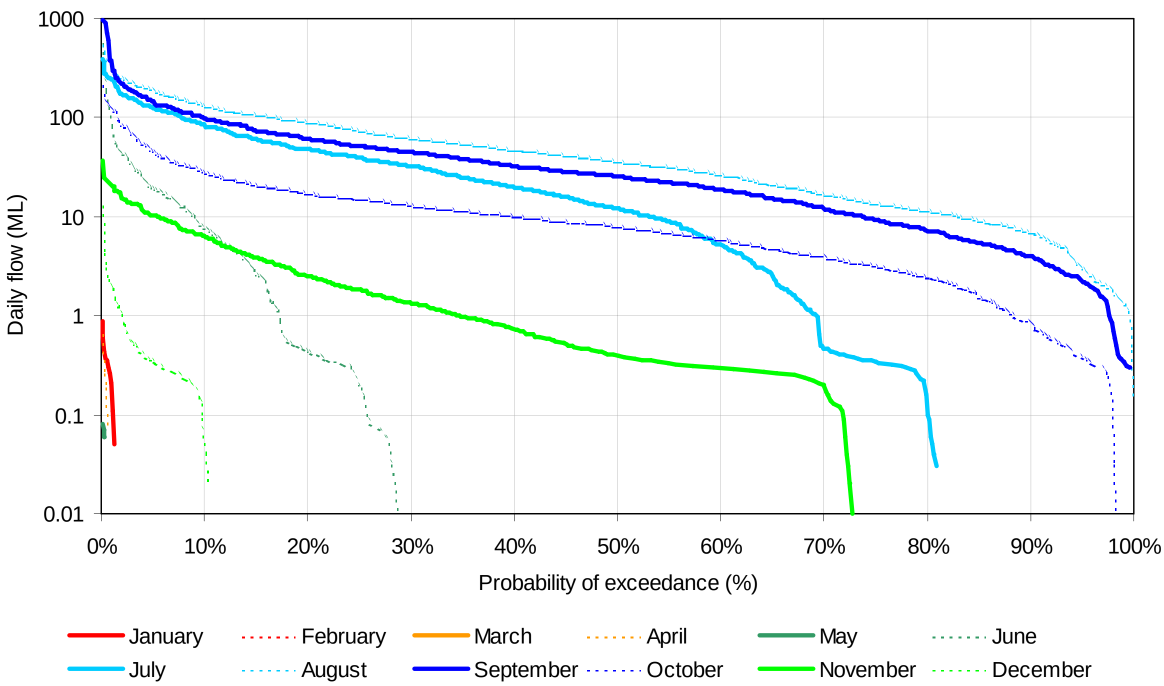


Figure 10-15. Ludlow River at Happy Valley (610005) monthly flow duration curves

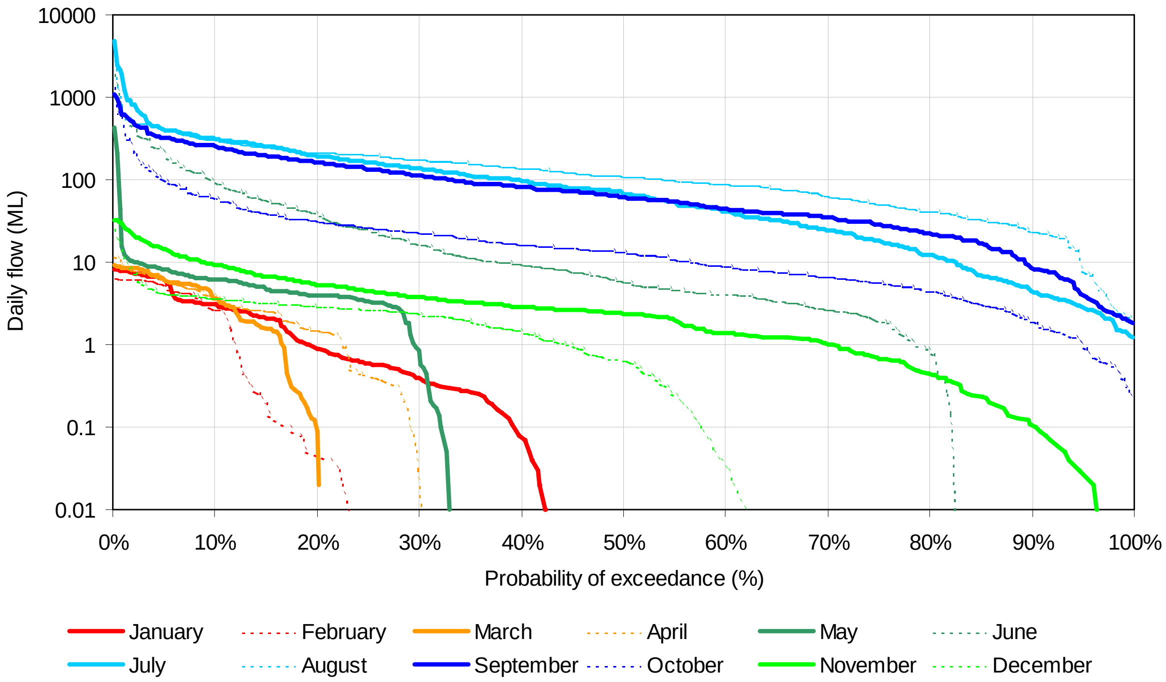


Figure 10-16. Ludlow River at Ludlow (610009) monthly flow duration curves

Baseflow analysis

The baseflow analysis for the Abba River (610016) (Figure 10-17) indicated that on average, 28 per cent of the total annual flow is derived from baseflow (ie a baseflow index of 28%), with a range from 25 to 32 per cent.

The baseflow analysis for the Ludlow River indicated that on average, 34 per cent of the total annual flow at Claymore (610007) and Happy Valley (610005) is derived from baseflow (ie a baseflow index of 34%), with a baseflow index (BFI) of 32 per cent at Ludlow (610009). All stations exhibit a large variation in the BFI: 28 to 39 per cent at Claymore, 26 to 39 at Happy Valley and 25 to 36 at Ludlow.

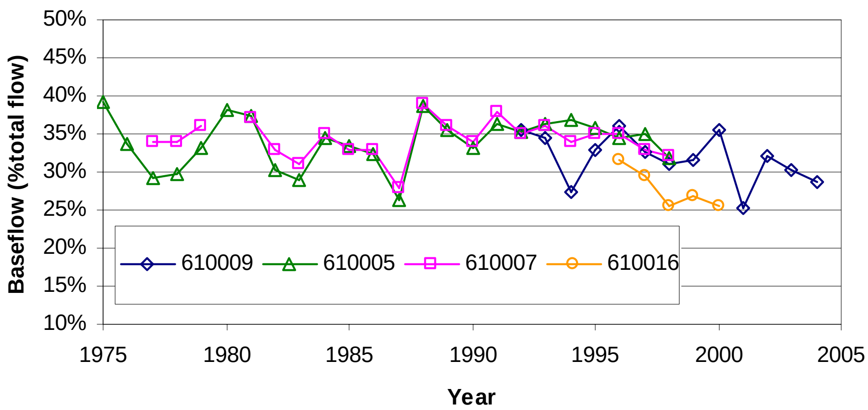


Figure 10-17. Wonnerup Sub-area baseflow indices

11 Capel

The Capel and Margaret Rivers are the only rivers currently proclaimed in the Cape-to-Cape region for surface water licensing. The Capel River Surface Water Management Area includes the Whicher catchment Capel 29 and the Five Mile Brook catchment and has been further divided into six Surface Water Management Sub-areas (Figure 2-2 and Figure 2-3):

- Capel River North Branch
- Capel River South Branch
- Capel River Central
- Gynudup Brook and Tren Creek
- Capel River West
- Five Mile Brook.

Capel River Central currently has one gauging station operating at Yates Bridge (610219) (Figure 2-6), which operated from 1966 to 1976 and was reopened in 1996 (Figure 11-1). A station downstream at Scott Road (610129), which operated from 1959 to 1968, has been used to extend the record at 610219.

Capel River West currently has one gauging station operating at Capel Railway Bridge (610010), which commenced operation in 1993 (Figure 11-2). Gynudup Brook has two historic gauging stations: Elgin Siding (610130) which operated from 1959 to 1963; and Elgin Main Drain – Capel (610131) which operated from 1959 to 1965; however, no useable streamflow records were produced at these sites. Capel River North and South have not had any gauging stations operating.

Upstream of Yates Bridge, the level of catchment clearing is approximately 30 per cent, while downstream the Capel Railway Bridge catchment is approximately 40 per cent. The Capel River and its tributaries are fresh (Mayer et al, 2005).

11.1 Annual flow

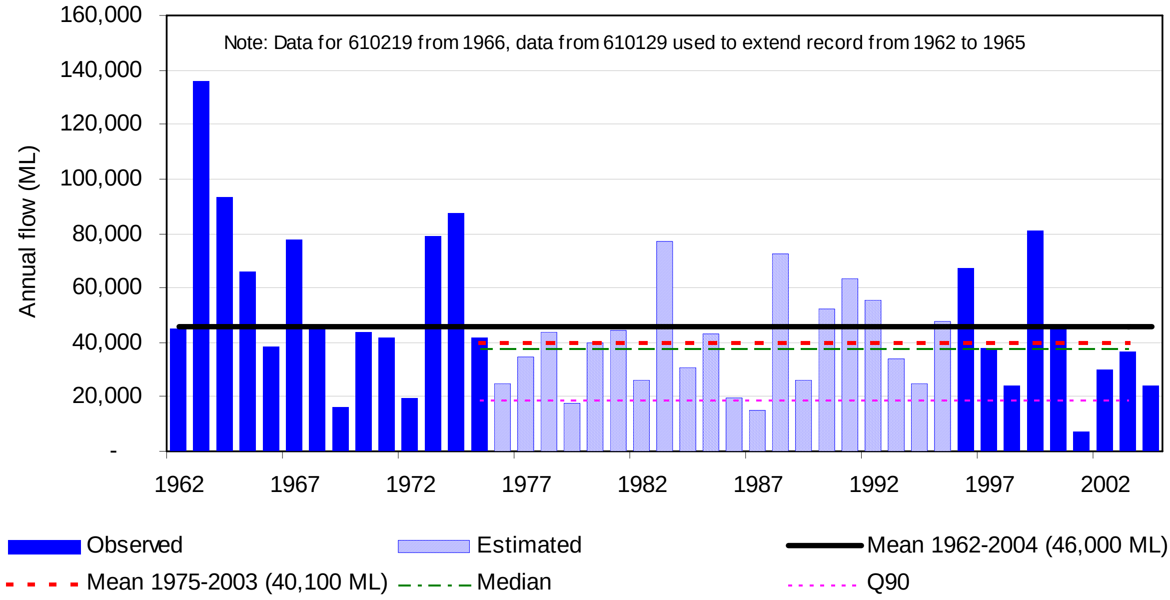


Figure 11-1. Capel River at Yates Bridge extended (610129/219) annual flow

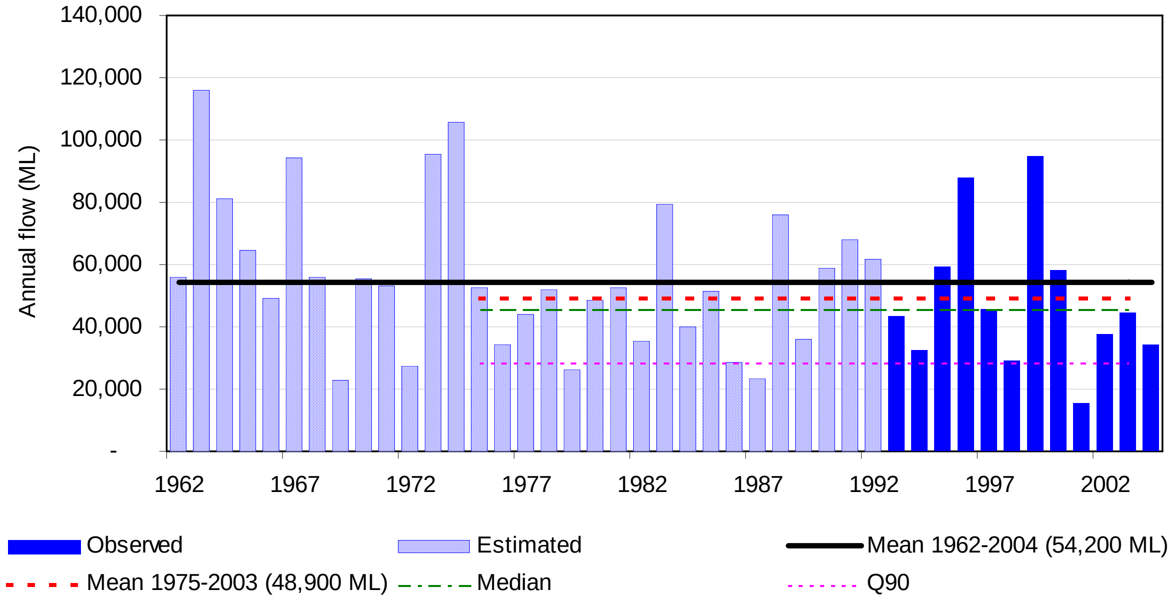


Figure 11-2. Capel River at Capel Railway Bridge (610010) annual flow

Annual flow in the Capel River is quite variable. The observed coefficients of variation (CVs) at Yates Bridge (610219) and Capel Railway Bridge (610010) are 0.59 and 0.48, and for the period 1975-2003 they are estimated to be 0.47 and 0.39 respectively. The maximum and minimum recorded annual flows are 136,000 ML and 7,200 ML respectively at Yates Bridge and 94,600 ML and 15,700 ML respectively at Capel Railway Bridge. The mean annual flow (MAF) estimate for 1975 to 2003 is 40,100 ML at Yates Bridge and 48,900 ML at Capel Railway Bridge (Table 11-1), a reduction of 16 and 12 per cent respectively, compared to 1962-1995. This reduction is relatively low compared to other catchments in the region, possibly due to groundwater contributions.

The estimated MAF for the Capel River Surface Water Management Area (combined Surface Water Management Sub-areas) is 77,600 ML (there is insufficient data available to determine MAFs for individual Sub-areas, so they have been estimated from a regional relationship).

Table 11-1. Capel River Sub-area mean annual flows

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
610219	315	45,400	47,100	40,100
610010	395	54,200	57,300	48,900
Capel River North Branch Sub-area	87.8			*13,600*
Capel River South Branch Sub-area	168			*22,000*
Capel River Central Sub-area	111			*8,400*
Capel River West Sub-area	81.2			*5,700*
Gynudup Brook and Tren Ck Sub-area	188			*21,200*
Five Mile Brook Sub-area	87.4			*6,700*
Capel River Surface Water Management Area	723			*77,600*

Note: Figures in *italics* have been derived from a regional relationship (REG75)

11.2 Daily flow

Continuous flow period

Figure 11-3 and Figure 11-4 show the observed continuous flow period for each calendar year since 1975 for the Capel River at Yates Bridge and Capel Railway Bridge respectively. Daily flow at Yates Bridge is continuous for most years; however, some years have had short periods of zero flow. Further downstream, flow is perennial at Capel Railway Bridge.

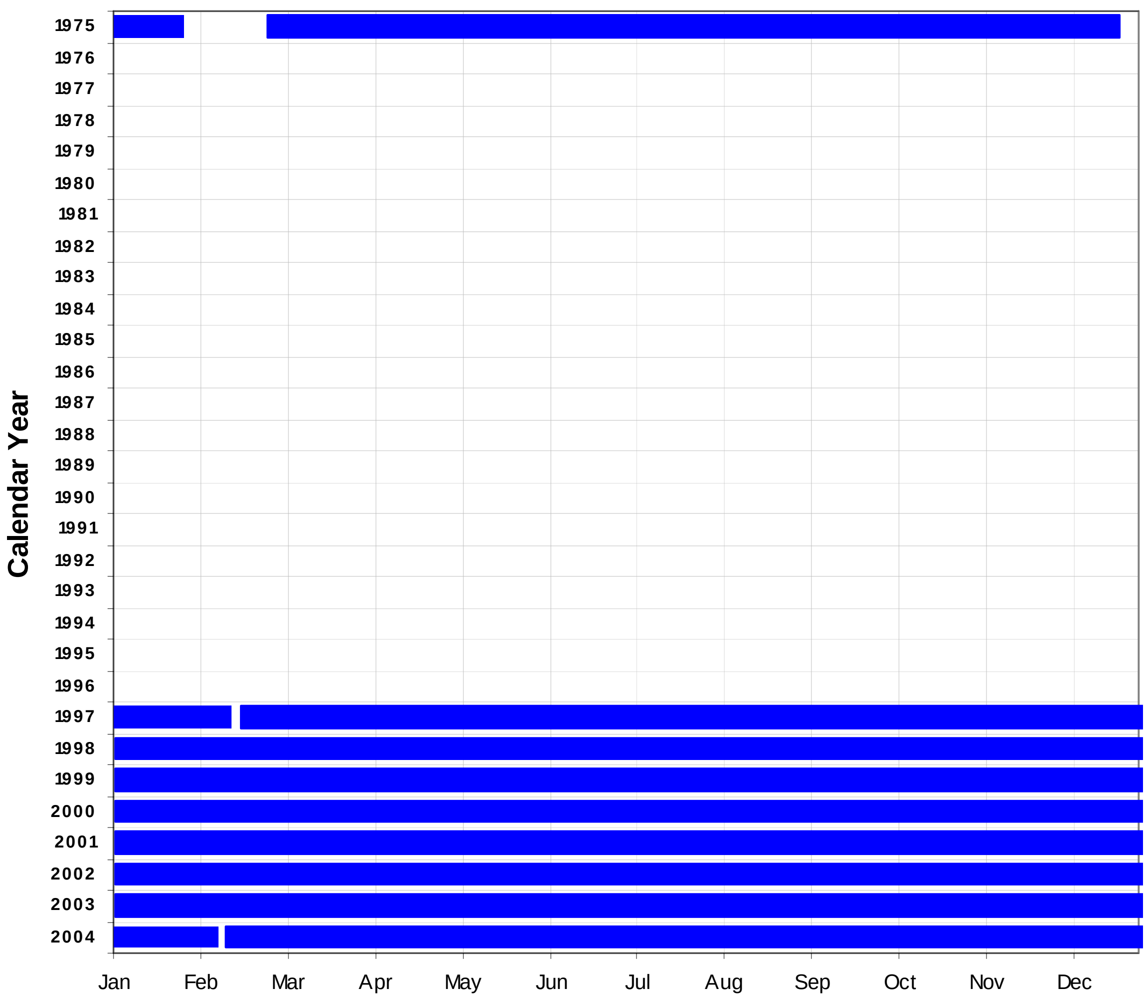


Figure 11-3. Capel River at Yates Bridge (610219) continuous flow period

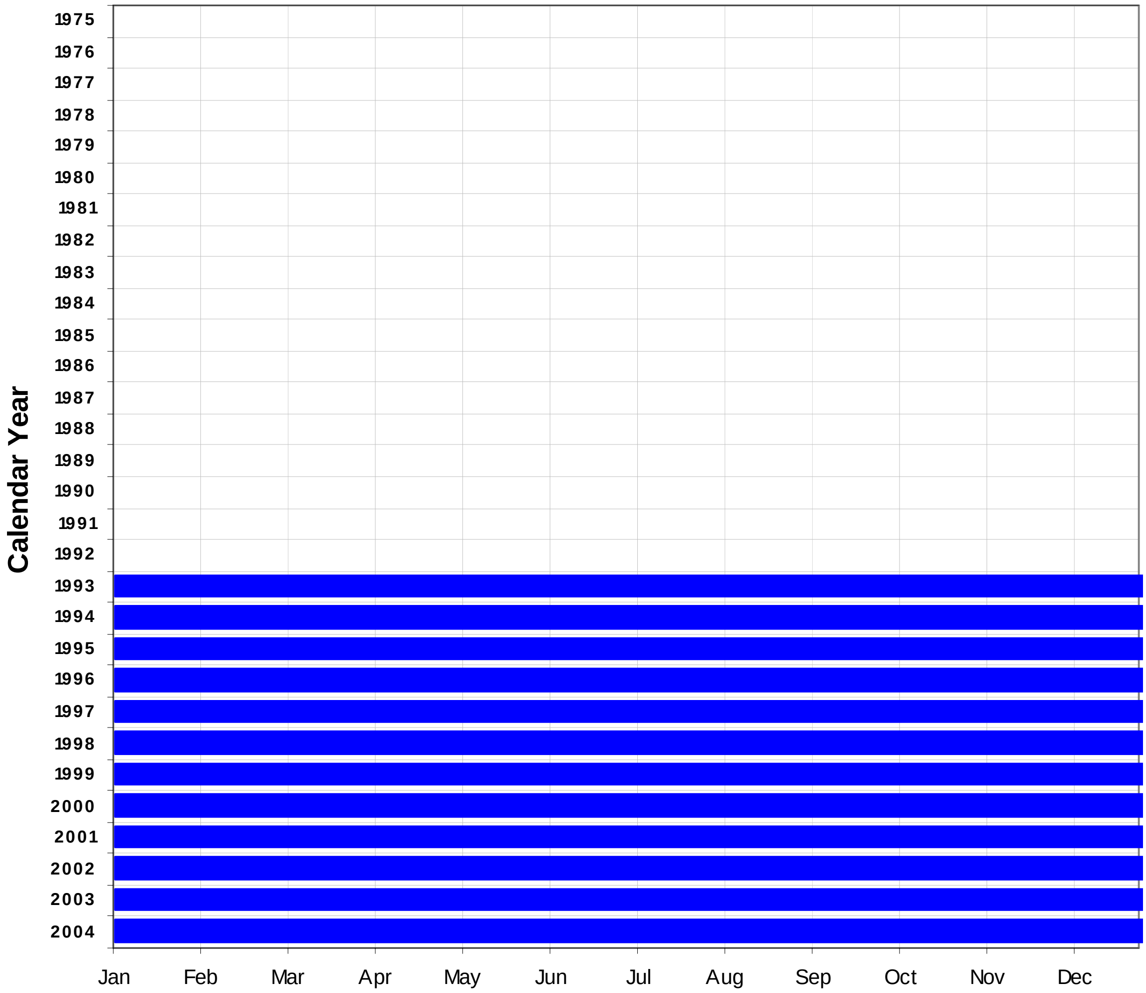


Figure 11-4. Capel River at Capel Railway Bridge (610010) continuous flow period

Flow duration curves

Annual flow duration analysis (median curve) for all of the observed data indicated the minimum daily flow is greater than 0.3 ML and the median daily flow is 11 ML at Yates Bridge (Figure 11-5). At Capel Railway Bridge, the minimum daily flow is greater than 9 ML and the median daily flow is 27 ML (Figure 11-6). The curve at Yates Bridge is shallow at the low-flow end suggesting significant groundwater contributions. The curve at Capel Railway Bridge is very shallow from the high-flow to the low-flow end indicating a stable stream with large amounts of surface storage and large groundwater contributions or releases from storage to maintain low flows.

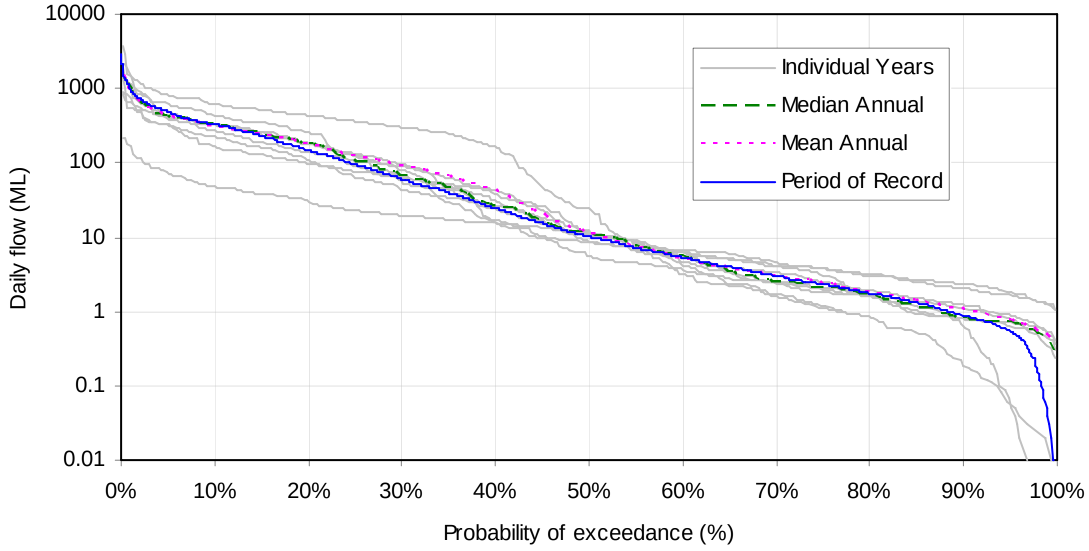


Figure 11-5. Capel River at Yates Bridge (610219) annual flow duration curves

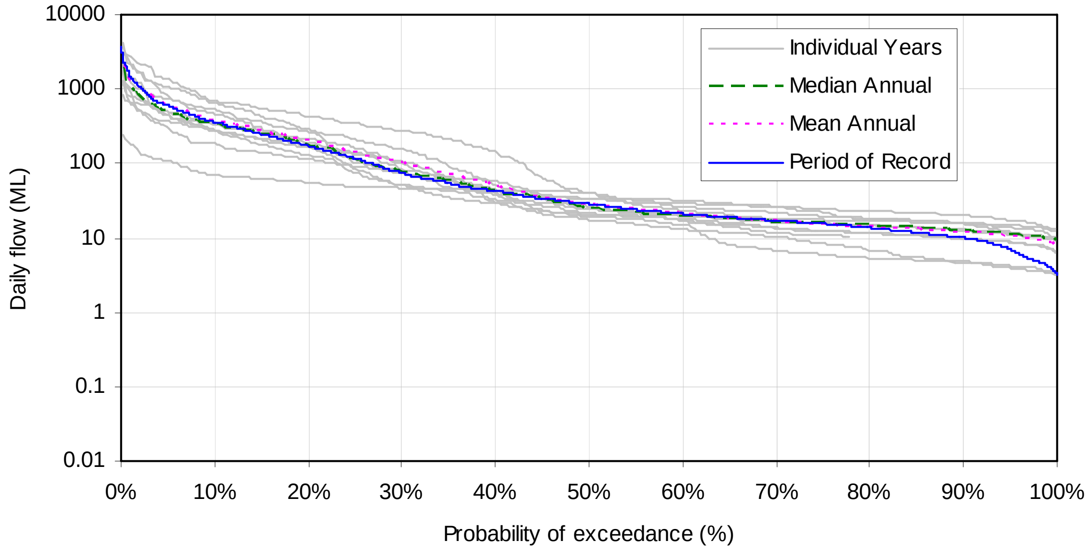


Figure 11-6. Capel River at Capel Railway Bridge (610010) annual flow duration curves

Monthly flow duration analysis for the Capel River at Yates Bridge (Figure 11-7) shows that flow is continuous between April and November and the corresponding median daily flow is greater than 2.6 ML. Flow is not continuous for the other months; however, it occurs more than 95 per cent of the time and the corresponding median daily flow is greater than 1.1 ML.

Monthly flow duration analysis for the Capel River at Capel Railway Bridge (Figure 11-8) shows that flow is continuous throughout the year and the corresponding median daily flow is greater than 12 ML. A minimum daily flow of 3.2 ML is maintained throughout the year. The curves for January through to March are very similar, suggesting that groundwater contributions are a dominant flow source during these months.

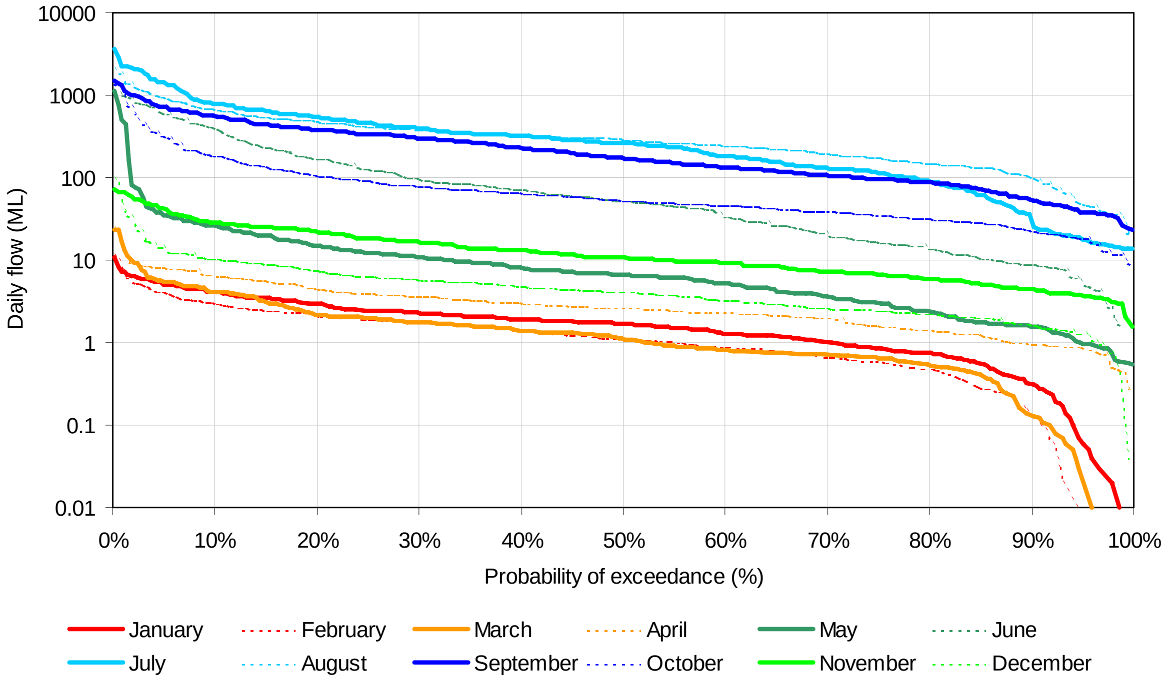


Figure 11-7. Capel River at Yates Bridge (610219) monthly flow duration curves

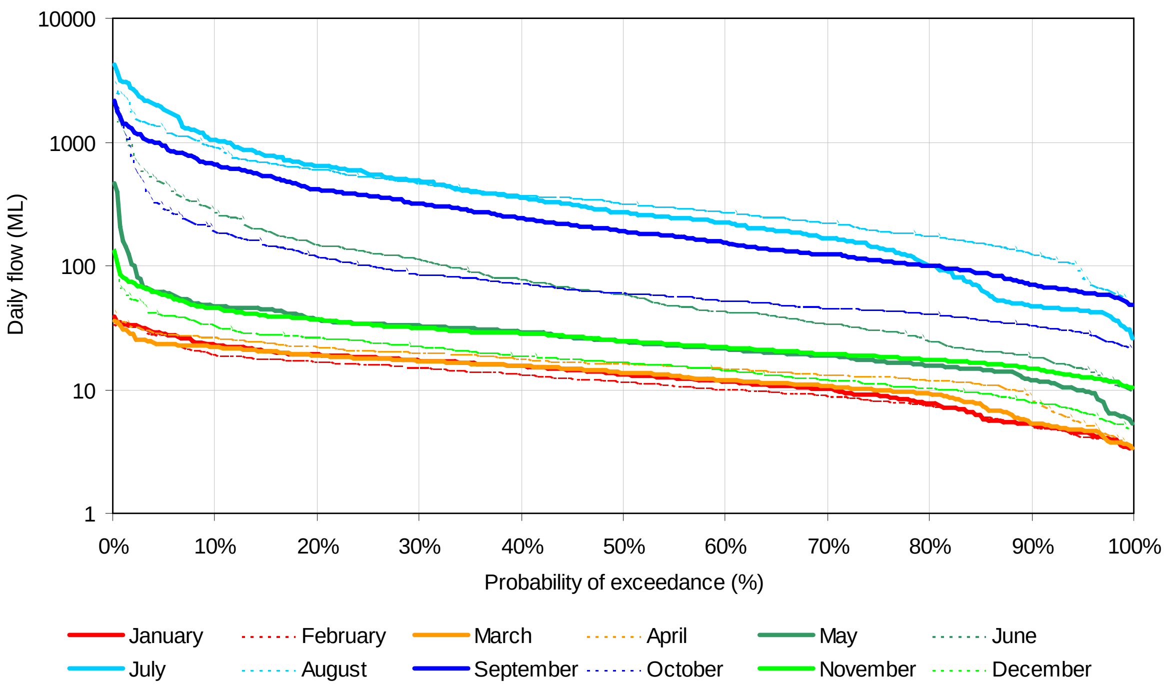


Figure 11-8. Capel River at Capel Railway Bridge (610010) monthly flow duration curves

Baseflow analysis

The baseflow analysis for Capel River indicated that on average, 36 per cent of the total annual flow at Yates Bridge (610219) is derived from baseflow (ie a baseflow index of 36%), with a range of 35 to 39 per cent (Figure 11-9). Further downstream, Capel Railway Bridge has a higher baseflow index of 40 per cent and exhibits more variation, with a range of 34 to 48 per cent.

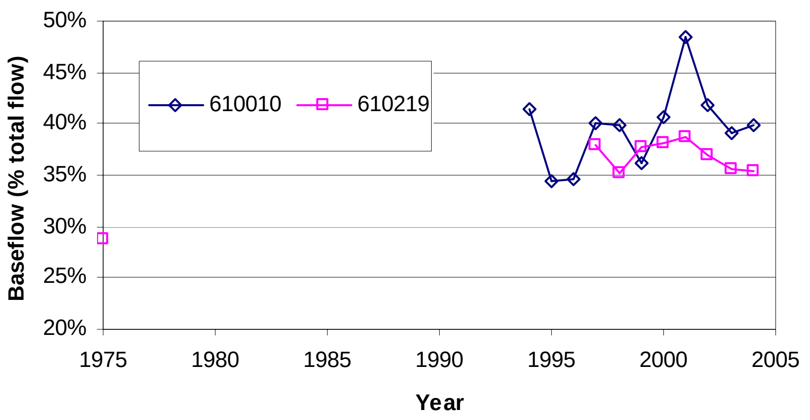


Figure 11-9. Capel River baseflow indices

12 Scott

The Scott River Surface Water Management Sub-area includes the Whicher catchment Scott 32 and extends to the coast (Figure 2-2 and Figure 2-3). The Sub-area currently has one streamflow gauging station operating: Brennan's Ford (609002) at the downstream end of the catchment has been operating since 1969 (Figure 2-6 and Figure 12-1). A gauging station further upstream operated at Milyeannup (609026) from December 1995 to April 1999, however, this station was not used in the analysis due to the short period of record. The Sub-area is approximately 30 per cent cleared and the river is fresh (Mayer et al, 2005).

12.1 Annual flow

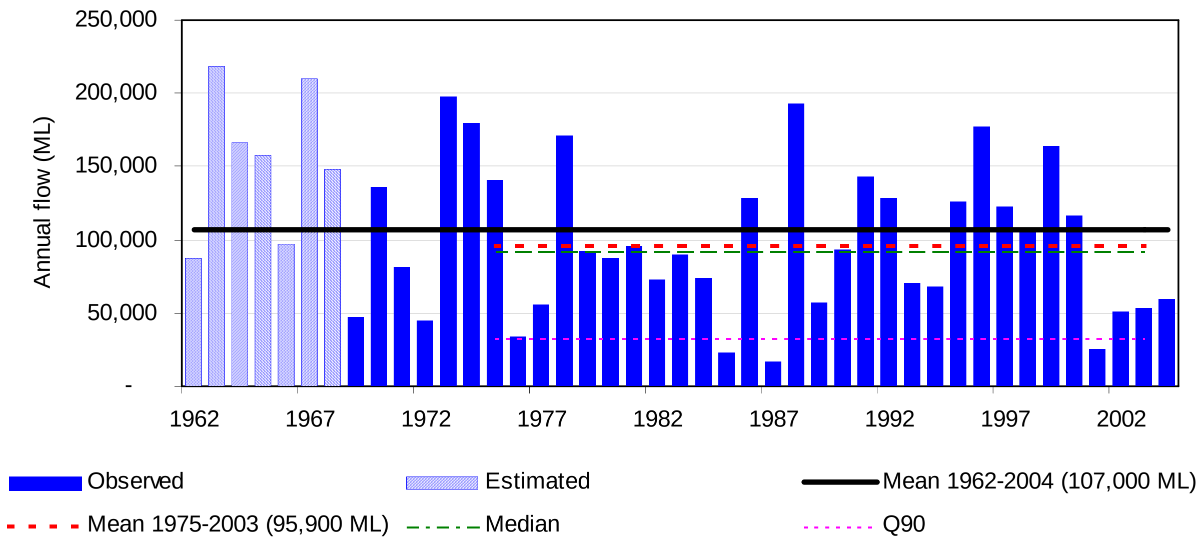


Figure 12-1. Scott River at Brennan's Ford (609002) annual flow

The observed coefficient of variation (CV) at Brennan's Ford (609002) is 0.52, and for the period 1975-2003 it is 0.5, indicating a relatively high variability in annual flow in the Scott River. The maximum and minimum recorded annual flows are 98,000 ML and 17,200 ML respectively. The mean annual flow (MAF) estimate for the period 1975 to 2003 is 95,900 ML (Table 12-1), a reduction of 13 per cent compared to the period 1962-1995. This reduction is the lowest for gauged catchments within the Lower Blackwood Surface Water Management Area.

The estimated MAF for the Scott River Surface Water Management Sub-area is 114,300 ML.

Table 12-1. Scott River Sub-area mean annual flows

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
609002	628	107,000	109,900	95,900
Scott Catchment	660	–	–	*101,000*
Scott Sub-area	748	–	–	*114,300*

Note: Figures in *italics* have been derived from areal scaling

12.2 Daily flow

Continuous flow period

Figure 12-2 shows the observed continuous flow period for each calendar year since 1975 for the Scott River at Brennan's Ford. Flow has been perennial (continuous) for the entire period.

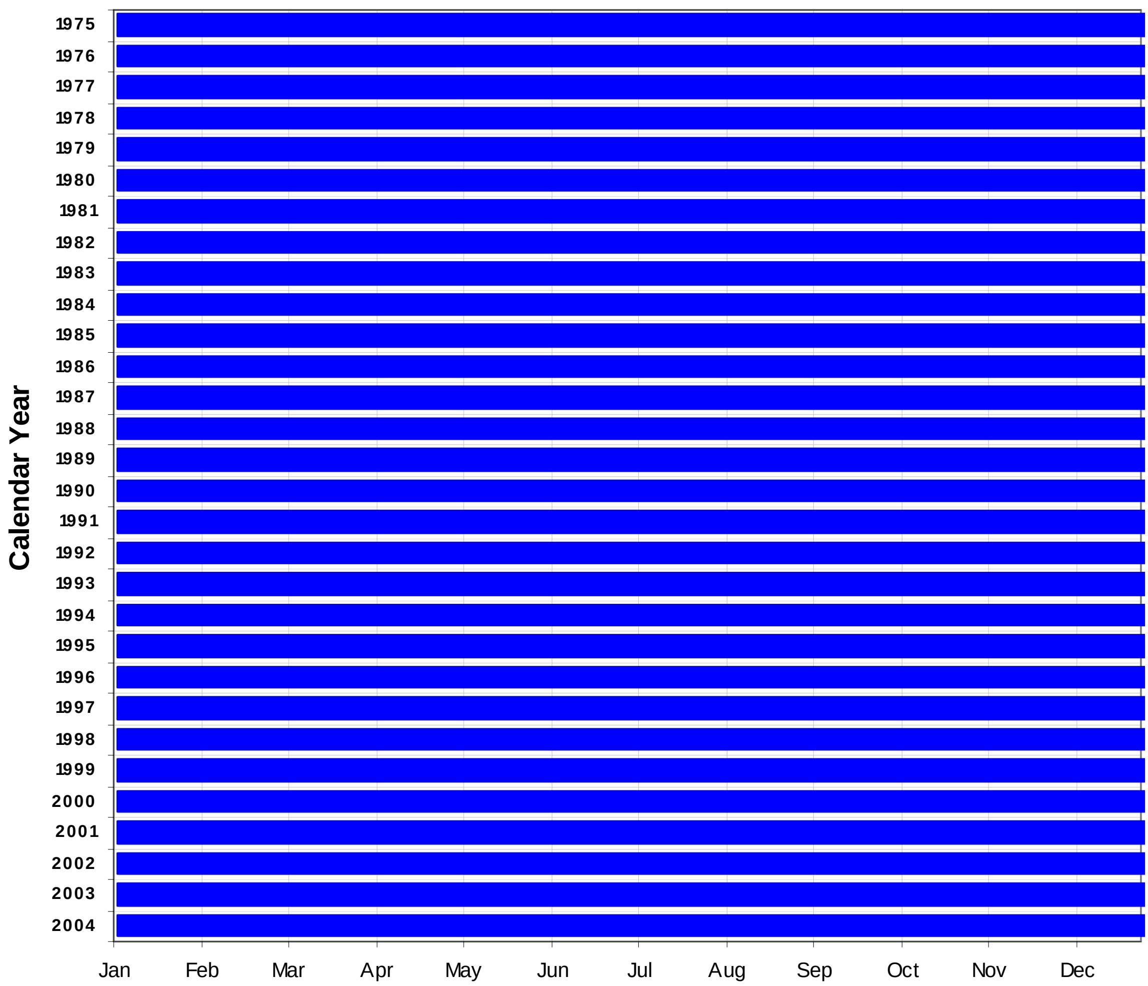


Figure 12-2. Scott River at Brennan's Ford (609002) continuous flow

Flow duration curves

The median annual flow duration curve (FDC) shows that the river is perennial with a median and minimum daily flow of 2.5 ML and 0.06 ML respectively at Brennan's Ford (Figure 12-3). The slope of the curve is shallow at the low-flow end indicating groundwater contributions, which are from the Leederville Aquifer.

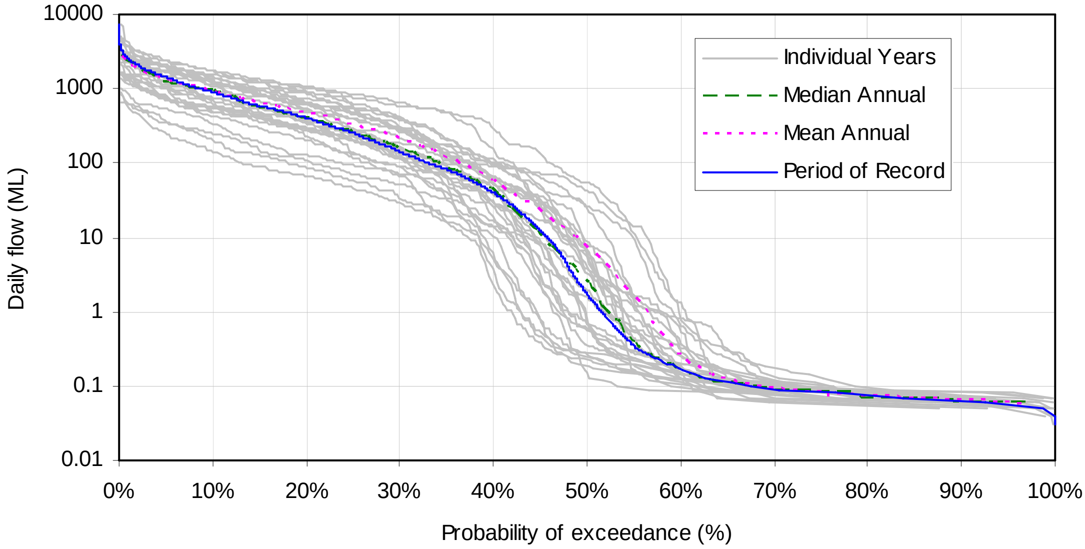


Figure 12-3. Scott River at Brennan's Ford (609002) annual flow duration curves

Monthly flow duration analysis for the Scott River (Figure 12-4) shows that flow is continuous throughout the year and the corresponding median daily flow is greater than 0.06 ML; however, the median daily flow from June to November is greater than 22 ML. A minimum daily flow of 0.04 ML is maintained throughout the year. The curves for January through to April are very flat for an exceedance probability greater than 10 per cent, indicating that groundwater contributions are the dominant flow source during these months.

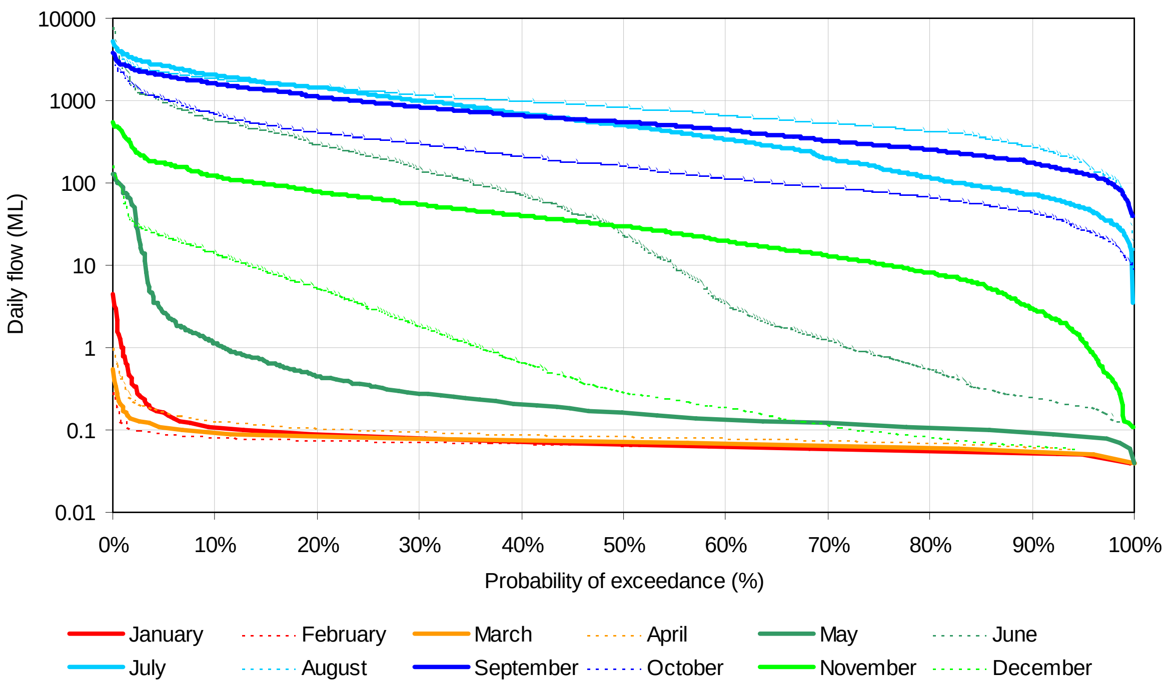


Figure 12-4. Scott River at Brennan's Ford (609002) monthly flow duration curves

Baseflow analysis

The baseflow analysis for the Scott River indicated that on average, 36 per cent of the total annual flow at Brennan's Ford (609002) is derived from baseflow (ie a baseflow index of 36%), with a range of 30 to 39 per cent (Figure 12-5). The analysis also indicates that the annual baseflow as a proportion of total flow has been relatively constant throughout the period 1975 to 2003.

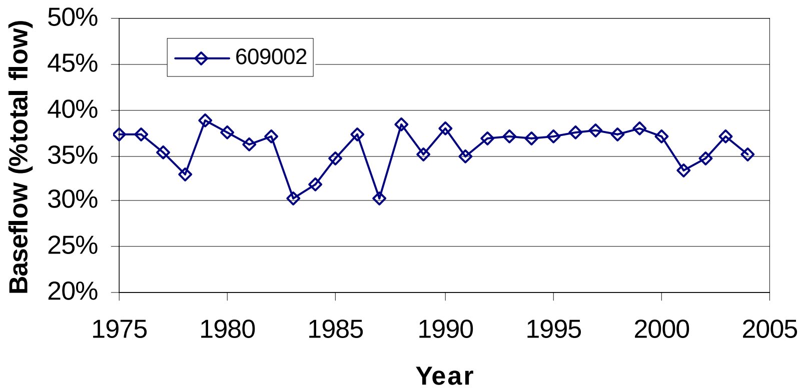


Figure 12-5. Scott River baseflow indices

13 Rosa

The Rosa Brook Surface Water Management Sub-area (Whicher catchment Rosa 35) (Figure 2-2 and Figure 2-3) currently has one streamflow gauging station operating: Crouch Road (609001) in the middle of the catchment operated from 1968 to 1979 and was recently reopened in July 2003 (Figure 2-6 and Figure 13-1). The Sub-area is located in State forest and is fully forested. Rosa Brook is fresh (Mayer et al, 2005).

13.1 Annual flow

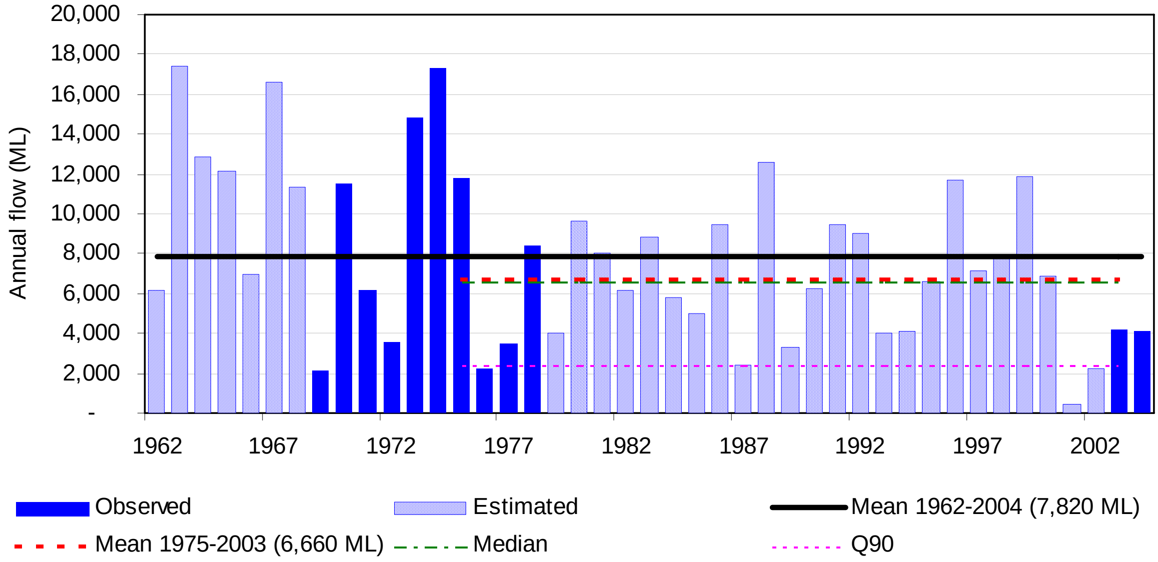


Figure 13-1. Rosa Brook at Crouch Road (609001) annual flow

The observed coefficient of variation (CV) at Crouch Road (609001) is 0.70, and for the period 1975-2003 it is 0.49, indicating a relatively high variability in annual flow in Rosa Brook. The maximum and minimum recorded annual flows are 17,400 ML and 2,180 ML respectively. The mean annual flow (MAF) estimate for the period 1975 to 2003 is 6,660 ML (Table 13-1), a reduction of 19 per cent compared to 1962-1995.

The estimated MAF for the Rosa Brook Surface Water Management Sub-area is 22,300 ML.

Table 13-1. Rosa Brook mean annual flow

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
609001	89.2	7,820	8,230	6,660
Rosa Sub-area	299	–	–	*22,300*

Note: Figures in *italics* have been derived from areal scaling

13.2 Daily flow

Continuous flow period

Figure 7-2 shows the observed continuous flow period for each calendar year since 1975 for Rosa Brook at Crouch Road. Although the period of record is short, flow is ephemeral, generally commencing in June and stopping in December.

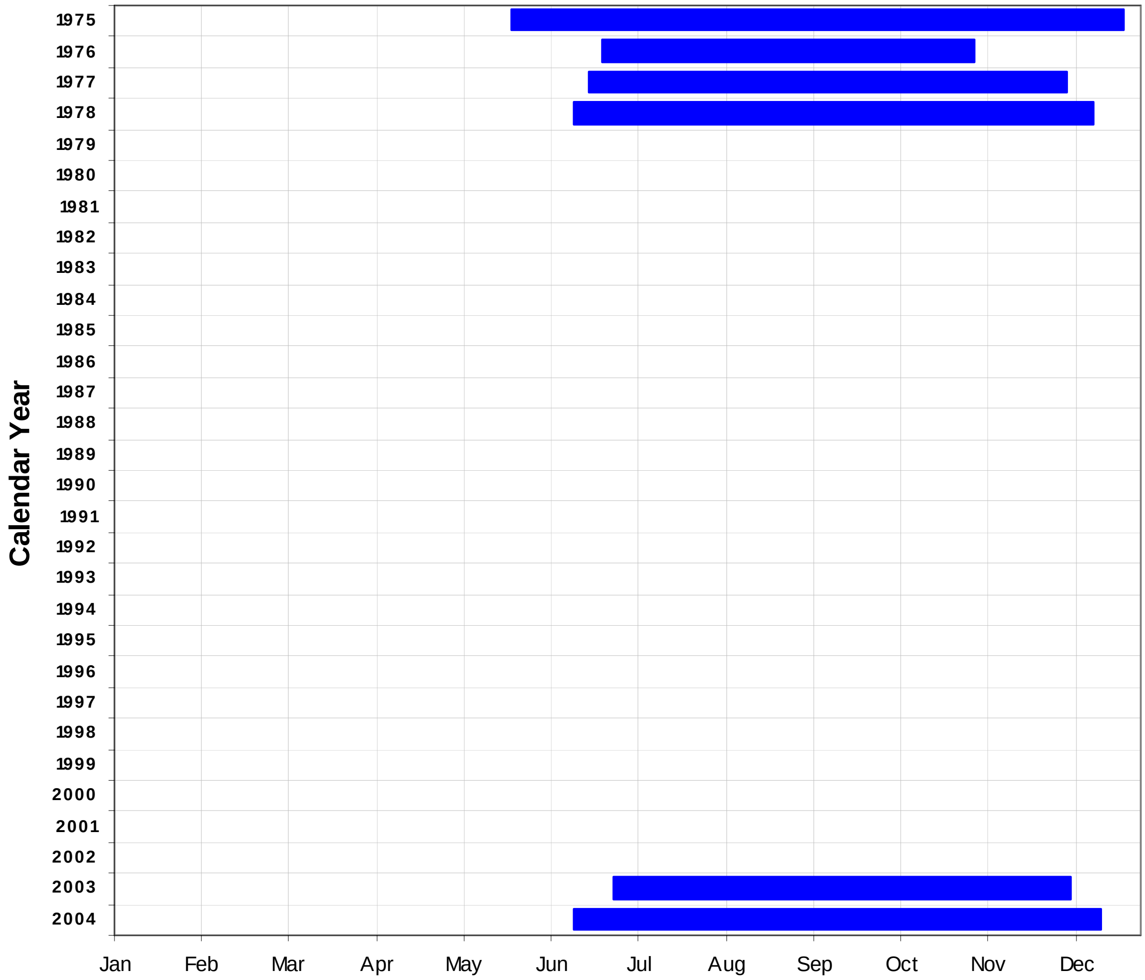


Figure 13-2. Rosa Brook at Crouch Road (609001) continuous flow period

Flow duration curves

The median flow duration curve (FDC) shows that Rosa Brook is ephemeral with 54 per cent of days having flow and a median daily flow of 2 ML at Crouch Road (Figure 13-3). The curve is very steep at the low-flow end, typical of forested catchments.

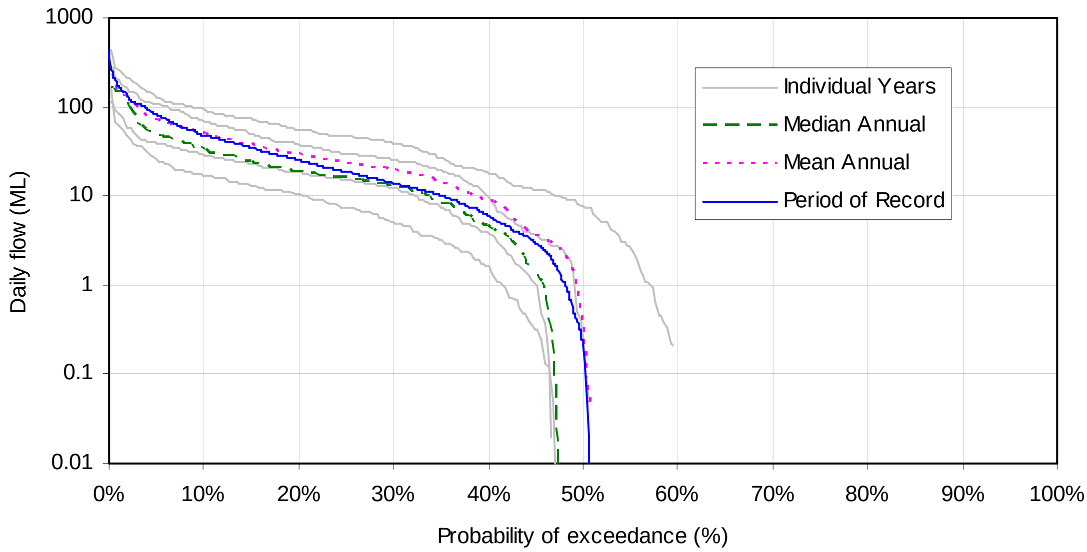


Figure 13-3. Rosa Brook at Crouch Road (609001) annual flow duration curves

Monthly flow duration analysis for Rosa Brook (Figure 13-4) shows that flow is continuous between July and October and the corresponding median daily flow is greater than 15 ML. Flow is not continuous for the other months and occurs less than 30 per cent of the time between December and April. Historically, there has been no flow during February to April.

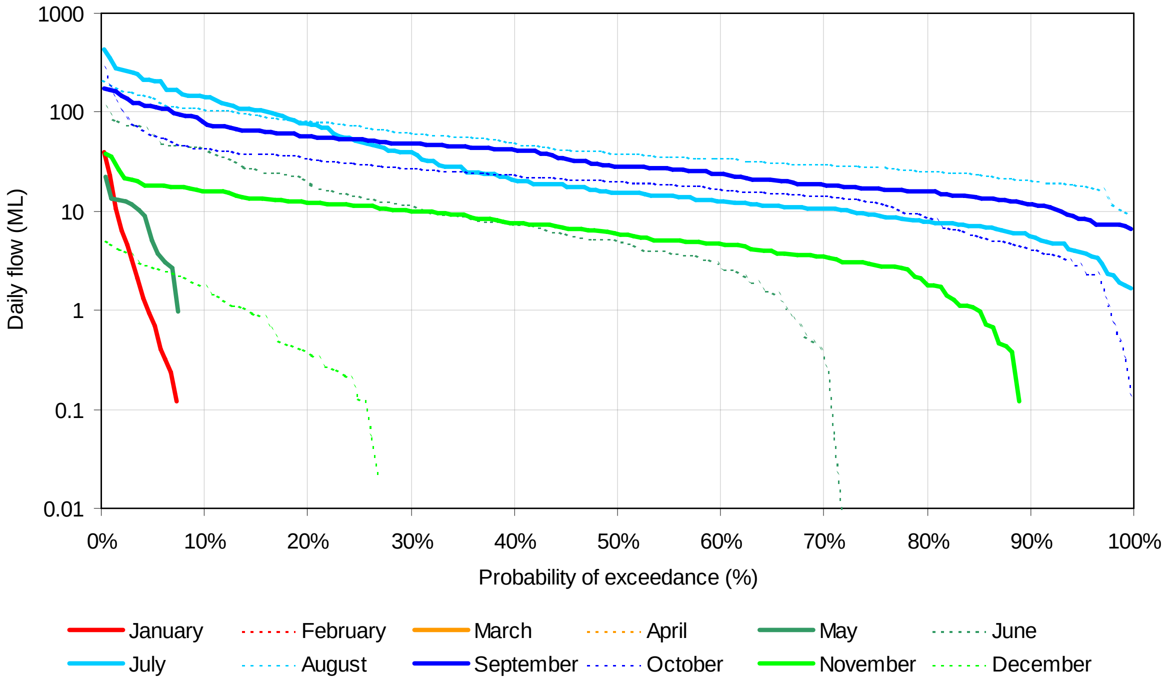


Figure 13-4. Rosa Brook at Crouch Road (609001) monthly flow duration curves

Baseflow analysis

The baseflow analysis indicated that on average, 39 per cent of the total annual flow at Crouch Road (609001) is derived from baseflow (ie a baseflow index of 39%) with a range of 35 to 44 per cent (Figure 13-5).

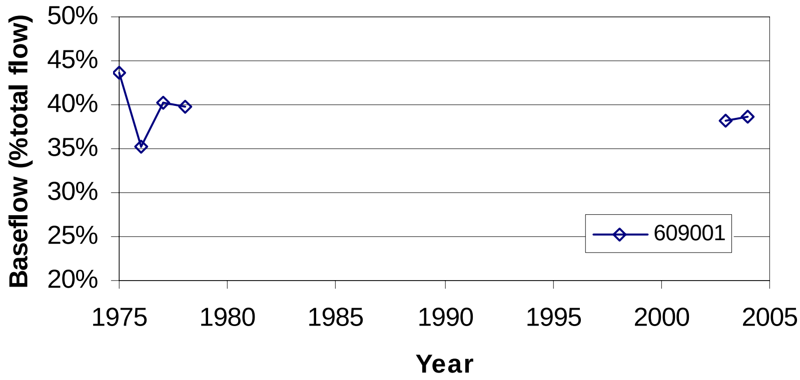


Figure 13-5. Rosa Brook baseflow indices

14 St John

The St John Brook Surface Water Management Sub-area (Whicher catchment St John 41) (Figure 2-2 and Figure 2-3) currently has one streamflow gauging station operating: Barrabup Pool (609018) at the downstream end of the catchment (Figure 2-6 and Figure 14-4). Historically, three other gauging stations have operated within the catchment:

- St Paul Brook at Dido Road (609004): 1974-2000 (Figure 14-1)
- St Paul Brook at Cambray (609003): 1974-2000 (Figure 14-2)
- Apostle Brook at Millbrook (609008): 1976-1999 (Figure 14-3).

The Sub-area is mostly forested (approximately 10% cleared). St John Brook and its tributaries are fresh (Mayer et al, 2005).

14.1 Annual flow

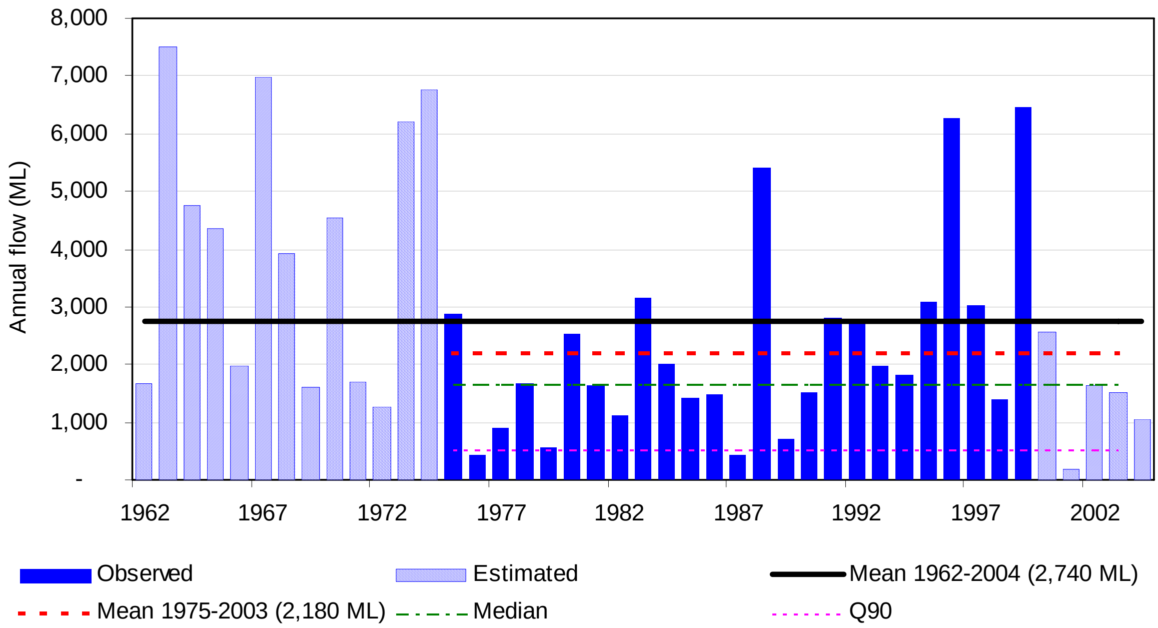


Figure 14-1. St Paul Brook at Dido Road (609004) annual flow

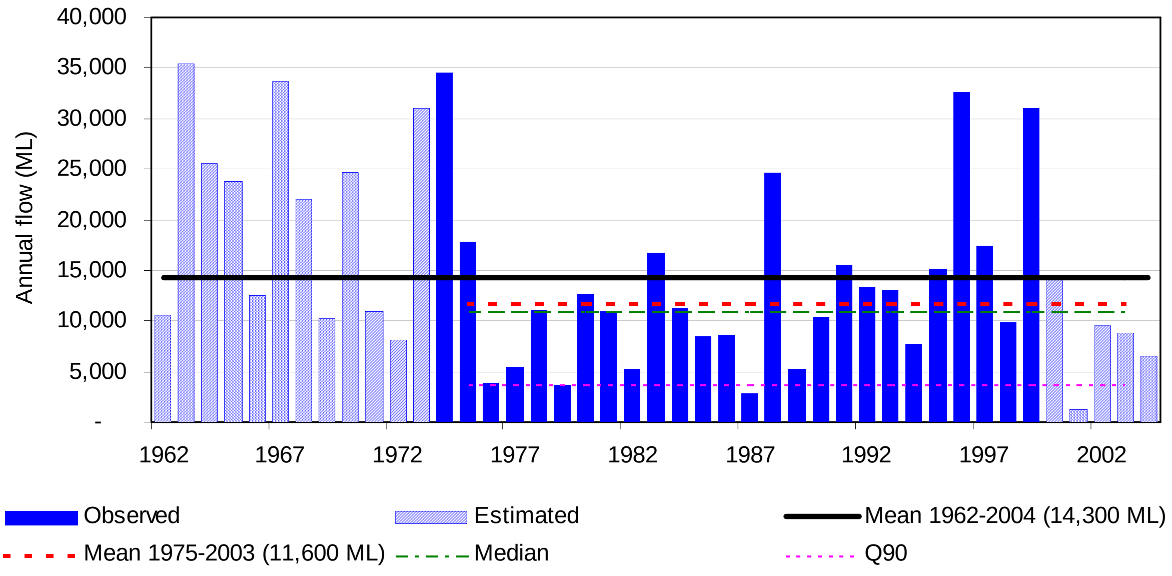


Figure 14-2. St Paul Brook at Cambray (609003) annual flow

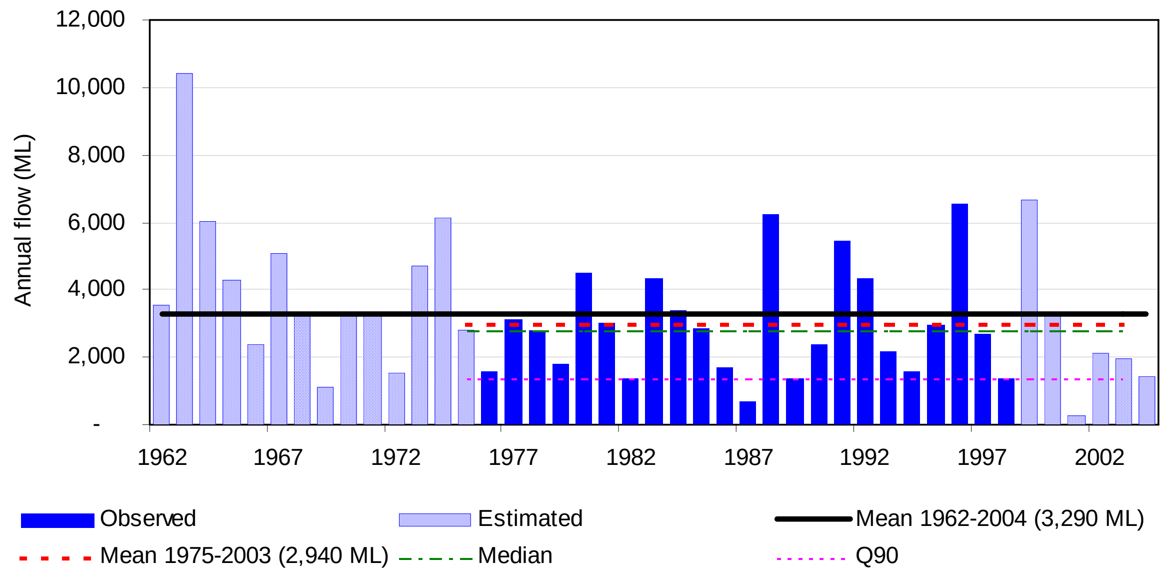


Figure 14-3. Apostle Brook at Millbrook (609008) annual flow

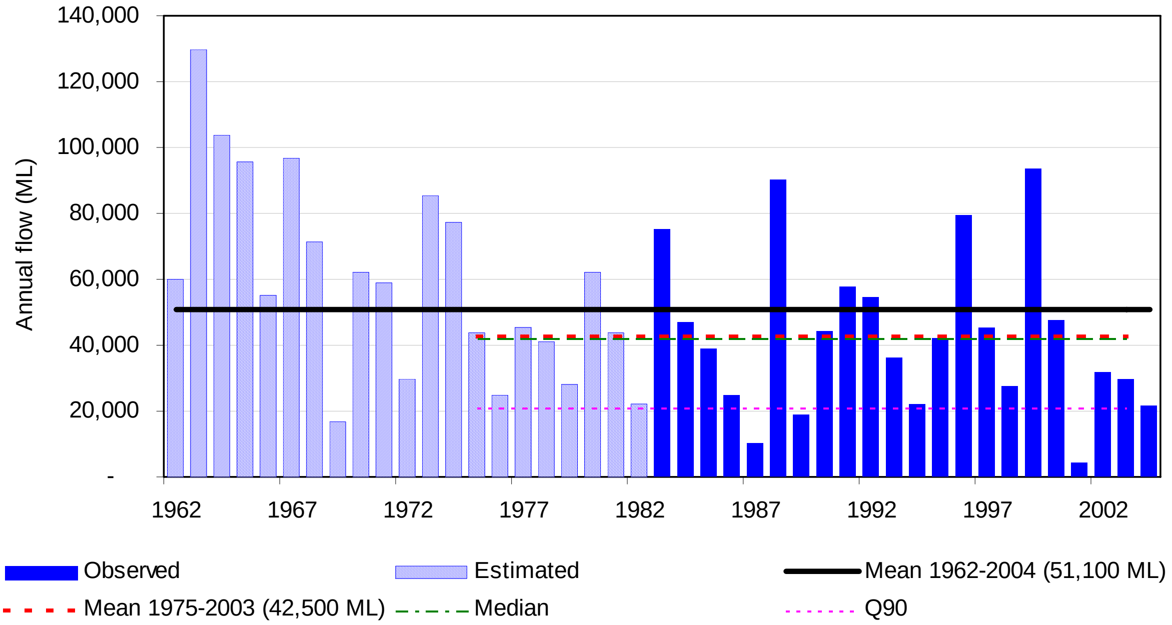


Figure 14-4. St John Brook at Barrabup Pool (609018) annual flow

Annual flow in the St John Sub-area is quite variable, especially in the upper reaches of the St Paul Brook. The observed coefficients of variation (CVs) range from 0.54 to 0.72, and there is a large difference between the minimum and maximum observed flows (Table 14-1).

The mean annual flow (MAF) estimates for the period 1975 to 2003 are 2,180 ML and 11,600 ML for St Paul Brook at Dido Road and Cambray respectively (Table 14-2), a reduction of 21 per cent compared to 1962-1995. The mean annual flow estimate for 1975 to 2003 for Apostle Brook at Millbrook is 6,580 ML (Table 14-2), a reduction of 13 per cent, compared to 1962-1995. The mean annual flow estimate for 1975 to 2003 for St John Brook at Barrabup Pool is 93,400 ML (Table 14-2), a reduction of 20 per cent, compared to 1962-1995. The reduction for Apostle Brook is less than for the other sites, possibly due to differing geology in the catchments.

The estimated MAF for the St John Surface Water Management Sub-area and catchment is 47,600 ML.

Table 14-1. St John Brook Sub-area CVs, and minimum and maximum flows

		Coeff. of Variability		Observed Flow (ML/a)	
River	**Station**	**Observed**	**1975-2003**	**Min.**	**Max.**
St Paul Brook	Dido Road (609004)	0.72	0.73	433	6,460
St Paul Brook	Cambray (609003)	0.65	0.67	2,830	34,600
Apostle Brook	Millbrook (609008)	0.54	0.58	677	6,580
St John Brook	Barrabup Pool (609018)	0.57	0.51	4,210	93,400

Table 14-2. St John Brook Sub-area mean annual flow

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
609004	26.0	2,740	2,750	2,180
609003	162	14,300	14,700	11,600
609008	27.6	3,290	3,390	2,940
609018	552	51,100	53,400	42,500
St John Sub-area	619	–	–	*47,600*

Note: Figures in *italics* have been derived from areal scaling

14.2 Daily flow

Continuous flow period

Figure 14-5 to Figure 14-8 show the observed continuous flow period for each calendar year since 1975 in the St John Brook Sub-area. Flow is ephemeral in St Paul Brook, generally starting in May and stopping in December at Dido Road and generally starting in June and stopping in January at Cambray, further downstream. Flow is also ephemeral in Apostle Brook, generally starting in June and stopping in December at Millbrook. At Barrabup Pool on the mainstream channel of St John Brook, flow is perennial.

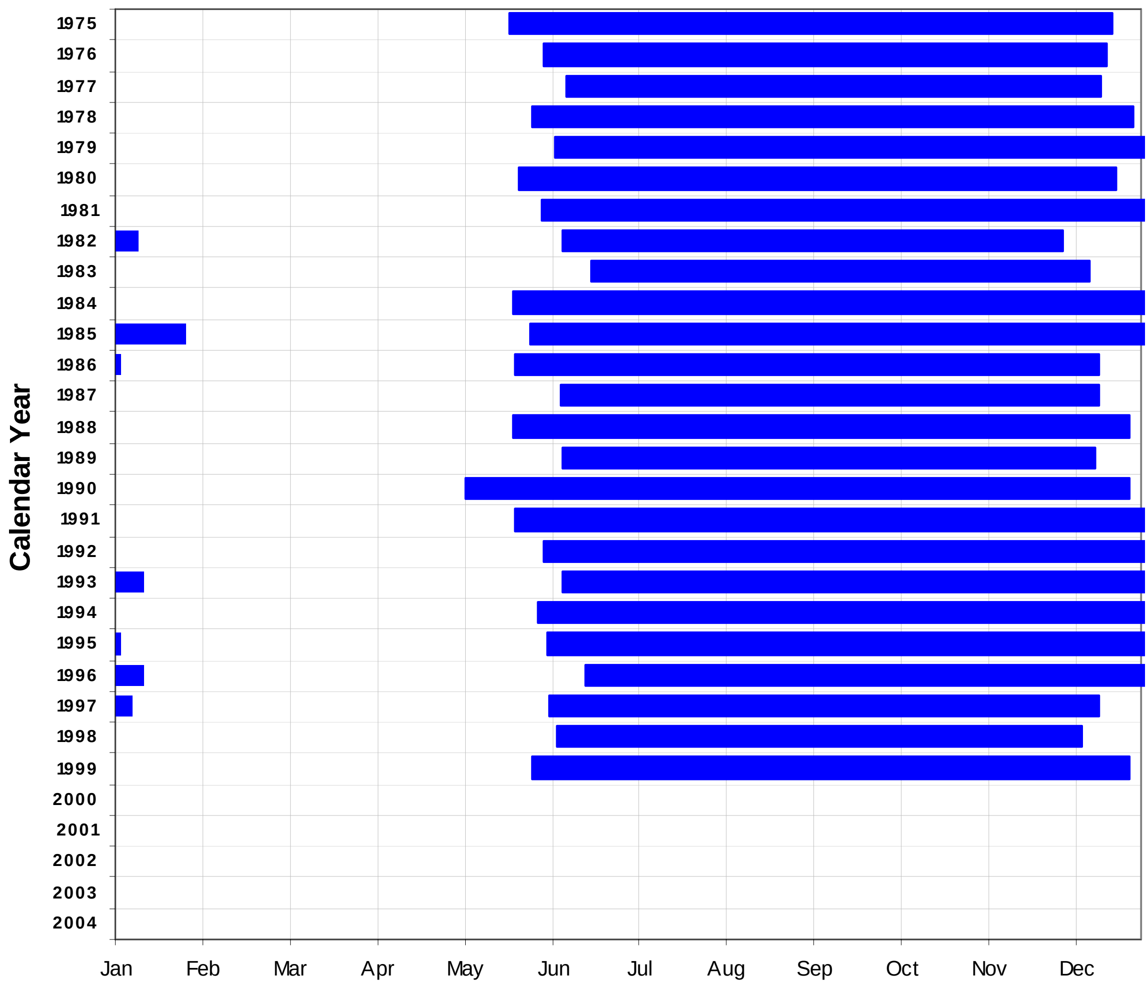


Figure 14-5. St Paul Brook at Dido Road (609004) continuous flow period

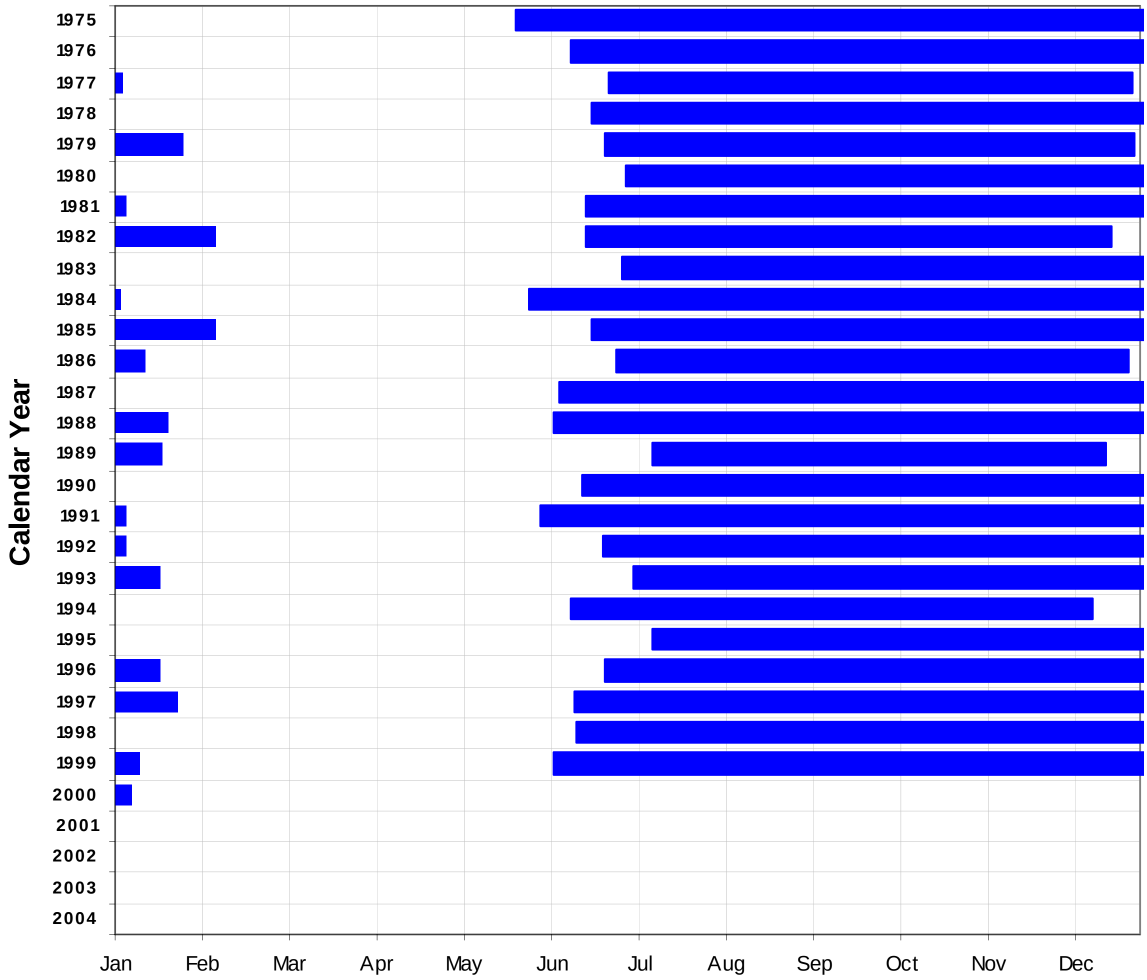


Figure 14-6. St Paul Brook at Cambray (609003) continuous flow period

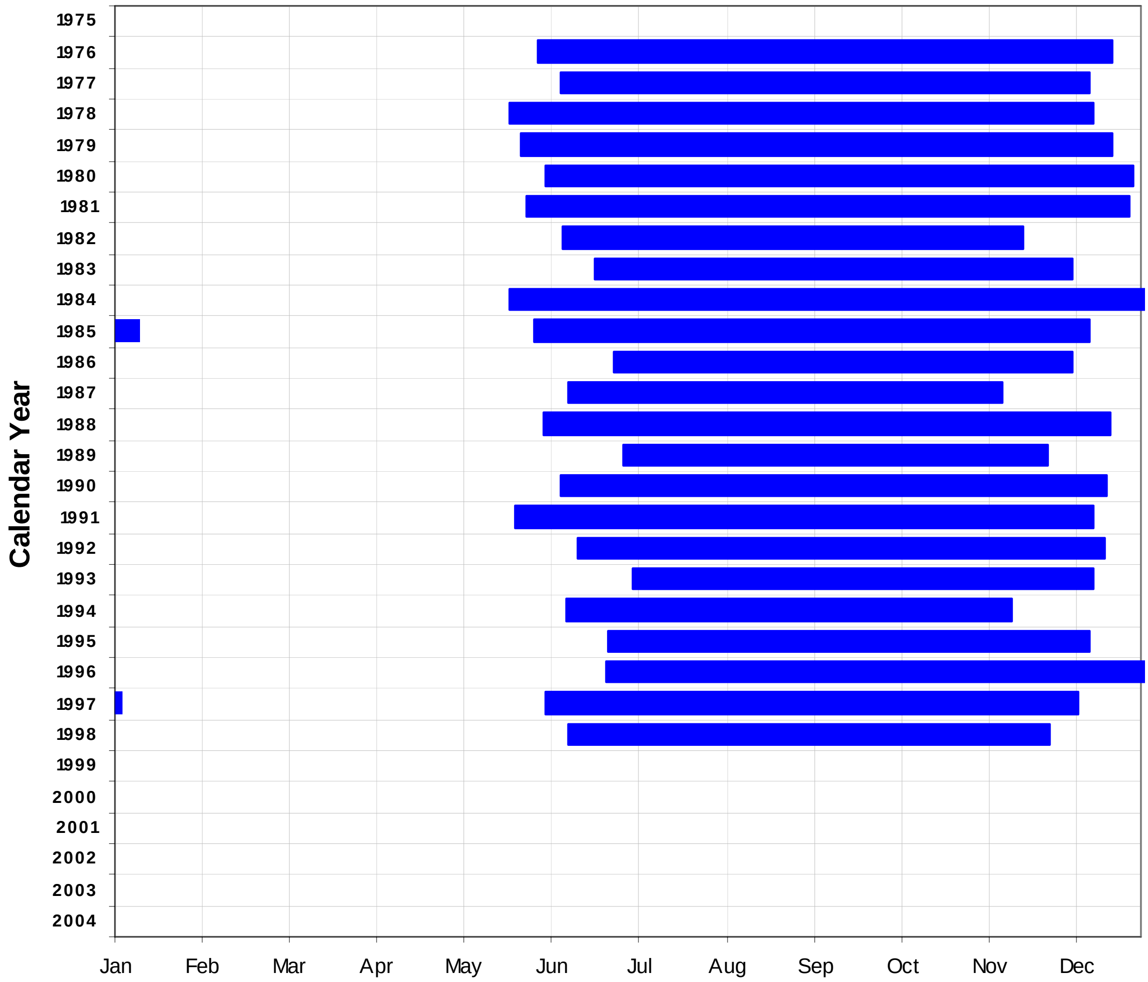


Figure 14-7. Apostle Brook at Millbrook (609008) continuous flow period

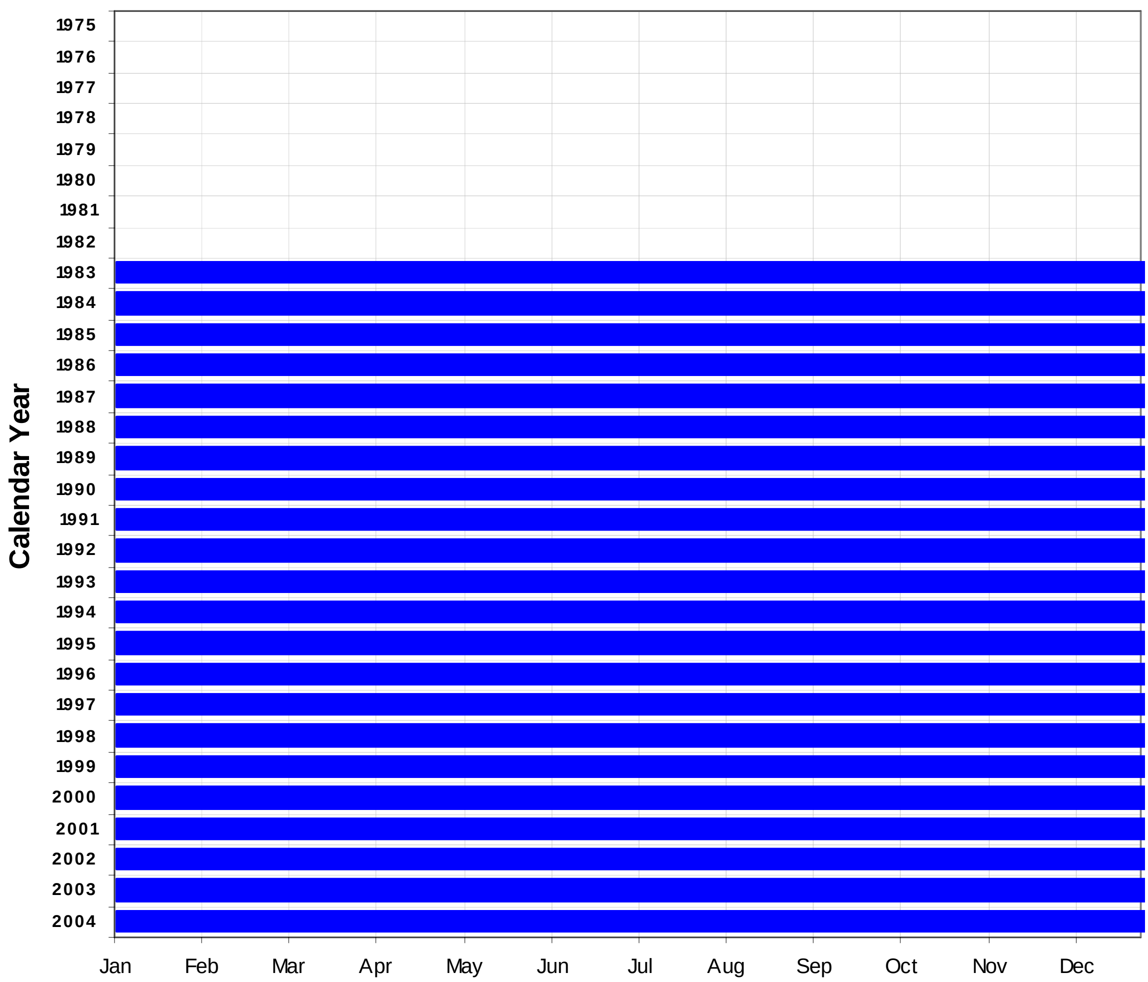


Figure 14-8. St John Brook at Barrabup Pool (609018) continuous flow period

Flow duration curves

The median annual flow duration curves (FDCs) for St Paul Brook at Dido Road (Figure 14-9) and Cambray (Figure 14-10) are similar. The curves show that streamflow is ephemeral and 57 per cent and 54 per cent of days have flow, at Dido Road and Cambray respectively. The median daily flow is 0.4 ML and 1.1 ML at Dido Road and Cambray respectively. At Millbrook on Apostle Brook (Figure 14-11), flow occurs less than 50 per cent of the time; therefore, the median daily flow is 0 ML.

The FDC for the mainstream channel of St John Brook at Barrabup Pool (Figure 14-12) shows that the stream is perennial with a median and minimum daily flow of 3.1 ML and 0.40 ML respectively. The slope of the curve is very shallow at the low-flow end, indicating large groundwater contributions, which are from the Leederville Aquifer.

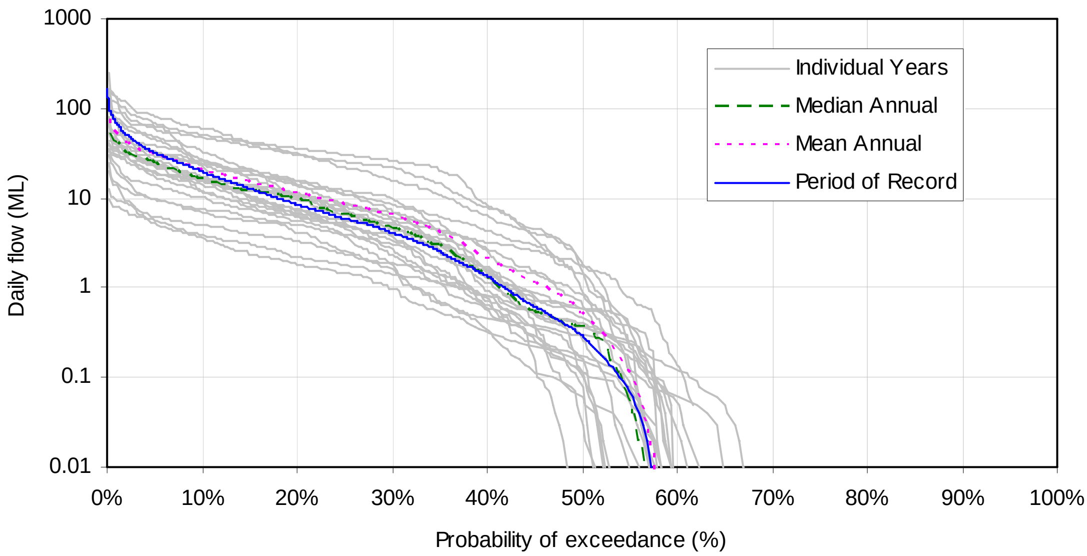


Figure 14-9. St Paul Brook at Dido Road (609004) annual flow duration curves

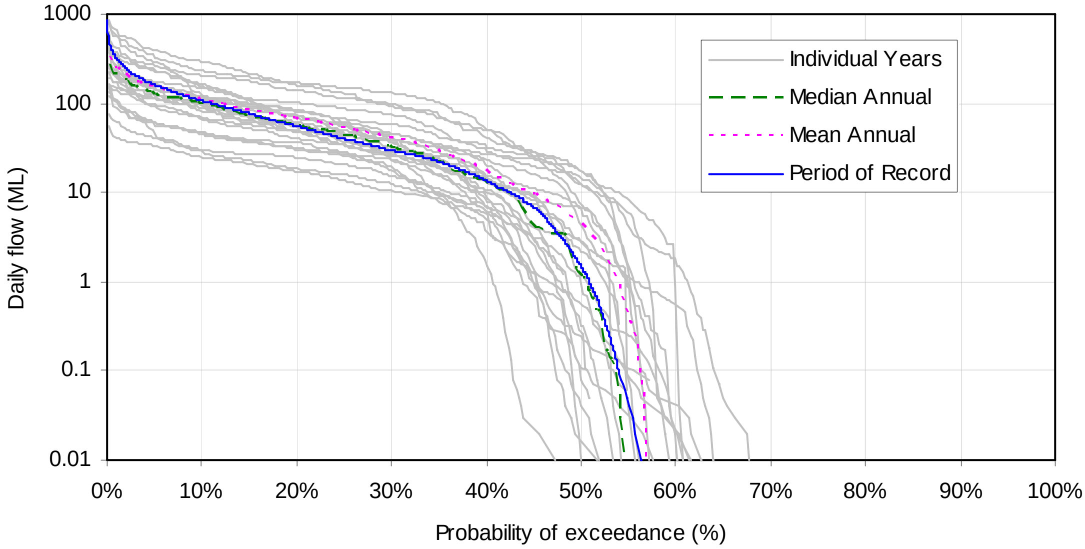


Figure 14-10. St Paul Brook at Cambray (609003) annual flow duration curves

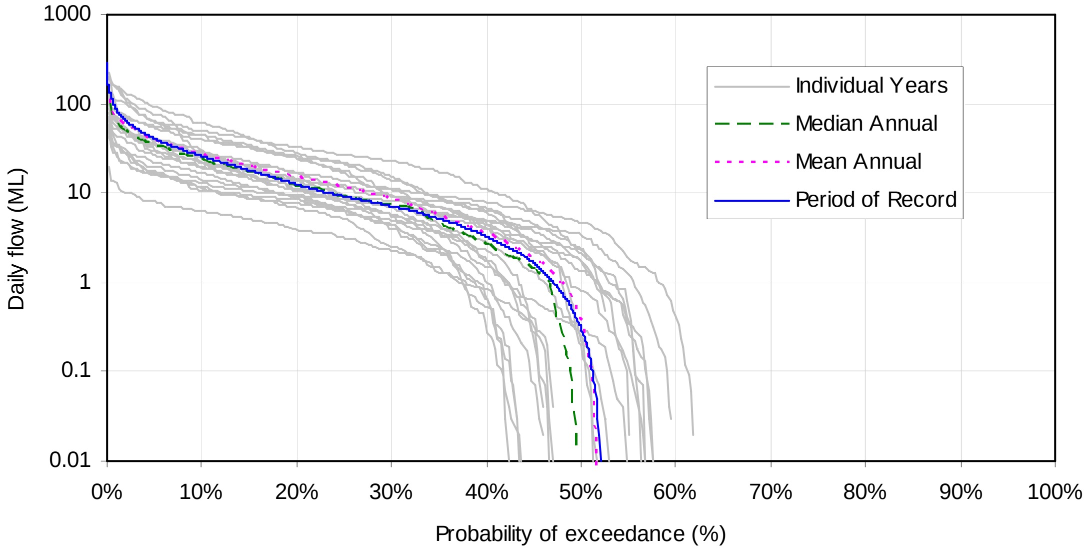


Figure 14-11. Apostle Brook at Millbrook (609008) annual flow duration curves

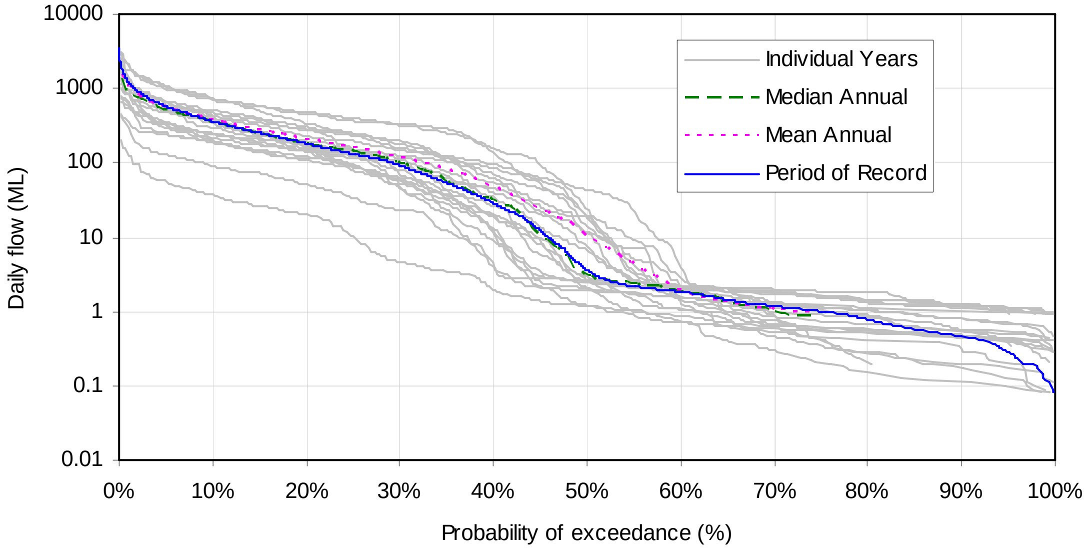


Figure 14-12. St John Brook at Barrabup Pool (609018) annual flow duration curves

Monthly flow duration analysis for St Paul Brook (Figure 14-13 and Figure 14-14) shows that flow is ephemeral. Flow is continuous between July and November, with a corresponding median daily flow greater than 6.4 ML and 18 ML at Dido Road and Cambray respectively. Flow is not continuous for the other months and historically there has been no flow between February and April at Dido Road and between March and April at Cambray.

Monthly flow duration analysis for Apostle Brook (Figure 14-15) shows that flow is highly ephemeral. Flow is continuous between August and October, with a corresponding median daily flow greater than 8.1 ML at Millbrook. Flow is not continuous for the other months and historically there has been no flow between February and April.

Monthly flow duration analysis for St John Brook at Barrabup Pool (Figure 14-16) shows that flow is continuous throughout the year and the corresponding median daily flow is greater than 0.57 ML; however, the median daily flow for the period July to November is greater than 28 ML. A minimum daily flow of 0.08 ML is maintained throughout the year.

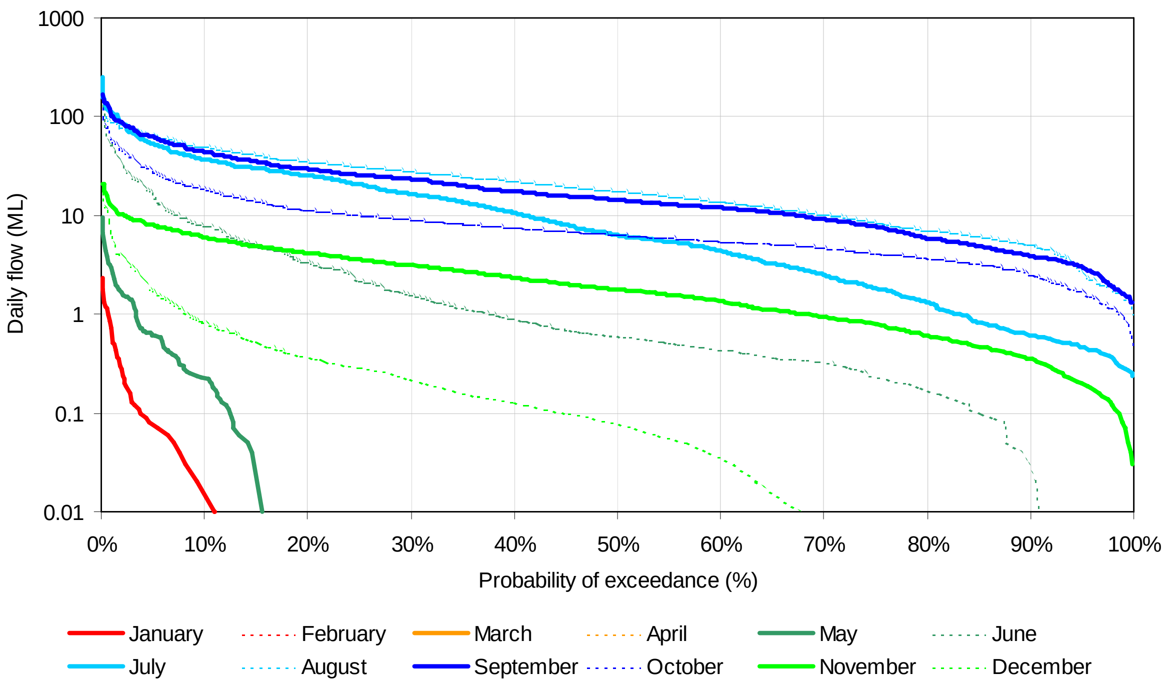


Figure 14-13. St Paul Brook at Dido Road (609004) monthly flow duration curves

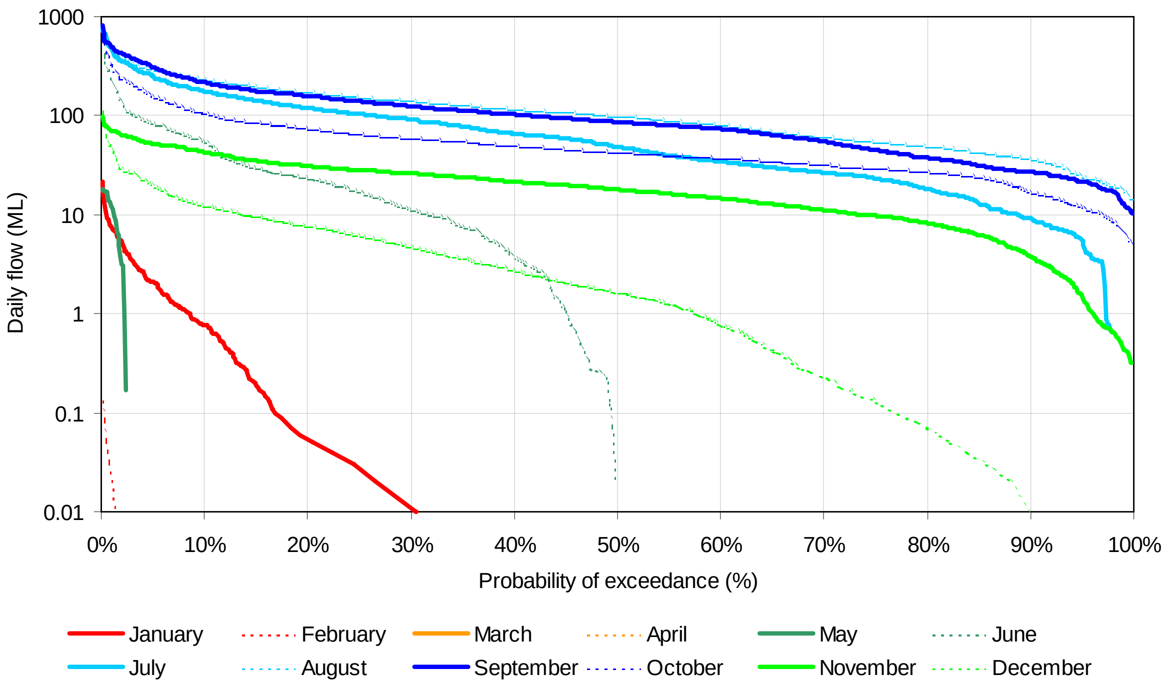


Figure 14-14. St Paul Brook at Cambray (609003) monthly flow duration curves

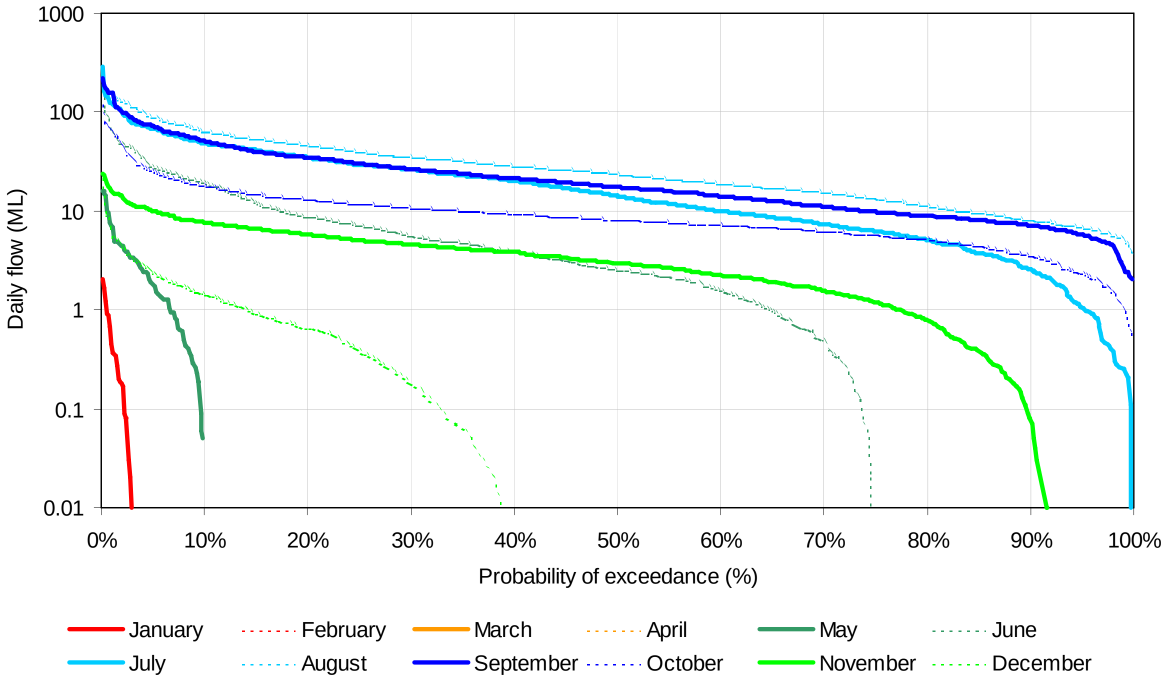


Figure 14-15. Apostle Brook at Millbrook (609008) monthly flow duration curves

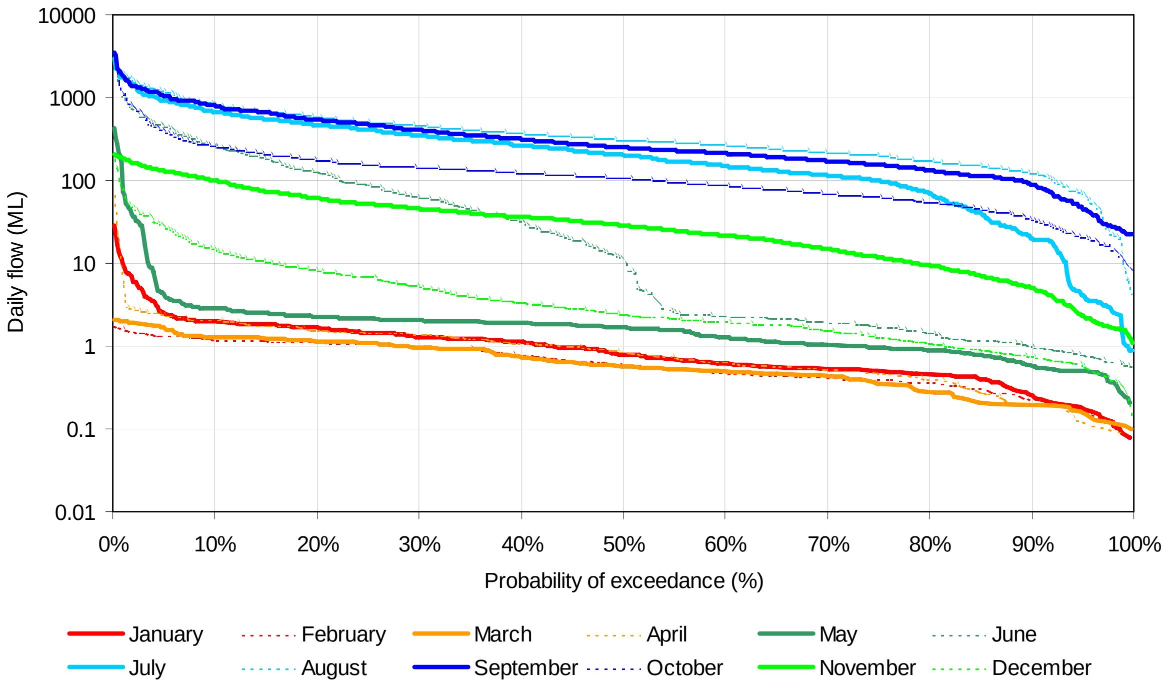


Figure 14-16. St John Brook at Barrabup Pool (609018) monthly flow duration curves

Baseflow analysis

The baseflow analysis for St Paul Brook (610016) (Figure 14-17) indicated that on average, 39 per cent of the total annual flow is derived from baseflow (ie a baseflow index of 39%), with a range from 32 to 43 per cent (complete years) at Dido Road (609004). Further downstream at Cambray (609003), the baseflow index (BFI) is 41 per cent, with a range from 36 to 44 per cent.

The baseflow index for Apostle Brook at Millbrook (609008) is 40 per cent, exhibiting less variation than St Paul Brook, with a range of 34 to 42 per cent. The baseflow index for the mainstream channel of St John Brook at Barrabup Pool (609018) is 39 per cent, with a range of 33 to 42 per cent.

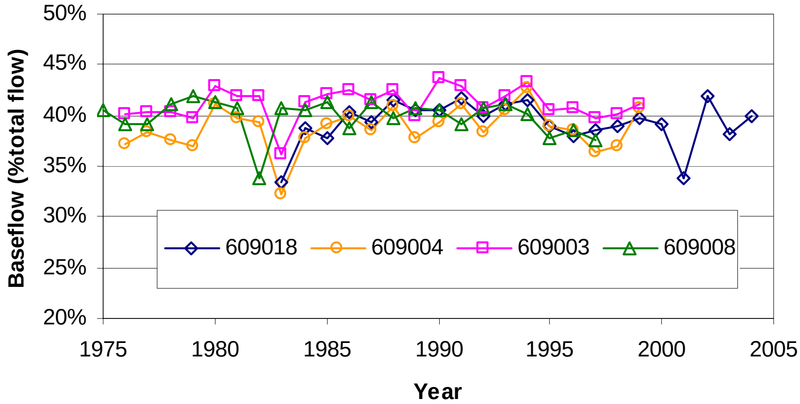


Figure 14-17. St John Sub-area baseflow indices

15 Barlee

The Barlee Brook Surface Water Management Sub-area (Whicher catchment Barlee 44) (Figure 2-2 and Figure 2-3) does not currently have any streamflow gauging stations operating. A station at Dickson Tower Road (608148) operated from 1962 to 1972 and was replaced by Upper Iffley (608001) in the middle of the catchment (Figure 15-3), which operated from 1972 to 2000 (Figure 2-6). Historically, two gauging stations also operated on a tributary of Easter Brook, in the upper reaches of the catchment:

- Easter Brook Tributary at Lewin North (608004): 1976-1997 (Figure 15-1)
- Easter Brook Tributary at Lewin South (608005): 1976-1997 (Figure 15-2).

The Barlee Sub-area is mostly forested (approximately 5% cleared). Barlee Brook and its tributaries are fresh (Mayer et al, 2005).

15.1 Annual flow

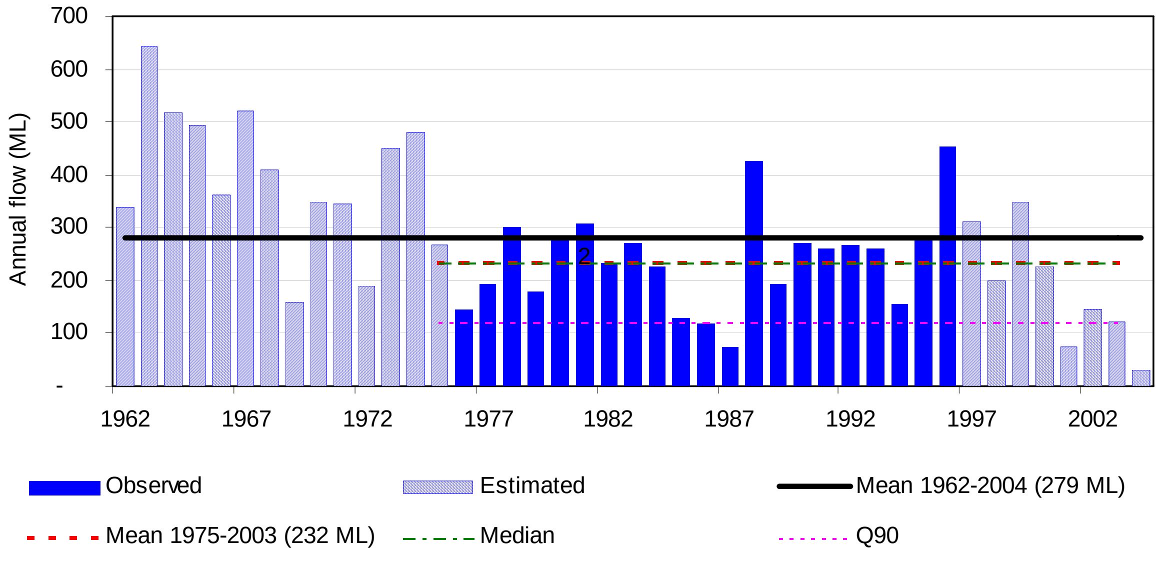


Figure 15-1. Easter Brook Tributary at Lewin North (608004) annual flow

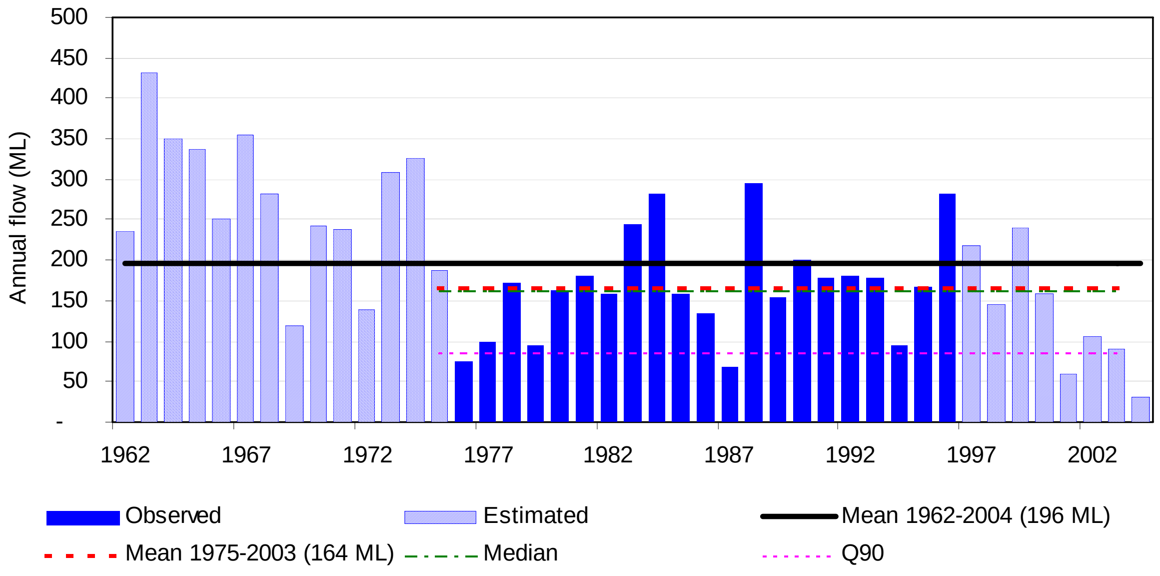


Figure 15-2. Easter Brook Tributary at Lewin South (608005) annual flow

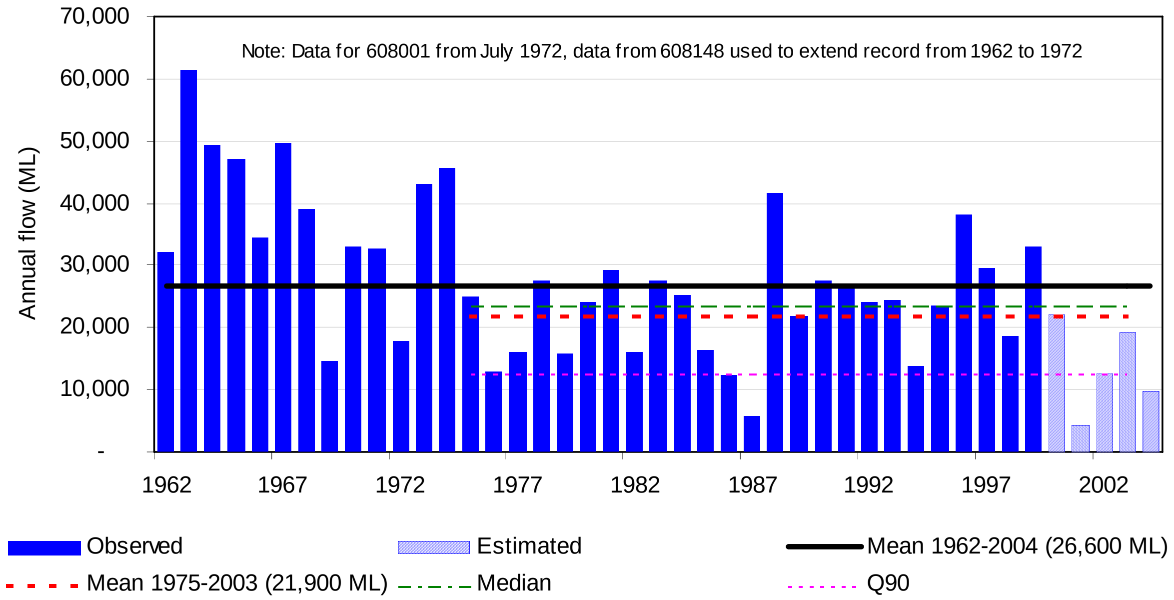


Figure 15-3. Barlee Brook at Upper Iffley extended (608148/001) annual flow

Variability in annual flow in the Barlee Brook Sub-area is moderate, as the coefficients of variation (CVs) range from 0.39 to 0.44 (Table 15-1). The mean annual flow (MAF) estimates for the period 1975 to 2003 are 232 ML and 164 ML for Easter Brook Tributary at Lewin North and Lewin South respectively (Table 15-2), a reduction of 22 and 21 per cent compared to 1962-1995. The mean annual flow estimate for 1975 to 2003 for Barlee Brook at Upper Iffley is 21,900 ML (Table 15-2), a reduction of 22 per cent, compared to 1962-1995.

The estimated MAF for the Barlee Surface Water Management Sub-area is 53,900 ML.

Table 15-1. Barlee Brook Sub-area CVs, and minimum and maximum flows

		Coeff. of Variability		Observed Flow (ML/a)	
River	**Station**	**Observed**	**1975-2003**	**Min**	**Max**
Easter Brook	Lewin North	0.39	0.40	75	453
Easter Brook	Lewin South	0.39	0.39	69	296
Barlee Brook	Upper Iffley	0.44	0.39	5,700	61,400

Table 15-2. Barlee Brook Sub-area mean annual flow

		Mean Annual Flow (ML)		
Location	**Area (km^2)**	**1962-2004**	**1962-1995**	**1975-2003**
608004	1.21	279	297	232
608005	0.82	196	208	164
608001	159	26,600	28,200	21,900
Barlee Sub-area	392	–	–	*53,900*

Note: Figures in *italics* have been derived from areal scaling

15.2 Daily flow

Continuous flow period

Figure 15-4 to Figure 15-6 show the observed continuous flow period for each calendar year since 1975 in the Barlee Brook Sub-area. Flow is highly ephemeral in Easter Brook Tributary, generally starting in June and stopping in December at Lewin North and generally starting in June and stopping in November at Lewin South. The continuous flow period for Barlee Brook at Upper Iffley is highly variable. Many years have continuous flow; however, shorter flow periods follow low-flow years.

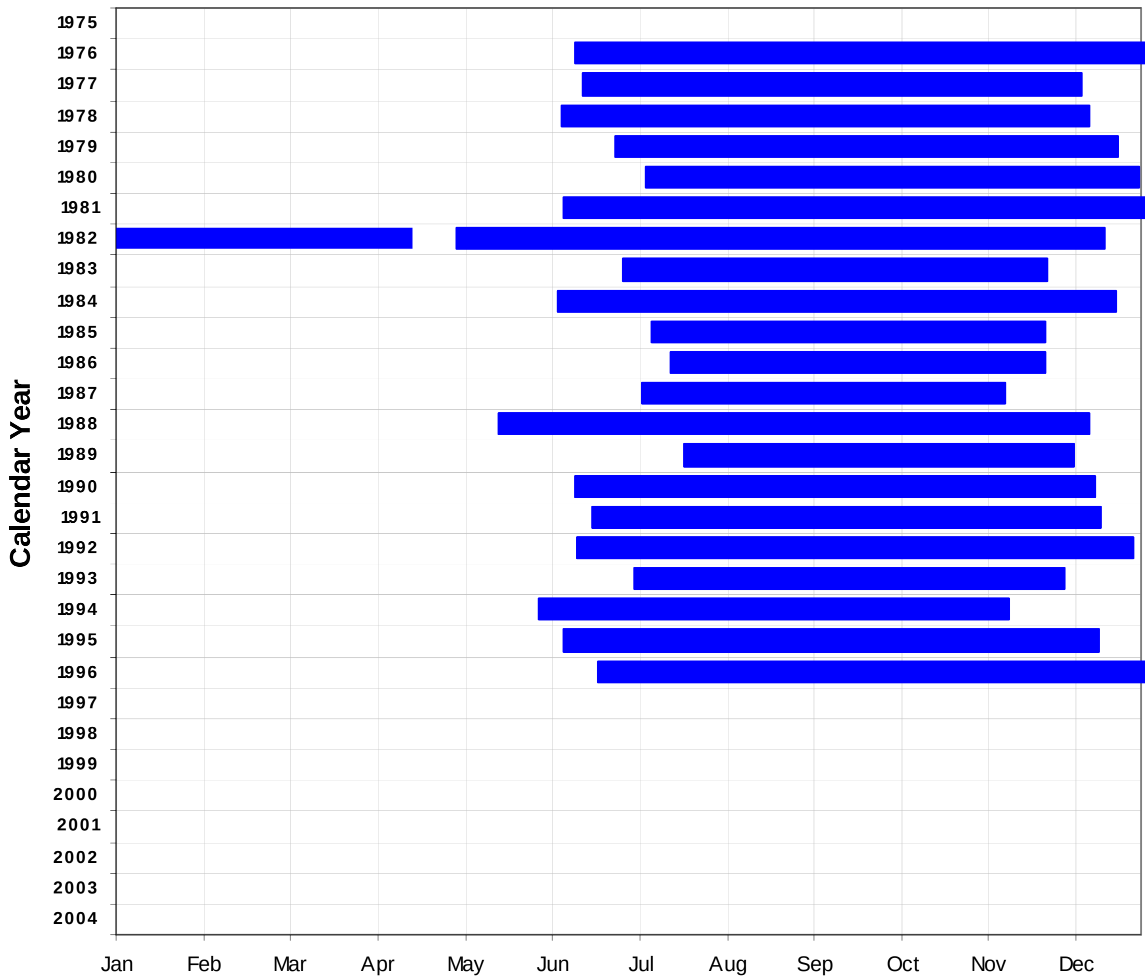


Figure 15-4. Easter Brook Tributary at Lewin North (608004) continuous flow period

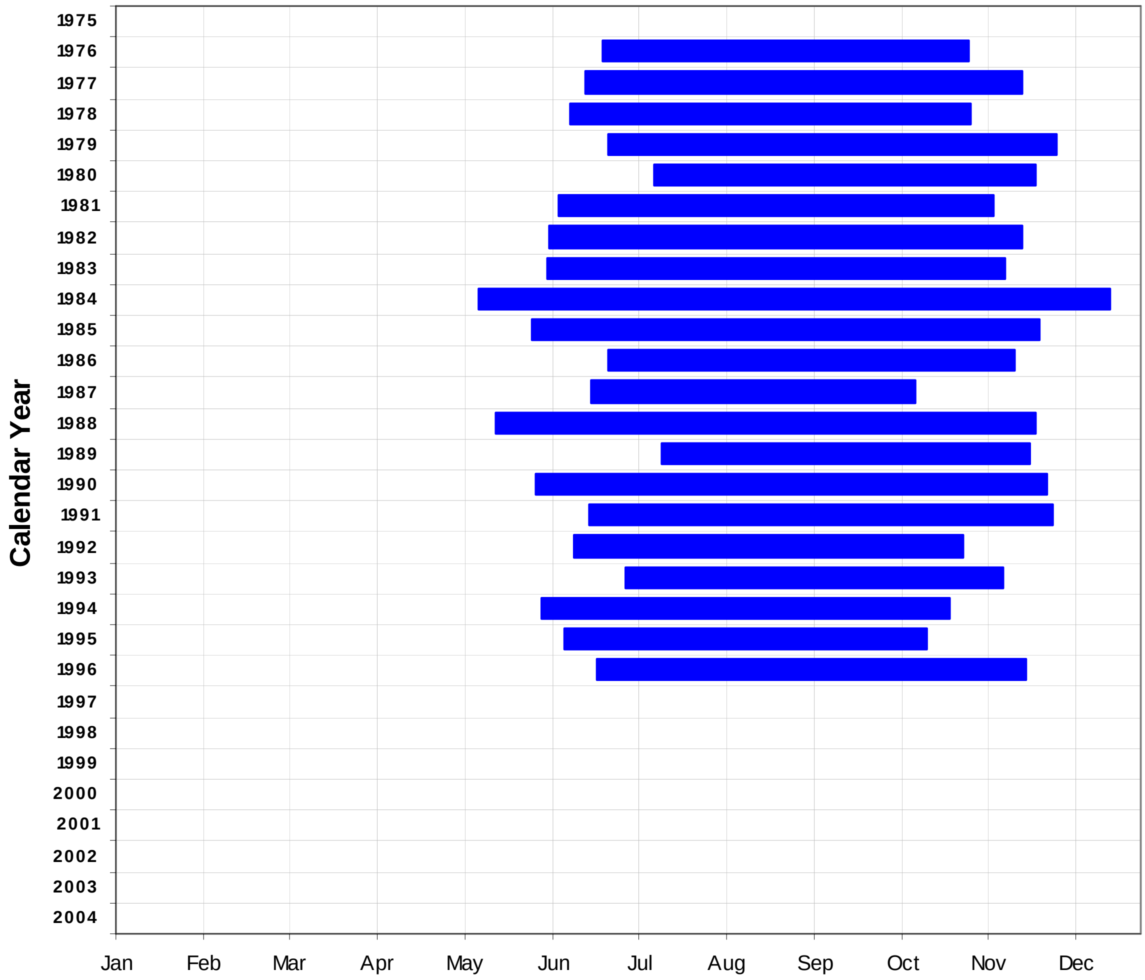


Figure 15-5. Easter Brook Tributary at Lewin South (608005) continuous flow period

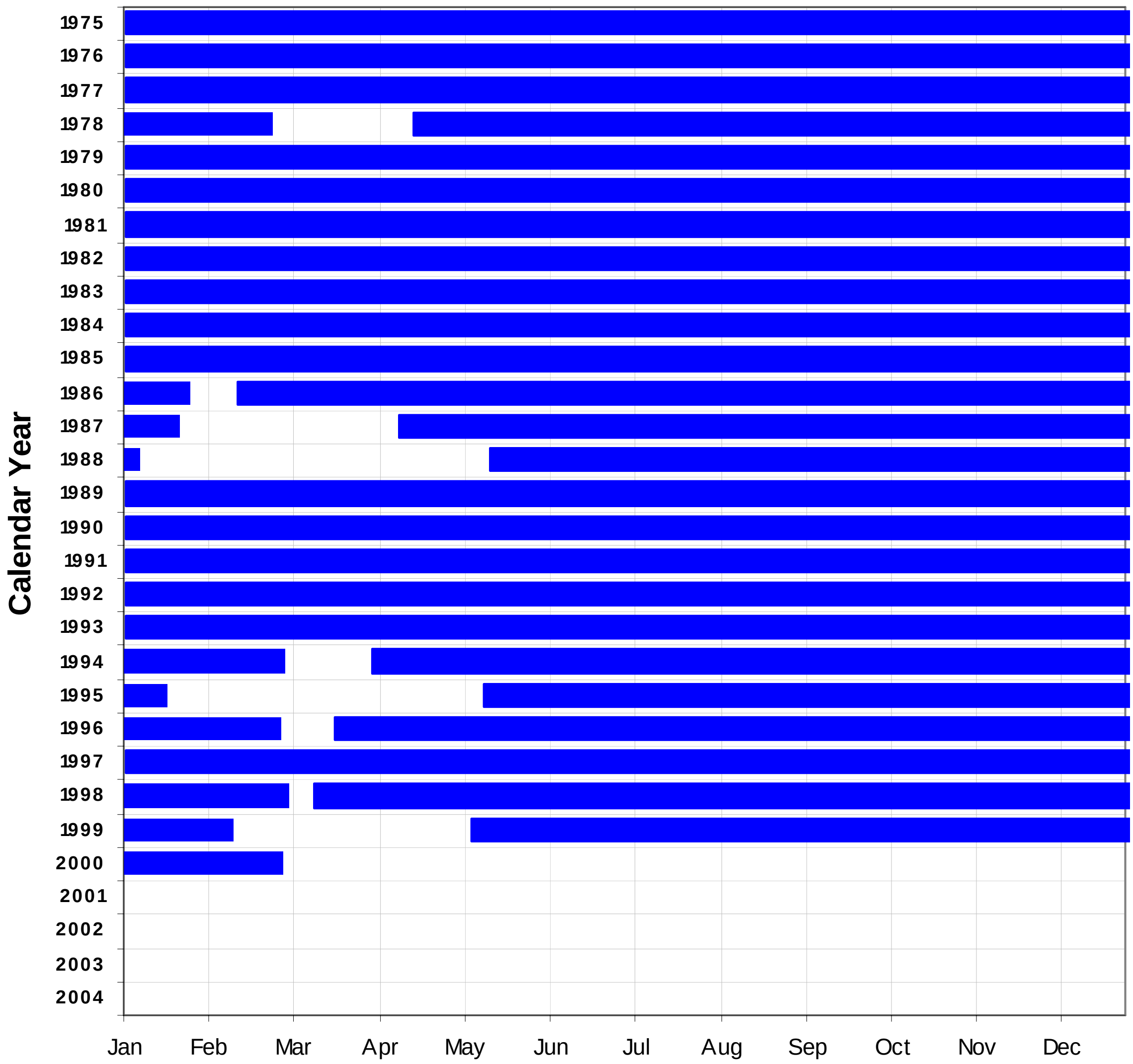


Figure 15-6. Barlee Brook at Upper Iffley (608001) continuous flow period

Flow duration curves

The median annual flow duration curves (FDCs) for Easter Brook Tributary show that streamflow is ephemeral with less than 50 per cent of days having flow at both Lewin North (Figure 15-7) and Lewin South (Figure 15-8); therefore, the median daily flow is 0 ML at both sites. The steepness of the curve is typical of small, forested catchments.

The FDC for Barlee Brook at Upper Iffley (Figure 15-9) shows that the streamflow occurs 94 per cent of the time, with a median daily flow of 13 ML. The slope of the curve is fairly shallow and constant, indicating a stable stream with large amounts of surface storage and groundwater contributions, which are from the Yarragadee Aquifer.

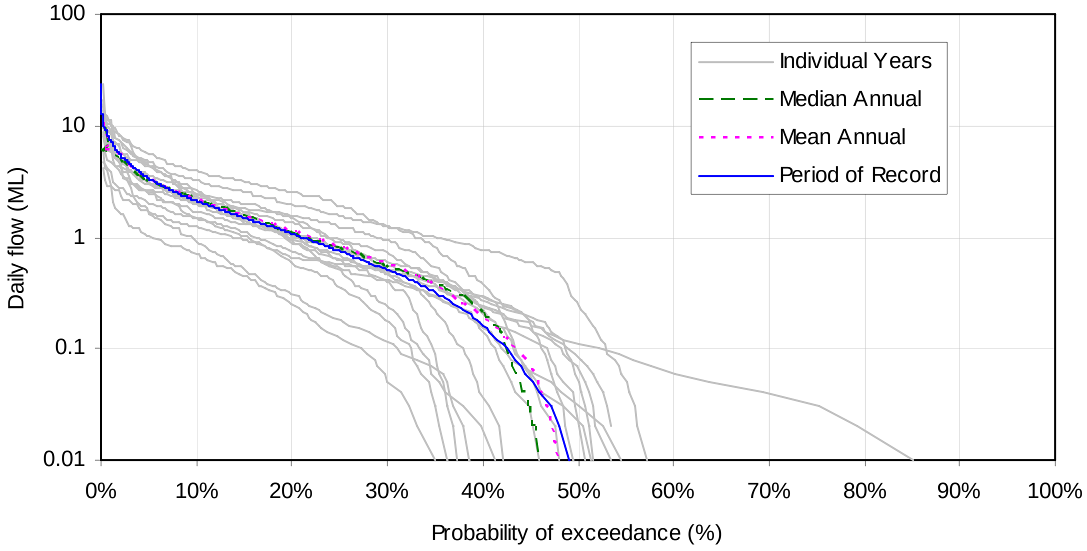


Figure 15-7. Easter Brook Tributary at Lewin North (608004) annual flow duration curves

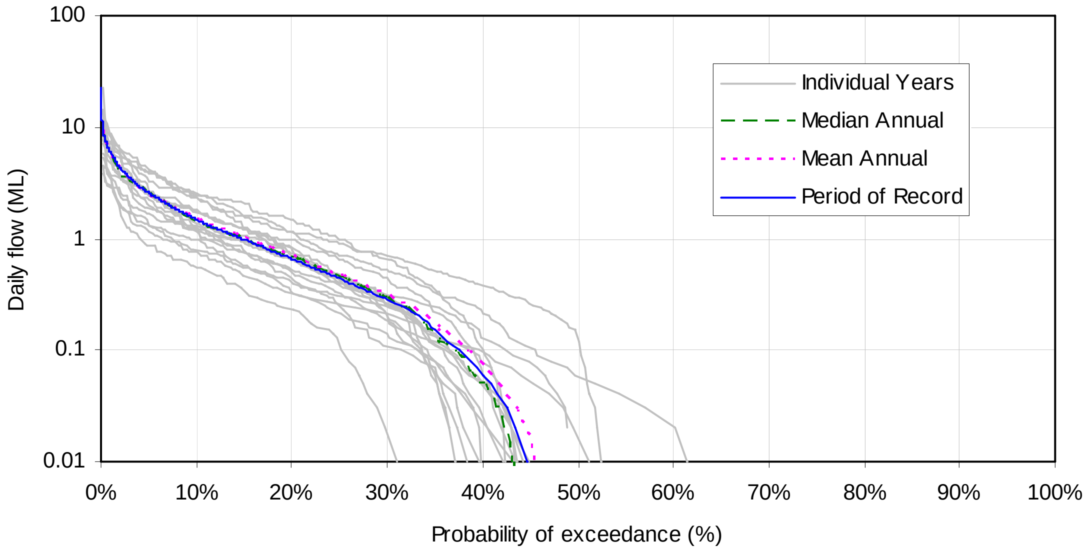


Figure 15-8. Easter Brook Tributary at Lewin South (608005) annual flow duration curves

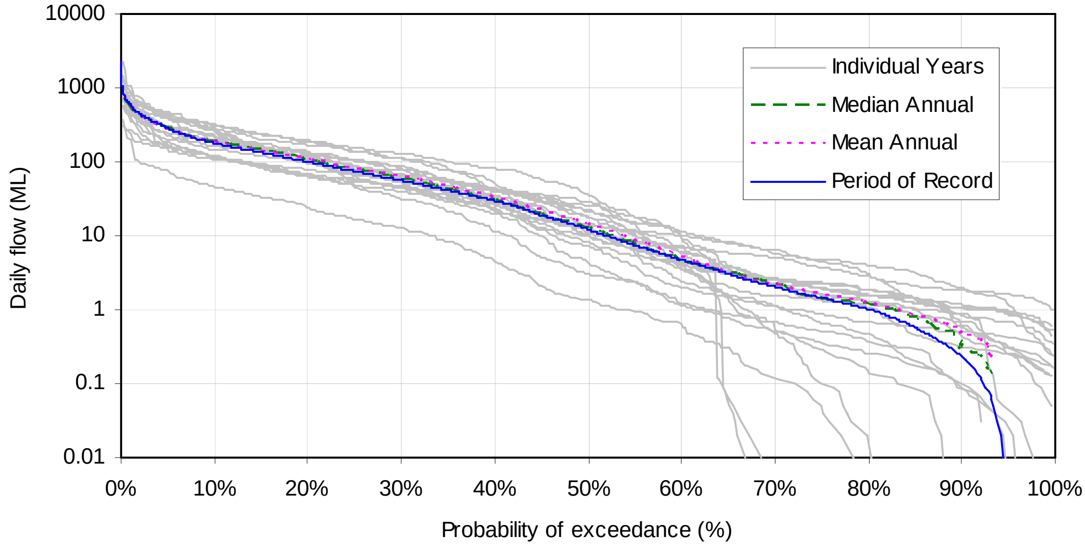


Figure 15-9. Barlee Brook at Upper Iffley (608001) annual flow duration curves

Monthly flow duration analysis for Easter Brook Tributary (Figure 15-10 and Figure 15-11) shows that flow is highly ephemeral. Flow is continuous between August and October at Lewin North, with a corresponding median daily flow greater than 0.46. Flow is not continuous for the other months and flow occurs less than 10 per cent of the time between January and May. Flow is continuous only in August at Lewin South, with a corresponding median daily flow greater than 1.1 ML. Flow is not continuous for the other months and flow occurs less than 10 per cent of the time between January and May. Historically, there has been no flow in March at Lewin South.

Monthly flow duration analysis for Barlee Brook (Figure 15-12) shows that flow is more regular throughout the year. Flow is continuous between June and December, with a corresponding median daily flow greater than 5.8 ML at Upper Iffley. Flow is not continuous for the other months; however, flow occurs at least 74 per cent of the time during these months with a median daily flow of at least 0.35 ML.

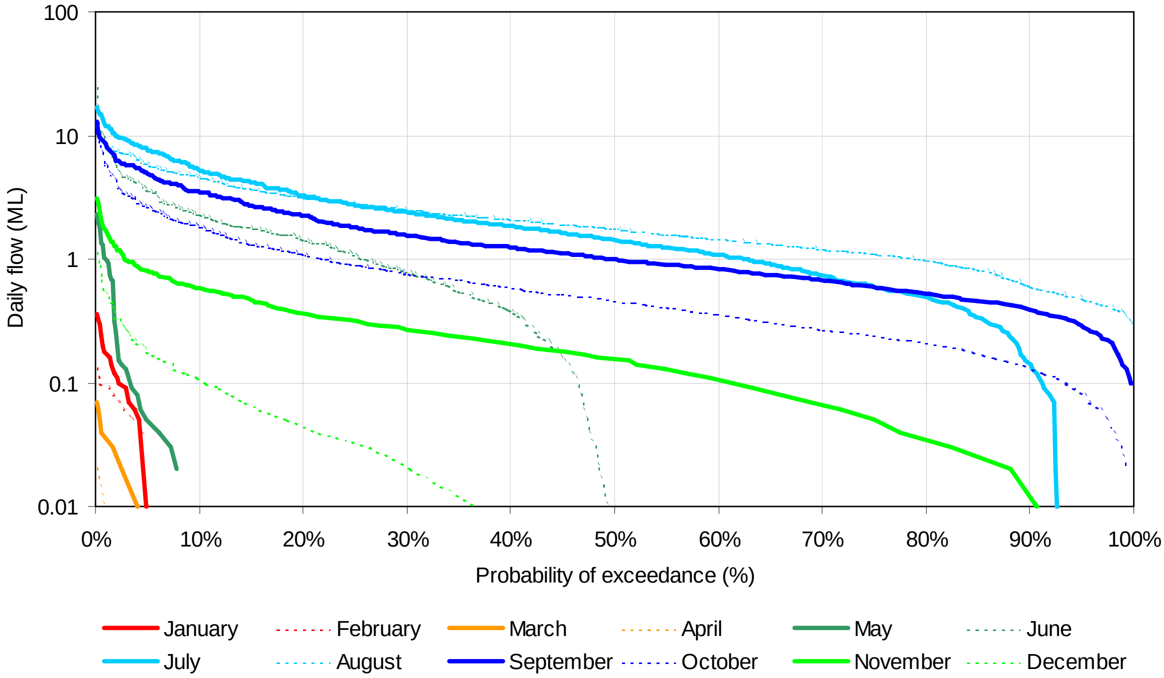


Figure 15-10. Easter Brook Tributary at Lewin North (608004) monthly flow duration curves

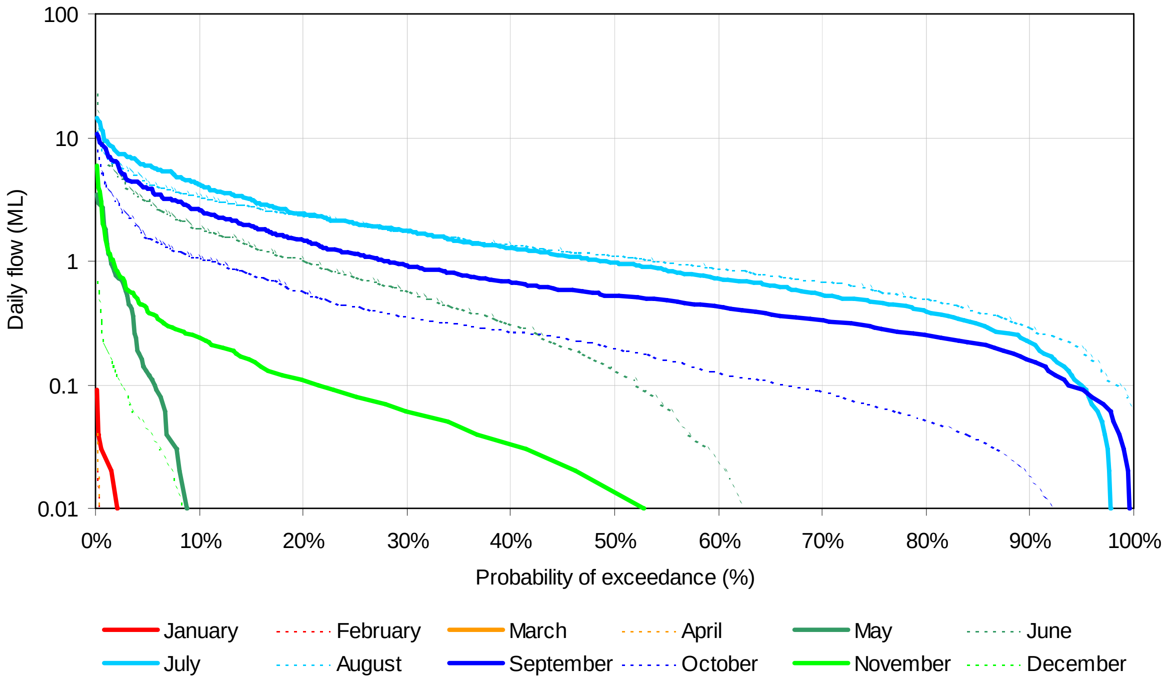


Figure 15-11. Easter Brook Tributary at Lewin South (608005) monthly flow duration curves

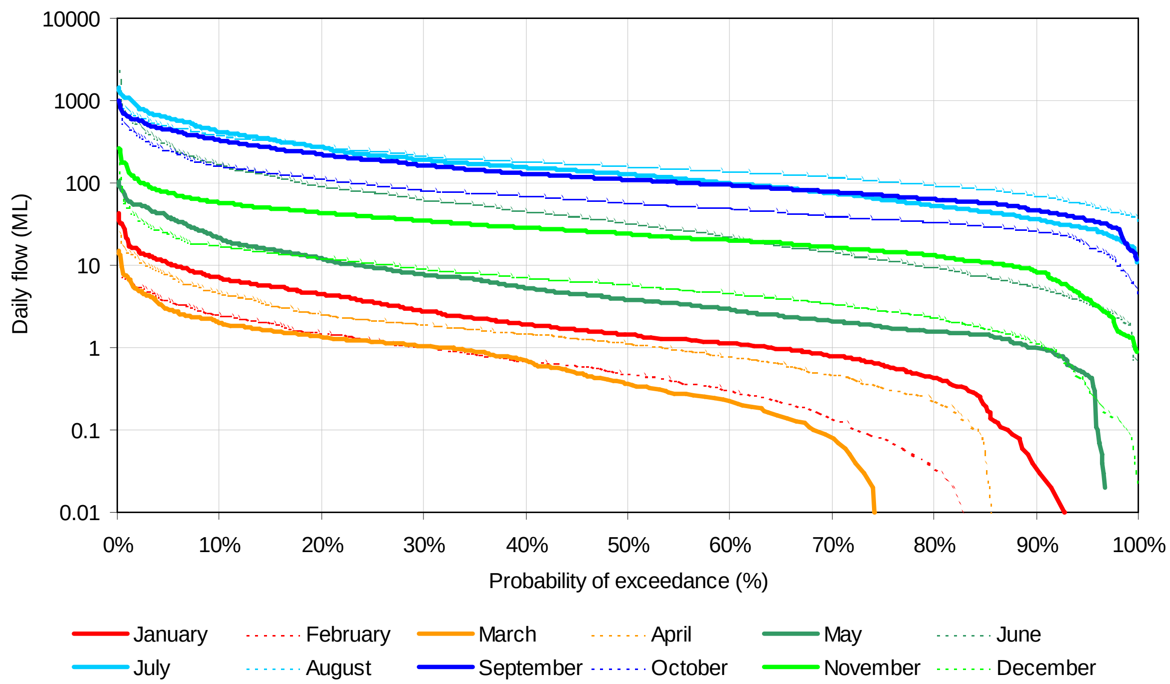


Figure 15-12. Barlee Brook at Upper Iffley (608001) monthly flow duration curves

Baseflow analysis

The baseflow analysis for Easter Brook Tributary (Figure 15-13), indicated that on average, 34 per cent of the total annual flow at Lewin North (608004) is derived from baseflow, with a range from 29 to 39 per cent. At Lewin South (608005), the baseflow index (BFI) is 29 per cent, with a range from 24 to 37 per cent. The baseflow index for Barlee Brook at Upper Iffley (608001) is 39 per cent, with a range of 33 to 43 per cent.

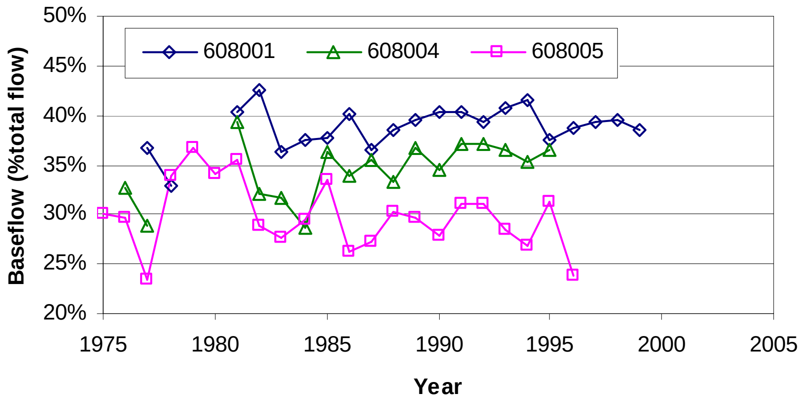


Figure 15-13. Barlee Sub-area baseflow indices

16 Discussion

This report summarises the available streamflow data from gauging stations in the Cape-to-Cape region of south-west Western Australia. The analyses use available streamflow data and indicate where good records are available and where there are gaps.

Annual rainfall has decreased by up to 10 per cent in the Cape-to-Cape region for the period 1975-2003 compared to long-term records. Annual streamflow has also declined for 1975-2003 compared to longer-term periods. In this study, mean annual flow for the period 1975-2003 was compared with mean annual flow for 1962-1995 as this latter period was used in the development of the REG6 model. The decrease in MAF from 1962-1995 to 1975-2003 ranges from eight to 36 per cent with an average of 20 per cent across the region.

Mean annual flows have been calculated for sub-areas using streamflow data where available (Table 16-1). The analyses show that streamflow is highly variable between catchments. Therefore, it is difficult to translate flow statistics from gauged catchments to ungauged catchments, as the catchments have different hydrologic regimes due to different geological, landuse and rainfall characteristics. Mean annual flows have been estimated for the ungauged subareas using the REG75 regional yield estimation model (Table 16-1).

Analysis of daily flow data has also yielded interesting results. The data from many streamflow gauging stations indicate that the continuous flow period is decreasing, which can impact on environmental flow requirements and licensing decisions such as when it is suitable to extract flow from streams. Other streams have more stable periods or are indicating increasing flow periods despite declining rainfall, suggesting groundwater interactions, streamflow regulation such as dam releases and land use change. (Table 16-1) provides the minimum flow period observed for each gauged catchment, which is the range from the latest start to the earliest ceasing of flow.

The information contained in this report provides a summary of current available streamflow data in the Cape-to-Cape region and the ramifications of using the period 1975 to 2003 for surface water allocation decisions. It is recommended that more detailed studies be undertaken for priority catchments and to investigate surface water – groundwater interactions, which are evident in some of the catchments in the Cape-to-Cape region.

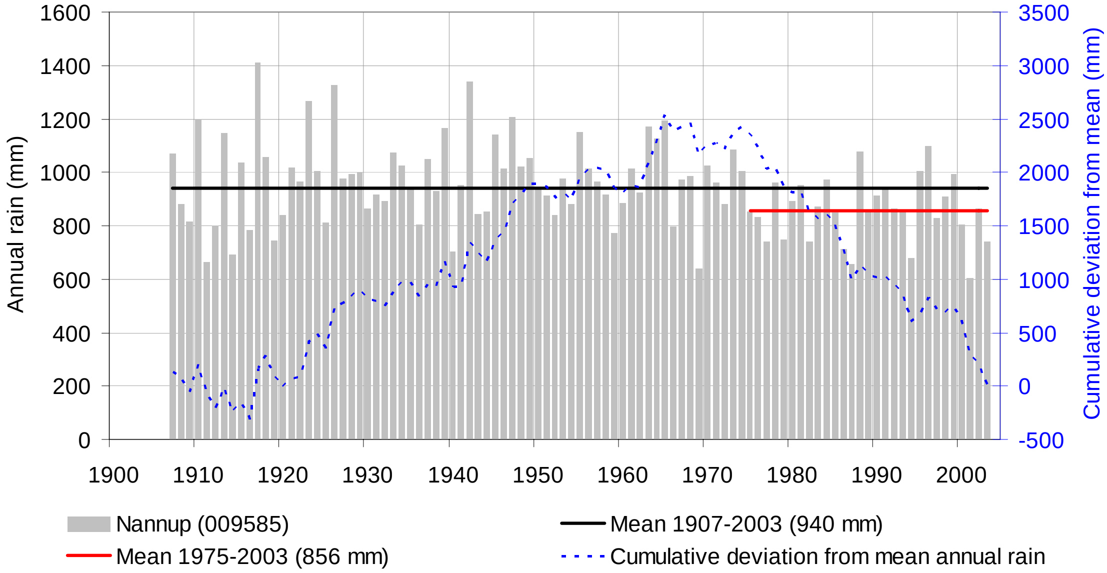
Table 16-1. Cape-to-Cape flow summary

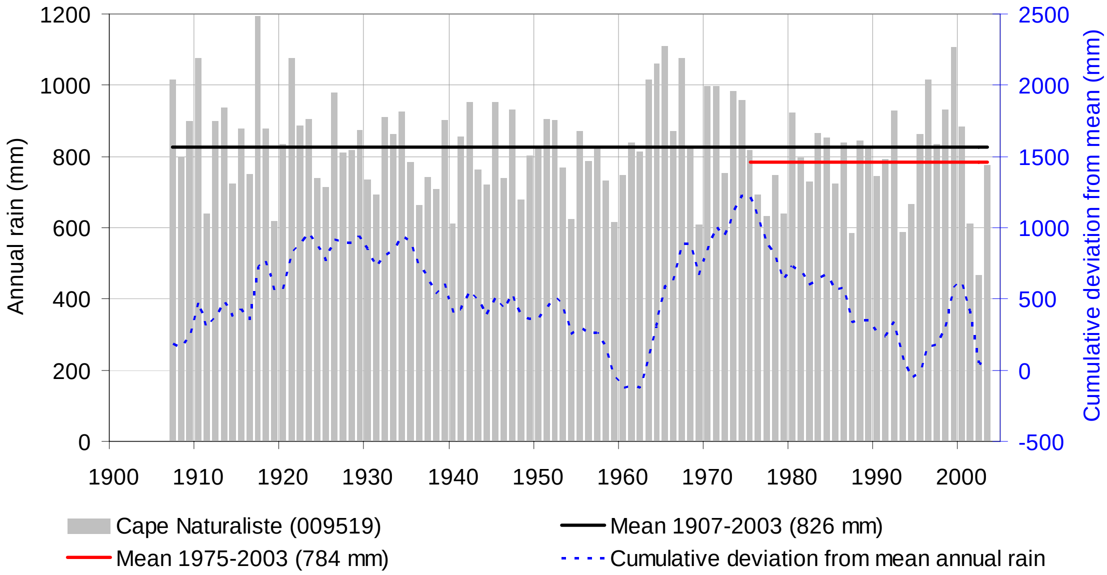
Sub-area[1]	Whicher Catchment		Area (km^2)	MAF[2,3] (ML/a)	Min Flow Period
Nillup	Nillup	1	71.1	*17,000*	–
Glen Warner	Glen Warner	2	40.8	*9,100*	–
Glen Warner North	Glen Warner North	3	57.8	*9,700*	–
Upper Chapman	Upper Chapman	4	118.1	36,400	–
Chapman	Chapman	5	67.0	20,100	May to January
McLeod SW	McLeod	6	111.8	*29,700*	–
Rushy	Rushy	7	22.7	*7,100*	–
Glenarty	Glenarty	8	42.6	*11,500*	–
Turnwood	Turnwood	9	47.5	*10,100*	–
Turner SW	Turner	10	96.4	*24,100*	–
Calgardup	Calgardup	11	72.1	*21,400*	–
Boodijidup	Boodijidup	12	62.4	*20,000*	–
Upper Margaret			274.0	*39,200*	–
Middle Margaret			85.9	*25,800*	–
Ten Mile Brook	Margaret	13	4.9	*1,200*	–
Margaret Town			31.8	*9,300*	May to January
Lower Margaret			49.2	*14,100*	–
Bramley	Bramley	15	46.9	*14,900*	–
Ellen	Ellen	14	27.0	*8,700*	–
Cowaramup	Cowaramup	16	26.4	*7,800*	–
Biljedup	Biljedup	17	20.9	*4,900*	–
Wilyabrup	Wilyabrup	18	89.1	25,900	May to December
Quninup	Quninup	19	30.3	*6,500*	–
Gunyulgup	Gunyulgup	20	65.9	*10,200*	–
Naturaliste	Naturaliste	21	64.0	*4,300*	–
Dunsborough Coast	includes Mary	22	158.3	*25,300*	–
Carbunup	Carbunup (to coast)	23	165.0	40,300	May to November
Buayanup	Buayanup (to coast)	24	201.0	*37,500*	–
Vasse	Vasse Sabina	25 26	283.0	40,000	May to November June to January
Wonnerup	Abba Ludlow	27 28	477.0	*32,700*	– June to November
Capel R North Branch			87.8	*13,600*	
Capel R South Branch			168.0	*22,000*	Continuous
Capel R Central			111.0	*8,400*	
Capel R West	Capel	29	81.2	*5,700*	
Gynudup Bk and Tren Ck			188.0	*21,200*	–
Five Mile Brook			87.4	*6,700*	–
West Bay	West Bay	30	63.4	*15,000*	–
Twinems Bend	Twinems Bend	31	39.6	*8,000*	–
Scott	Scott	32	748.1	114,300	Continuous
Adelaide	Adelaide	33	106.0	*14,600*	–
Careys/Peenebup	Careys	34	61.5	*7,600*	–
Rosa	Rosa	35	298.8	22,300	June to October
Judy	Judy	36	155.9	*18,200*	–
Milyeannup	Milyeannup	37	156.7	*22,600*	–
Red Gully	Red Gully	38	145.6	*17,300*	–
McAtee	McAtee	39	123.2	*12,200*	–
Jalbarragup	Jalbarragup	40	92.9	*7,700*	–
St John	St John	41	618.8	47,600	Continuous
Carlotta	Carlotta	42	180.2	*20,900*	–
Tanjannerup	Tanjannerup	43	23.3	*1,500*	–
Barlee Brook	Barlee	44	391.6	53,900	May to January
Ellis	Ellis	45	134.3	*9,800*	–

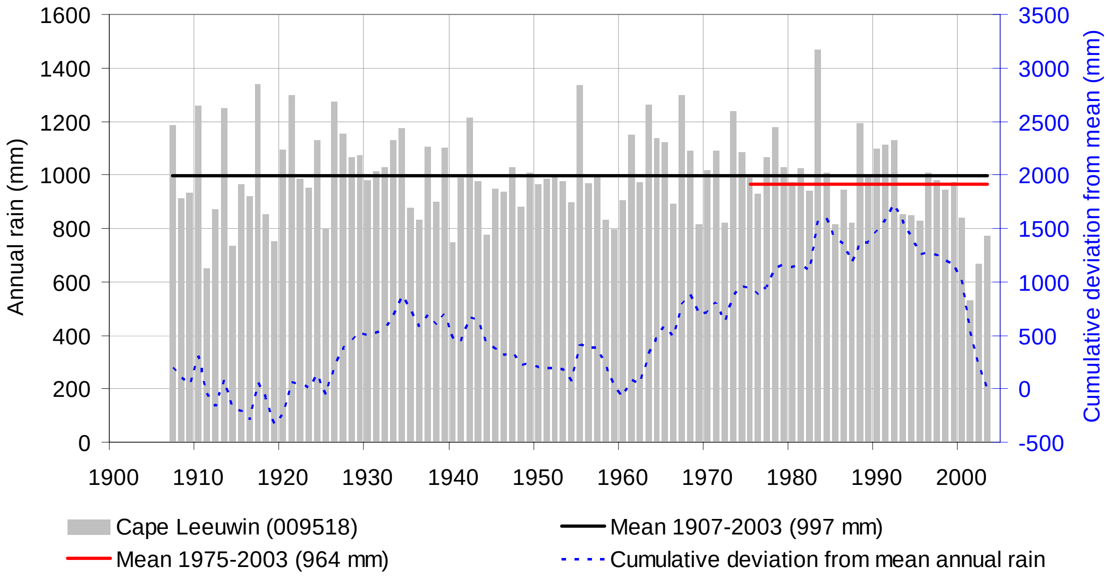
Notes: 1 Subarea names and areas from GIS SDE: Surface Water Management Sub-areas (6/09/05)
2 The mean annual flow (MAF)is for the period 1975 – 2003
3 *Italics* indicate the MAF has been estimated from a regional relationship (REG75)

Appendices

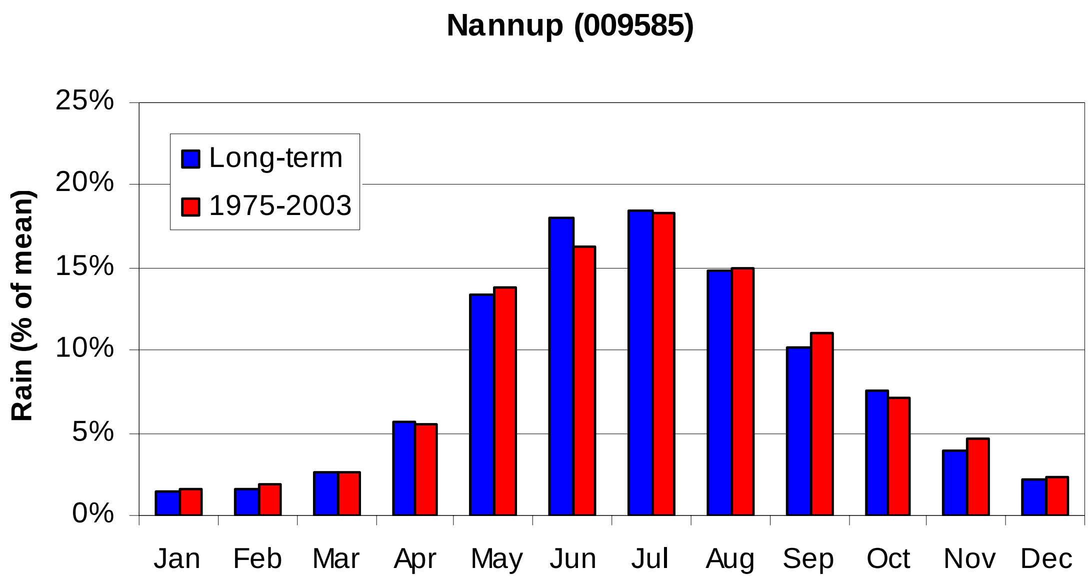
Appendix A — Mean annual rainfall

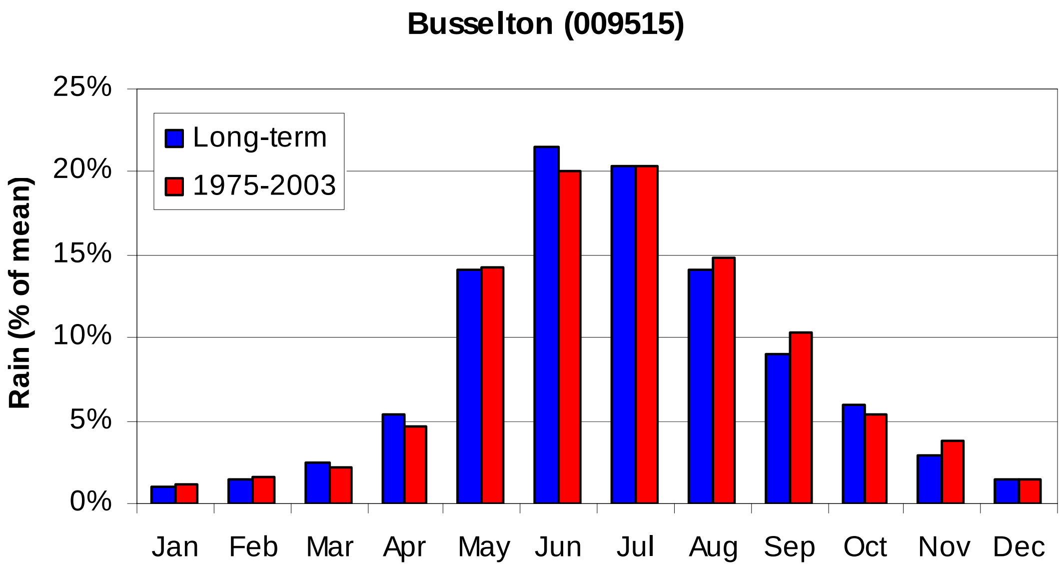


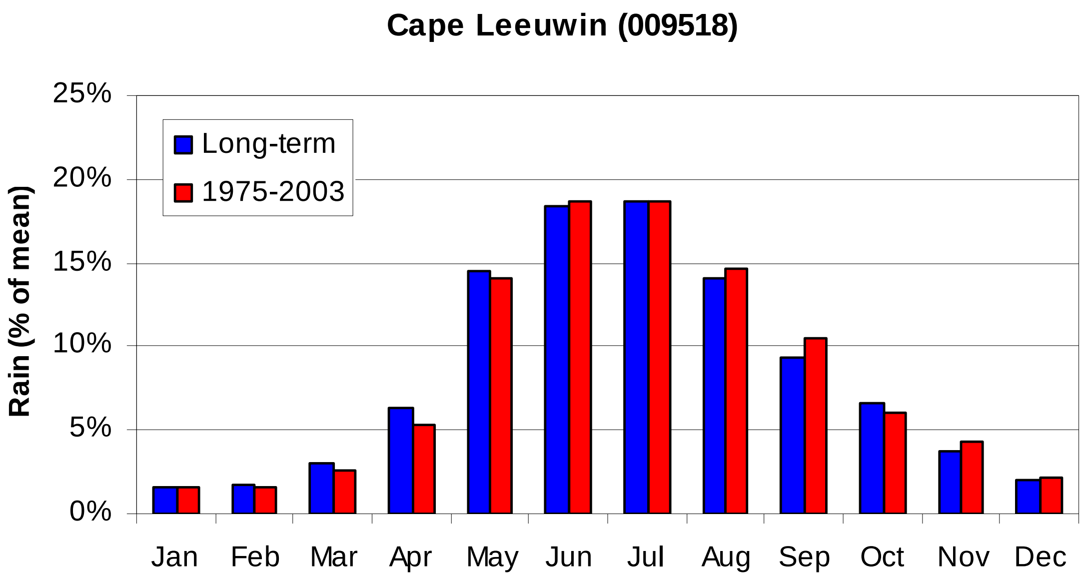


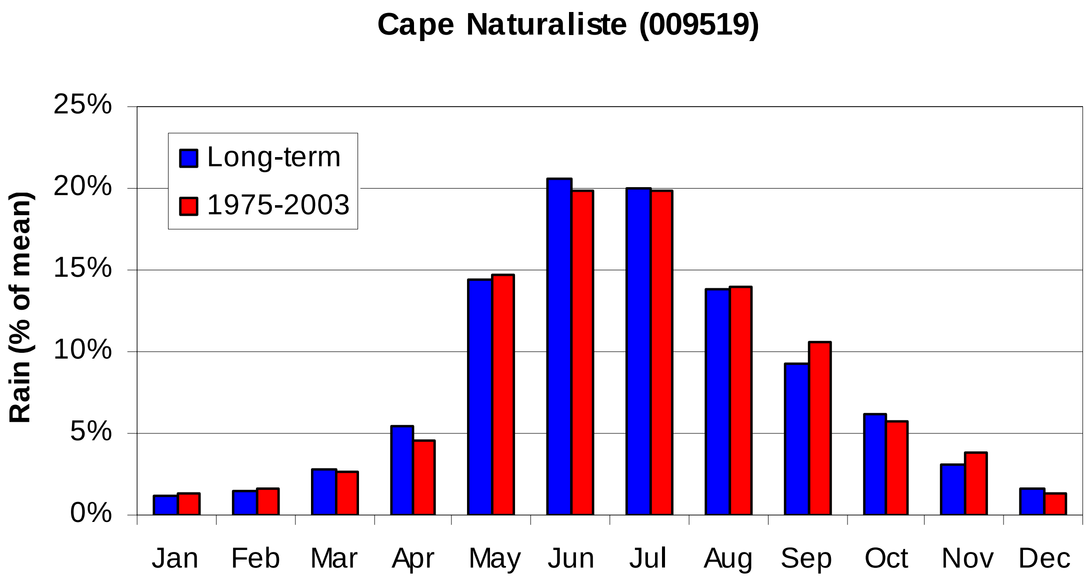

1600
1400
1200
1000
800
600
400
200
0
Annual rain (mm)
3500
3000
2500
2000
1500
1000
500
0
-500
Cumulative deviation from mean (mm)
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Cape Leeuwin (009518)
Mean 1907-2003 (997 mm)
Mean 1975-2003 (964 mm)
Cumulative deviation from mean annual rain

Appendix B — Monthly rainfall distribution






Cape Leeuwin (009518)
Rain (% of mean)
25%
20%
15%
10%
5%
0%
Long-term
1975-2003
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Cape Naturaliste (009519)
Rain (% of mean)
25%
20%
15%
10%
5%
0%
Long-term
1975-2003
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Appendix C — Annual flow statistics for the period 1975-2003

Station	Period of record	Catchment area (km^2)	Rainfall (mm)	Clearing (%)	MAF (ML)	Q_{50} (ML)	Q_{90} (ML)	CV	Q_{50} compared to MAF	1975-2003 MAF compared to 1962-1995 MAF
608004	76-96	1.21	1230	0	232	233	121	0.40	1%	-22%
608005	76-96	0.82	1230	1	164	163	87	0.39	-1%	-21%
608148/001	62-99	159.1	1175	6	21,891	23,547	12,591	0.39	8%	-22%
609004	75-99	26.04	930	0	2,183	1,662	535	0.73	-24%	-21%
609003	74-99	161.61	950	0	11,566	11,000	3,699	0.67	-5%	-21%
609008	76-98	27.55	925	40	2,937	2,779	1,355	0.58	-5%	-13%
609018	83-04	552.26	960	10	42,501	41,958	21,279	0.51	-1%	-20%
609001	69-78, 03-04	89.18	980	0	6,660	6,616	2,408	0.49	-1%	-19%
609025/019	62-04	13368	600	64	535,508	534,227	233,449	0.55	0%	-18%
609023	95-04	45.17	1130	60	13,538	13,421	7,689	0.36	-1%	-16%
609022	95-04	180.02	1120	31	55,445	53,995	28,521	0.39	-3%	-17%
609002	69-04	627.6	1080	30	95,873	92,597	32,178	0.50	-3%	-13%
610008	77-99	15.52	940	0	1,596	1,274	501	0.67	-20%	-13%
610128/001	62-04	443	1070	21	85,826	86,897	42,224	0.40	1%	-18%
610006	73-04	82.26	1105	72	23,862	23,556	12,618	0.36	-1%	-16%
610015	95-04	159.39	1055	54	38,941	38,123	24,743	0.30	-2%	-14%
610003	72-04	47.66	1005	47	10,645	9,670	5,704	0.49	-9%	-8%
610025	01-04	77.64	900	30	10,977	10,887	4,231	0.50	-1%	-23%
610014	95-04	261.73	900	68	37,206	33,716	12,401	0.55	-9%	-26%
610016	95-01	127.87	895	80	16,604	12,483	4,105	0.71	-25%	-36%
610007	77-98	9.5	955	0	232	156	57	0.88	-33%	-30%
610005	73-98	109.22	925	1	5,008	4,112	1,061	0.98	-18%	-29%
610009	91-04	207.8	915	25	14,152	13,280	5,084	0.72	-6%	-20%
610219	66-75, 96-04	315.12	1005	28	40,075	37,621	19,174	0.47	-6%	-16%
610010	93-04	394.74	990	40	48,897	45,485	28,333	0.39	-7%	-12%

Note: Q_{50} = median annual flow

Appendix D — Observed daily flow statistics

Station	Q_{50}/Q_{10} (%)	Q_{90}/Q_{50} (%)	Mean BFI (%)
608004	0.0%	–	34%
608005	0.0%	–	29%
608001	6.4%	2.5%	39%
609004	2.3%	0.0%	39%
609003	1.1%	0.0%	41%
609008	0.2%	0.0%	40%
609018	0.9%	16%	39%
609001	5.1%	0.0%	39%
609019	8.9%	18%	43%
609023	4.3%	0.0%	40%
609022	6.7%	0.0%	41%
609002	0.3%	2.4%	36%
610008	0.0%	–	41%
610001	7.0%	0.0%	42%
610006	1.0%	0.0%	37%
610015	7.9%	0.0%	41%
610003	6.7%	0.0%	38%
610025	3.3%	0.0%	39%
610014	0.0%	0.0%	26%
610016	0.2%	0.0%	28%
610007	0.0%	–	34%
610005	0.0%	–	34%
610009	0.8%	0.0%	32%
610219	3.4%	7.3%	36%
610010	7.8%	44%	40%

Notes:

1 Q_{50}/Q_{10} and Q_{90}/Q_{50} are measures of the high-flow end and low-flow end slopes of a flow duration curve

2 Q_{90}/Q_{50} = -, indicates $Q_{50} = 0$

3 BFI = baseflow index

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Contributors

This report was prepared by Sally Bowman from Water Resource Management. The author wishes to thank the following people within the Department of Water for assistance with the report:

Mark Pearcey – technical comments on the various versions

Lesley Criddle and Karen Exley-Mead – GIS.

Sunil Varma – groundwater information

Richard Pickett – regional information

For more information contact:

Water Resource Assessment Branch

Water Resource Management Division

Department of Water

Level 4, 168 St George’s Terrace

PO Box K822

PERTH WA 6842

Telephone 6364 7600

Facsimile 6364 6525