DWLBC REPORT

Surface water assessment of the Bremer River Catchment

2008/13

Government of South Australia
Department of Water, Land and Biodiversity Conservation

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Report DWLBC 2008/13

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the state. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources, it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continue to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Rob Freeman
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

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SUMMARY

This technical report describes the methodology and outcomes of a detailed hydrological assessment of the Bremer River Catchment. It is one of a series of hydrological studies undertaken for the individual catchments in the Eastern Mount Lofty Ranges Prescribed Water Resources Area. The study quantifies the surface water resources within the catchment, examines the impact of farm dams on the resources using rainfall-runoff modelling, and provides guidance regarding future water resources management policies.

This report will be used as a technical foundation for the state government's consideration of water resources management measures required for the catchment. The main findings of the study are summarised below and further described in section 6 of this report.

Catchment hydrology: The Bremer River Catchment is located in the Eastern Mount Lofty Ranges ~30 km from Adelaide. Rainfall in the area is highly variable, ranging from ~860 mm in the northwest to 400 mm where the Bremer River discharges to the plains.

Topography also varies greatly, as the elevation ranges from 500 m around Mount Barker to less than one metre where it drains to Lake Alexandrina.

Streamflow has been measured in the catchment at Hartley since 1973, with the mean and median annual streamflow calculated at 16 300 and 13 200 ML, respectively.

The ratio of runoff to rainfall varies for the different sub-catchments, ranging from ~11% for the higher rainfall sub-catchments in the northwest to as low as 1 or 2% where the catchment reaches the plains.

Farm dam development: Based on a combination of aerial photography and survey findings, there are ~1700 dams with a combined estimated capacity of 4500 ML in the Bremer River Catchment. The distribution of dams roughly follows the distribution of rainfall, with more development in the upper reaches where there is correspondingly higher rainfall. On a catchment scale, the Bremer River is under-developed in relation to the River Murray Catchment Water Management Plan (RMCWMP) development limits. Total dam capacity accounts for 27% of mean winter runoff at the gauge. However, several major sub-catchments are over-developed.

Impacts of farm dams on the hydrology of the catchment: Reduction in flows due to farm dams was assessed at annual, monthly and daily time scales. Annual reductions in flows were found to be highest in sub-catchments with the highest farm dam density.

- Rodwell Creek showed the largest reduction in streamflow due to dams at 23% of the mean annual flow.
- Mount Barker Creek, despite having a higher rainfall and a significant baseflow component, showed a 14% reduction in the mean annual.
- Total reduction in flows across the whole catchment is 10% of mean annual streamflow.
- Flow reductions were highest in the summer and autumn months, but even winter months were significantly impacted in the highly developed sub-catchments. Upper Mount Barker Creek sub-catchment for example showed a reduction in mean September streamflow of 5%. This is the month with the highest modelled flows for the period.
- Daily flows at a catchment scale indicated a reduction in the median daily flow (50th percentile) of:

- 39% for Mount Barker Creek
- 57% for the Bremer River Catchment (with flow from Mount Barker Creek removed and including Red and Rodwell Creeks).

Recommendations:

Improved catchment modelling depends on both quality streamflow and climate data. It is recommended that:

- Operation of all current gauging stations be continued to allow future monitoring of the outcomes of the current water allocation process.
- Streamflow gauging of recently updated water level monitoring sites be carried out at a range of flow levels in order to verify current ratings.
- In order to correctly assess the impact of farm dams, it is necessary to improve the estimation of farm dam capacities. Accurately surveying farm dams in key positions within the catchment would greatly enhance the ability of the process to predict their impact.
- The use of sub-daily data would greatly improve current modelling and understanding of catchment hydrology. It is recommended that, where possible, data from relevant pluviometers be used to construct and calibrate catchment rainfall–runoff models.

Reductions in catchment yield, reduced flows during transitional seasons, and decreased low and medium flows will require various management mechanisms to ensure sustainability of the resource. Because of this, it is recommended that:

- Further development of farm dams in the catchment be restricted until an appropriate water allocation plan is in place, and provision for suitable measures for water trading are made.
- Best practice irrigation measures be encouraged in order to enhance the capability of the resource to cope with development.
- Under the current Notice of Prescription, stock and domestic dams are exempt from any management rules. This provides little flexibility in terms of placing future restrictions on extraction, diversion or use. It is recommended that this decision be revisited at the review of the first water allocation plan.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE OF STUDY

This report describes the assessment of the surface water resources of the Bremer River Catchment upstream of the Angas–Bremer Prescribed Wells Area (PWA). It was undertaken by the Department of Water, Land and Biodiversity Conservation (DWLBC) for the South Australian Murray–Darling Basin Natural Resource Management (SAMDB NRM) Board. The report describes the methodology and outcomes of the study, and provides a basis for surface water resource management options for the future.

The study has the following scope:

- Quantification of the surface water resource.
- Construction and calibration of rainfall–runoff model.
- Assessment of the impact of farm dams on the catchment.

1.2 BACKGROUND

Surface water use in the upper reaches and groundwater use in the plains are vital to the economics of the Eastern Mount Lofty Ranges (EMLR) region. However, the rapid development of farm dams over the last two decades in the region has raised considerable concern regarding the sustainability of water resources and the impacts seen on the ecosystems that are dependent upon them. Preliminary investigations indicate that farm dam development in the high rainfall areas of a number of catchments in the EMLR have either reached or exceeded allowable levels of development as defined in the Catchment Water Management Plan for the River Murray in South Australia (RMCWMB 2003).

This led to the state government declaring both a Notice of Prohibition, and a Notice of Intent to Prescribe the watercourse, surface, and groundwater resources of the EMLR. Following the declaration, the DWLBC was commissioned to carry out a series of detailed hydrological studies of the individual catchments in the EMLR. The combined water resources of the EMLR were prescribed by the state government on 8 September 2005. Water allocation planning is currently in progress.

1.3 STUDY APPROACH

The analysis and data generated by this study are based on the outputs from a computer rainfall-runoff model. The development of the model used available data from a variety of sources:

- hydrological and climate data such as rainfall and evaporation
- topographical data, useful for the delineation of catchments and stream ordering
- aerial photography and videography for the identification of farm dams and ecological assets such as permanent pools

- farm dam surface area–volume relationships, based on previous studies to determine levels of development within the catchment.

Following the collection of all available data, the next step was to develop a rainfall–runoff model, which involved the following steps:

- analysis of available hydrological data, i.e. rainfall, evaporation, streamflow
- collection and collation of water-use data
- subdivision of the whole Bremer River Catchment into major and minor sub-catchments based on hydrological boundaries
- input of data for each minor sub-catchment into the Water Community Resource Evaluation and Simulation System (WaterCRESS) modelling platform
- modelling of various scenarios for the purpose of identifying possible catchment management options
- analysis and discussion of results of the modelling process.

The results of the scenarios modelled are presented in this report on a major sub-catchment level, and also on an annual, monthly and daily basis. This provides better understanding of not only the impacts of dams on annual catchment yields, but also the impacts on flow regimes that are critical for environmental flow assessment. This facilitates the assessment of potential risks to the sustainability of the overall surface water resource and to water-dependent ecosystems, which provides a basis for consideration for future water management options.

2. CATCHMENT DESCRIPTION

2.1 OVERVIEW

The Bremer River Catchment is located in the EMLR ~30 km from Adelaide (Fig. 1).

The topography of the upper catchment ranges from ~450 m in the northwest to ~50 m at the confluence of the Bremer River and Rodwell Creek. Below this confluence, the Bremer River flows out onto the Angas–Bremer Plains, where it travels ~20 km past the town of Langhorne Creek, to an elevation of less than 1 m, and into Lake Alexandrina. The upper part of the catchment (above the confluence) has been divided into eight major sub-catchments — Upper Mount Barker Creek, Lower Mount Barker Creek, Upper Bremer River, Lower Bremer River, Nairne Creek, Dawesley Creek, Red Creek, and Rodwell Creek (Fig. 2).

Rainfall in the catchment is highly variable due the diverse topographical extent, and ranges from over 800 mm in the northwest to ~400 mm annually on the lower plains around Langhorne Creek. Markedly lower rainfall occurs to the east of the north–south ridgeline that bisects the catchment.

Streamflow data is available from 11 streamflow measuring stations mostly located in the upper reaches of the catchment. The most downstream streamflow measurements are collected at the Hartley gauging station. Data from that station have been collected since 1973 and show a mean and median annual outflow (1973–2006) of 16 300 and 13 200 ML, respectively. Modelled streamflow for the catchment upstream of the Angas–Bremer Irrigation Management Zone (1974–2003) show mean and median annual flows of 19 490 and 15 970 ML, respectively. For the observed period of record, this gives a runoff coefficient of 6% for the Bremer River Catchment although it varies considerably through the catchment.

Land use is predominantly made up of grazing—both broadscale and irrigated—with marginal amounts of the catchment being used to grow commercial crops such as wine grapes, as well as flowers, olives and other exotic species.

Based on aerial photography, the total number of farm dams in the Bremer River Catchment is ~1700, with an estimated storage capacity of 4500 ML. The majority of this development is in the upper, wetter sub-catchments of Mount Barker Creek, Nairne Creek and Dawesley Creek.

2.2 LAND USE

2.2.1 LAND-USE SURVEY 2003

Land-use data provide information on the nature of the use of land (e.g. forestry, livestock grazing, horticulture, and residential). This, in addition to the land and water management information (e.g. irrigated or unirrigated, usage of water from wells or from farm dams), provides a better understanding of resource availability and resource usage within the catchment.

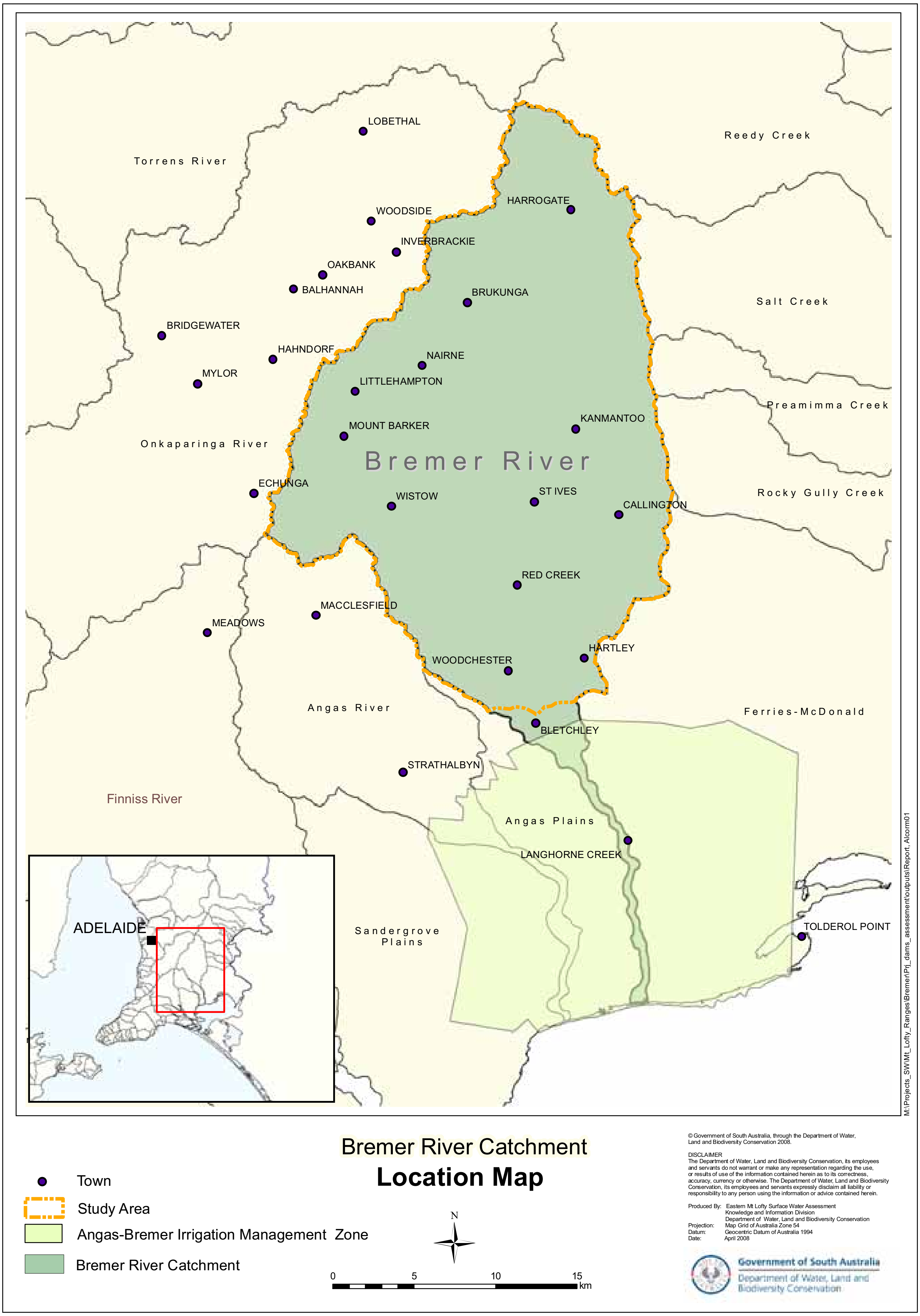


Figure 1 Bremer River location map

Land-use data for the catchment area were obtained from the land-use data set of the EMLR carried out by DWLBC for the SAMDB NRM Board in 2003–04. The exercise involved interpreting high-resolution aerial photography (1:20 000) overlain with the latest available digital cadastral database as well as field verification. Results of the survey are presented in Figure 3 and Table 1 based on the ten categories presented below:

1. Livestock: includes both intensive and broadscale grazing and other animal husbandry.
2. Field crops: includes cereals, legumes and pasture.
3. Forestry/protected/cultural areas: encompasses areas of plantation forestry, protected native vegetation and cultural areas.
4. Accommodation: residential.
5. Horticulture—row crops: includes all row crops such as grapes, vegetables etc.
6. Horticulture—trees: includes citrus, olives.
7. Mining: includes mining and extractive industries.
8. Manufacturing/commerce.
9. Cultural/recreation services.
10. Transport/storage/utilities.

Table 1 Land use in the Bremer River Catchment, 2003

Land use	**Area** (km^2)	**% of total area**
Livestock	545.7	79
Field crops	87.3	13
Forestry/protected/recreation area	22.5	3
Accommodation	15.0	2
Horticulture—row crops	14.2	2
Horticulture—trees	1.9	0.28
Mining and extractive industries	1.4	0.21
Manufacturing/commerce	1.3	0.19
Cultural/recreation services	0.8	0.12
Transport/storage/utilities	0.3	0.05

2.3 CATCHMENT SUB-DIVISION

For the purpose of modelling, it is required that the entire catchment be divided into discrete components, called sub-catchments. Initially the Bremer River is split into nine major sub-catchments (Fig. 2), each of which represents a different tributary system, and results from the investigation will be reported on at this scale.

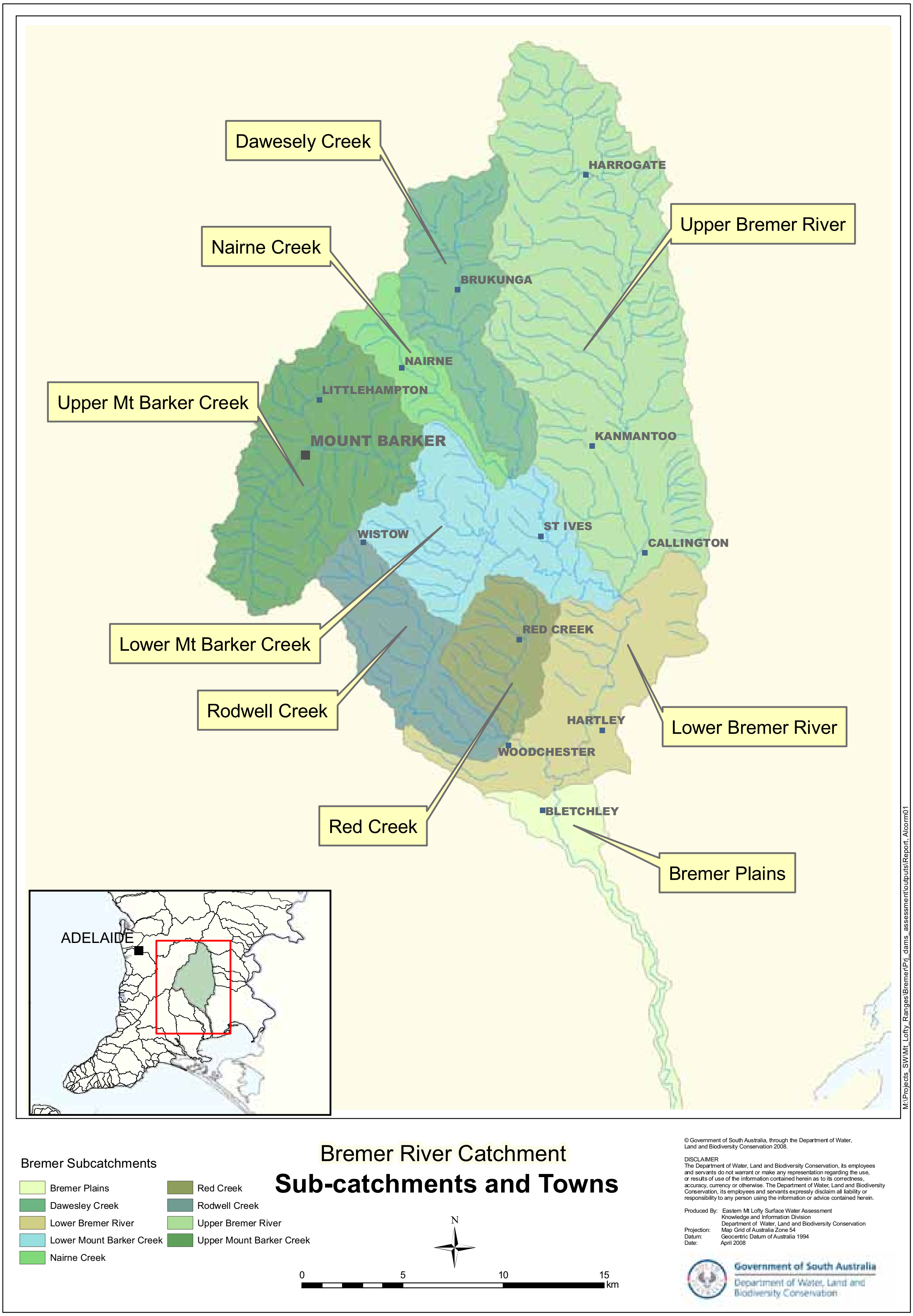


Figure 2 Sub-catchments and towns in the Bremer River Catchment

2.3.1 MAJOR SUB–CATCHMENTS

The major sub-catchments are defined based on the following factors:

- existing or recognised catchments from previous studies (RMCWMP, Mount Barker Management Plan)
- areas forming a major tributary of the Bremer River, generally of third order or above
- areas comprising a large area of catchment which may be defined as less than third order but otherwise draining a significant portion of the catchment
- areas that are significantly different in catchment characteristics such as rainfall or topography.

Dividing the catchment in this way allows each area to be assessed separately and creates elements of scale suitable for implementing management actions, should they be required as part of the prescription process.

Table 2 Major sub-catchments of the Bremer River Catchment

Sub-catchment	Towns	Elevation range (m)	Rainfall range (mm)	Area (km^2)
Upper Mount Barker Creek	Mount Barker, Littlehampton	270–510	630–860	86
Nairne Creek	Nairne	170–475	510–780	23
Dawesley Creek	Brukunga, Dawesley	170–515	490–840	56
Lower Mount Barker Creek	St Ives	70–510	420–810	65
Rodwell Creek	Wistow, Woodchester	70–445	460–760	45
Red Creek	Red Creek	70–275	460–560	29
Upper Bremer River	Harrogate, Kanmantoo, Callington	65–535	400–810	195
Lower Bremer River	Hartley	35–230	410–560	68
Bremer Plains	Bletchley, Langhorne Creek	0–35	380–470	23

2.3.2 MINOR SUB–CATCHMENTS

From a modelling perspective, it is necessary to define each minor sub-catchment depending on what the local characteristics of each area are. It is constructive to define different areas where controlling factors, such as on-stream dams, are the dominant feature of the local hydrology. The Bremer River Catchment was divided into 278 minor sub-catchments that were defined with the following considerations in mind.

- Where a dam was considered to be blocking a stream, this becomes the lower end of the sub-catchment which contributes to that point.
- In areas where more than one dam is blocking the catchment but the influence of a major dam is predominant, all other dams above are grouped into one dam node situated at the lowest point of the sub-catchment.
- Sub-catchments with no dams but having well-defined contributing areas are included—these are generally called free-to-flow zones and are necessary to enable routing of flows over long distances of unimpeded flows.

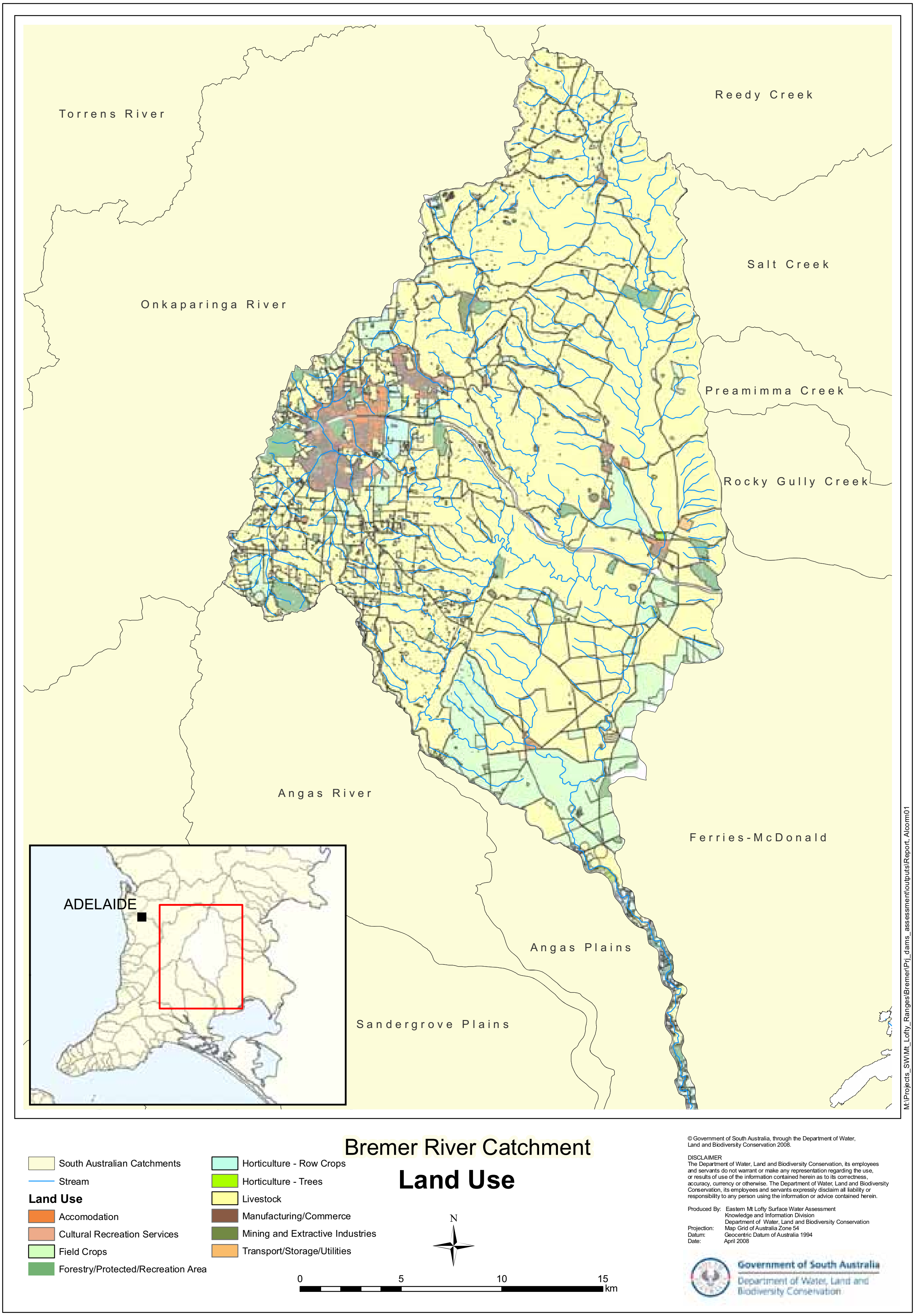


Figure 3 Bremer River land use

Minor sub-catchment division was carried out using a freely available software package called CatchmentSIM (Ryan & Boyd 2002). The process involved using a digital elevation model (DEM) to define the extent of catchment area above selected points.

Using the criteria listed above to determine the end point of each minor sub-catchment, all points are digitised onto the DEM and sub-catchments are automatically generated using a set of algorithms to determine flow accumulation and flow paths for each cell within the entire catchment. Historically, such software has run into problems of sub-catchment delineation in areas of low topographic relief, and there were a few locations within the lower reaches of the Bremer River where this occurred. Where this was a problem, particularly with external catchment boundaries, the final sub-catchments where exported and edited in another geographic information system (GIS) package to ensure that catchments are consistent with existing boundaries and internal boundaries are hydrologically correct.

This enabled analysis of further data requirements for the model, such as average rainfall of the sub-catchment, area of sub-catchment, combined farm dam capacity, and percentage of diversion to water storages. The set-up of the sub-catchment within the platform is described in section 4.3.

2.4 FARM DAMS

Farm dams are water storage structures generally constructed in regional (rural) areas for capturing the runoff generated from the catchment area above them (Fig. 4). Stored water is then used for domestic, stock and irrigation purposes. While water stored in the farm dams provides an additional source of water to rainfall and water pumped from groundwater wells, they also act as a barrier for the runoff generated from the catchment area upstream of the dam, until the dam spills. This directly affects the availability of water to users (including the environment) downstream of the dam, particularly when the dam is large. The other negative impact of this is the change in the flow regime of the stream, which directly affects the riverine and other water-dependent ecosystems. One of the main purposes of this study is to estimate these impacts on the flow regime in the catchment.

The constant increase of land being brought into intensive agricultural use in the Mount Lofty Ranges (MLR) has necessitated the construction of more water storage facilities, and hence the inevitable construction of a large number (and higher storage capacity) of farm dams. This increase in construction of farm dams has been more predominant and rapid in the highland areas with intense vineyard development. Assessment of catchments across the region has been carried out by DWLBC, including the Barossa Valley (Cresswell 1991), Onkaparinga River Catchment (Teoh 2002), Upper River Torrens Catchment (Heneker 2003), Upper Marne River and Upper Finniss River Catchments (Savadamuthu 2002, 2003), and the Tookayerta Catchment (Savadamuthu 2004).

Existing farm dam information (in the form of spatial datasets) was reviewed and updated where appropriate. This involved using aerial photography taken in 2003 and 2005. The 2003 coverage extends over the entire Bremer River Catchment and formed the basis for a dataset used in the land-use survey carried out in 2004 (Daley & Dwyer 2004).

Figure 4 Farm dam in the Upper Mount Barker sub-catchment

The 2005 dataset covers only the western edge of the upper catchment, but this area carries the highest density of farm dam development, so its inclusion here is vital. Both datasets were used to derive the updated spatial coverage of farm dams used in this model. It was often found during this review process that some data were incorrectly identified as farm dams, and that some farm dams were missed in the original data capture. Given the large geographic distribution and number of farm dams involved, this is not entirely unexpected.

The other error commonly encountered in digitising farm dams is the correct interpretation of the full supply level, which is used as the basis for determining maximum dam volume. This type of error can be attributed either as an artefact of image resolution or merely operator error through oversight or misinterpretation.

The extent of farm dam development is currently estimated using various means including:

- the overall number of dams and their storage capacity
- the estimation of farm dam density, measured in volume (ML) per area of upstream catchment (km^2) for a given catchment
- estimated volume as a ratio of winter runoff from the catchment upstream (referred to as the RMCWMP Development Level)
- estimated volume as a ratio of median annual runoff from the catchment upstream (referred to as the State Water Plan Limit).

2.4.1 NUMBER AND STORAGE CAPACITY

In this study, farm dam capacities were estimated using the most recent dam surface area – volume relationship (McMurray 2004b):

Equation 1 – For surface area <15 000 m^2:

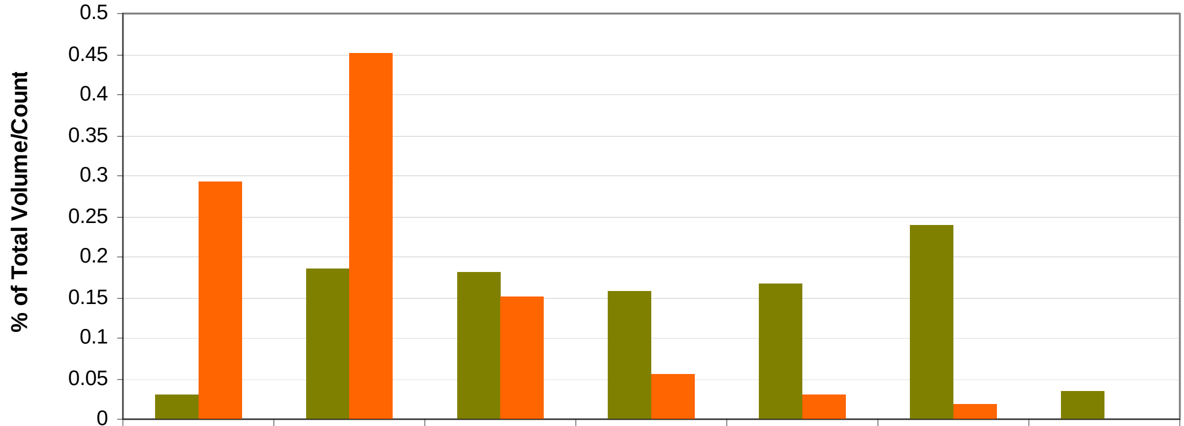
$$\textit{Dam capacity (ML)} = 0.0002 \times \textit{Surface area}^{1.25}$$

Equation 2 – For surface area ≥15 000 m^2:

Dam capacity (ML) = 0.0022 x Surface area

Based on the farm dam dataset, the total number of farm dams in the Bremer River Catchment is 1771. Using the formulae shown above, the total estimated storage capacity of these is 4500 ML.

Figure 5 shows that the total percentage of volumes is mostly evenly distributed across the size classification. Forty five per cent of dams are in the range 0–2 ML, and make up less than 20% of the total volume. The highest percentage of volume in classification lies in the range 20–50 ML, which comprises just 2% of the total number of dams.



	<0.5 ML	0.5-2 ML	2-5 ML	5-10 ML	10-20 ML	20-50 ML	>50 ML
Volume %	3%	19%	18%	16%	17%	24%	3%
Count %	29%	45%	15%	6%	3%	2%	0%

Figure 5 Combined volume of farm dams in each size classification for the Bremer River Catchment

2.4.2 WATER USE FROM FARM DAMS

Using data gained from the ongoing land and water-use survey, which is part of the prescription and allocation process, dams were assigned a type—irrigation, or stock and domestic. The verification of this data is ongoing.

Water use from individual or grouped farm dams within the model was assigned a value based on whether the dam was considered to be used for irrigation or stock and domestic purposes. Stock and domestic dams were assigned an annual demand of 30% (McMurray 2004a) of the dam volume in the distribution pattern as shown in Figure 6. This pattern follows the monthly distribution of evaporation which assumes a higher demand during the warmer summer months. Demand from irrigation is assumed to be higher and is set at 50% of the dam capacity, with water being demanded over the months of October to March.

Factors affecting the ability of the dam to supply the maximum demand include:

- storage held in the dam prior to the irrigation season
- inflows from catchment drainage above
- the local climate during the season (rainfall, evaporation, etc.).

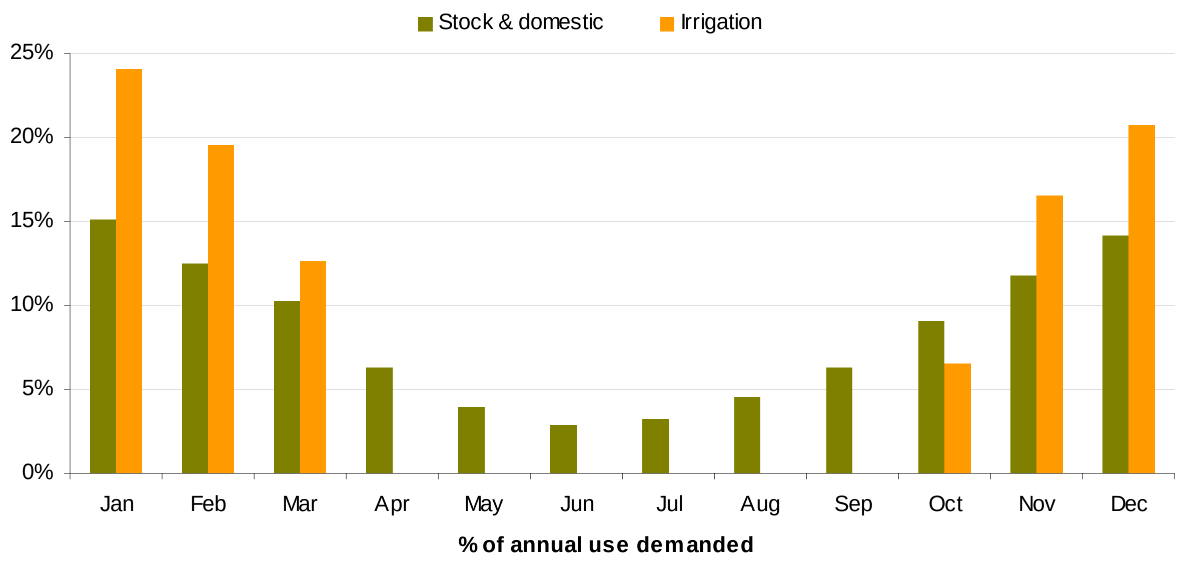


Figure 6 Demand distribution pattern for irrigation or stock and domestic dams for the Bremer model

The actual volume taken from the dam(s) will therefore vary from year to year.

The limitations of these assumptions are acknowledged, and it is noted that actual on-ground use may vary greatly from that modelled for this investigation. However, in the absence of metered water use from farm dams collected over a number of seasons, it is expected that these figures provide a reasonable initial estimate.

Maximum water use from farms dams is therefore estimated to be ~1500 ML for the whole Bremer River Catchment, which is 34% of the maximum estimated farm dam capacity in the catchment.

2.4.3 FARM DAM DENSITY

Farm dam density, is an important indicator of the intensity of farm dam development, and includes catchment area in its calculation, as shown below.

Equation 3:

$$FarmDamDensity(ML/km^2) = \frac{TotalFarmDamCapacity(ML)}{CatchmentArea(km^2)}$$

The farm dam density of the Bremer River Catchment varies greatly from 5 ML/km^2 in the dry sub-catchment of Red Creek up to 23 ML/km^2 in the wetter sub-catchments.

Dam density in the Bremer River Catchment is represented in Figure 8.

2.4.4 DAM DEVELOPMENT LIMITS

2.4.4.1 River Murray Catchment Water Management Plan, 2003

The River Murray Catchment Water Management Plan (RMCWMP) defines the limits for development of the surface water resource of the catchment as:

'The surface water sub-catchment zone limit of all dams (ML) = 0.3 (30% of) X area of the surface water sub-catchment zone (sq km) X long term average rainfall between the months of May and November (mm) X runoff coefficient; where the runoff coefficient is 0.1 (10%), unless otherwise specified in a relevant Water Allocation Plan.' (RMCWMB, 2003, p.182).

To assess the status of development as per this definition, dam development limits were estimated for Bremer River Catchment on a catchment level, and major and minor sub-catchment levels (Table 3).

Table 3 Farm Dam development assessed against the RMCWMP 30% limit

Sub-catchment	**Adjusted winter runoff** (ML)	**Estimated dam capacity** (ML)	**RMCWP limit*** (ML)	**Current development %****
Upper Mount Barker Creek	5377	1807	1613	34%
Nairne Creek	1239	265	372	21%
Dawesley Creek	2608	823	782	32%
Lower Mount Barker Creek	1199	275	360	23%
Upper Bremer River	4738	734	1421	15%
Lower Bremer River	92	9	28	10%
Rodwell Creek	1084	541	325	50%
Red Creek	155	41	46	27%

*30% adjusted winter runoff

**Dam capacity/adjusted winter runoff

Although some surface water zones exhibit relatively high dam densities, the use of the RMCWMP limits to define stressed areas does not always reflect this. This is due to the zones of high surface water development being located in the highest rainfall and runoff producing parts of the catchment. No single surface water zone exceeds the limits set out in the RMCWMP, but when analysed on a minor sub-catchment scale there are a number of areas where higher stress was identified. Figures 8 and 9 show the level of dam density on major and minor sub-catchment scales, respectively.

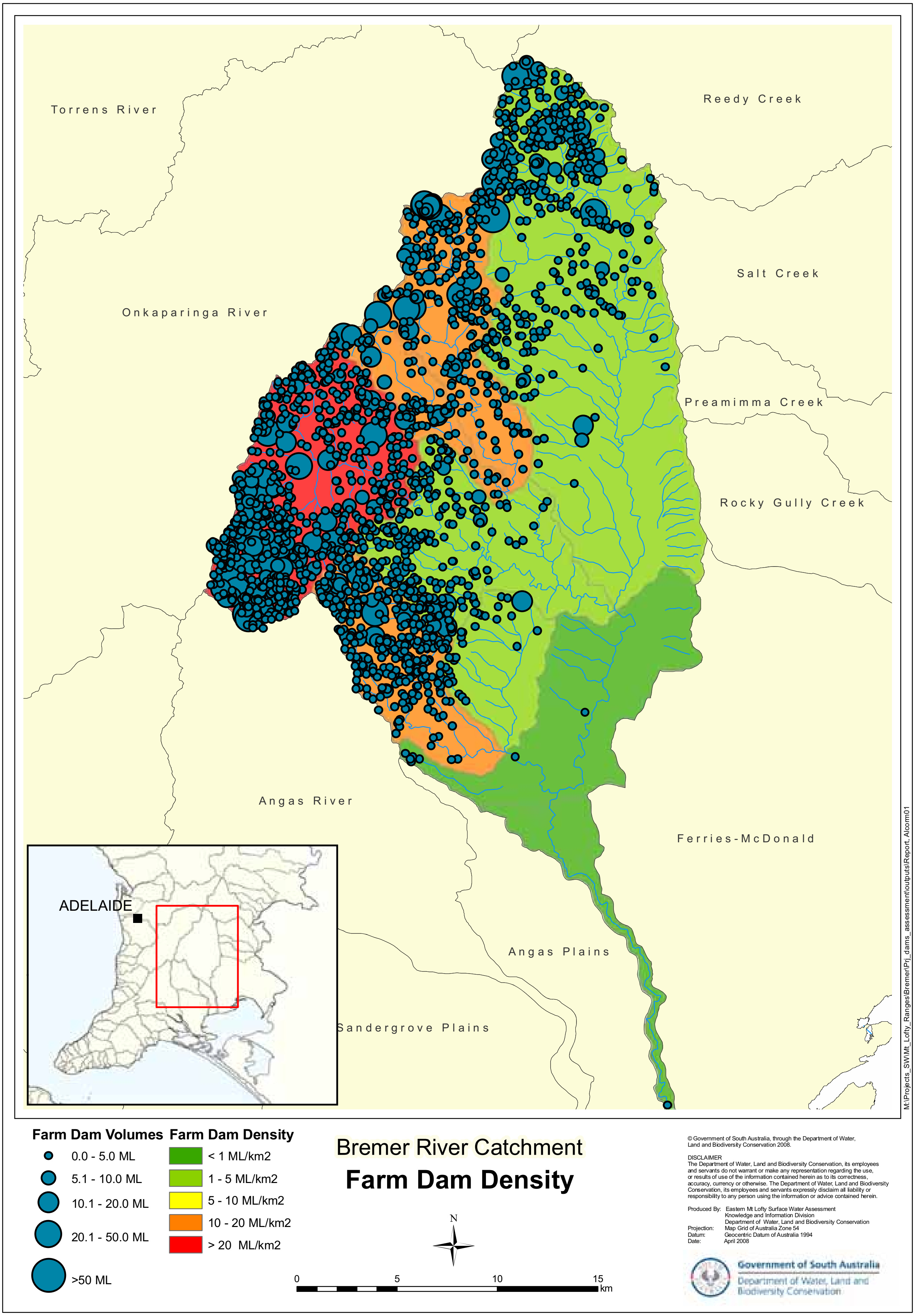


Figure 7 Bremer River Catchment farm dam density

3. CATCHMENT HYDROLOGY

3.1 RAINFALL AND EVAPORATION DATA

Rainfall and evaporation data were obtained from the Department of Natural Resources (Qld) rainfall database SILO. The data are part of the Patched Point Dataset (PPD), which has been disaggregated and infilled using the methods described in Jeffrey et al. (2001).

Ten rainfall stations in and around the Bremer River Catchment were chosen based on the availability and length of records (Fig. 9). The sites are listed in Table 5 with their long-term (1895–2006) mean and median annual rainfall, and period of record.

Table 5 Climate sites used in the Bremer River WaterCRESS model

Site No.	Site name	Site established*	Mean annual (mm)	Median annual (mm)	Mean annual evaporation (mm)
23713	Echunga	1896	808	787	1337
23829	Woodside	1883	794	786	1587
23733	Mount Barker	1870	759	728	1348
23728	Macclesfield	1885	724	694	1391
23739	Nairne	1883	672	653	1356
23722	Harrogate	1896	546	551	1630
23747	Strathalbyn	1874	493	481	1572
23724	Kanmantoo	1874	469	463	1526
24508	Callington	1883	375	372	1615
24516	Langhorne Creek	1900	370	365	1604

* Where site was established post-1895, data have been extended back using a nearby station.

It should be noted that using rainfall and evaporation data exclusively from the SILO database is a departure from previous technical investigations. Various methods of infill and disaggregation were used within DWLBC to ensure a consistent and continuous rainfall record. The decision was made to migrate to using this dataset in an effort to align with an increasing number of external projects using the SILO data.

3.1.1 TREND ANALYSIS

To test for the presence of trends in the long-term rainfall data, several methods can be used. One test is to observe the annual residual mass curve. The residual for each year is defined as the difference between the rainfall total for that year and the long-term average rainfall. The curve is then generated by summing the residuals year by year. If the rainfall over a number of years is consistently above the average, the residual will be positive and as a result the curve will show an upwards trend. Likewise, for consecutive years below the long-term average, a downward trend in the residual mass curve will result.

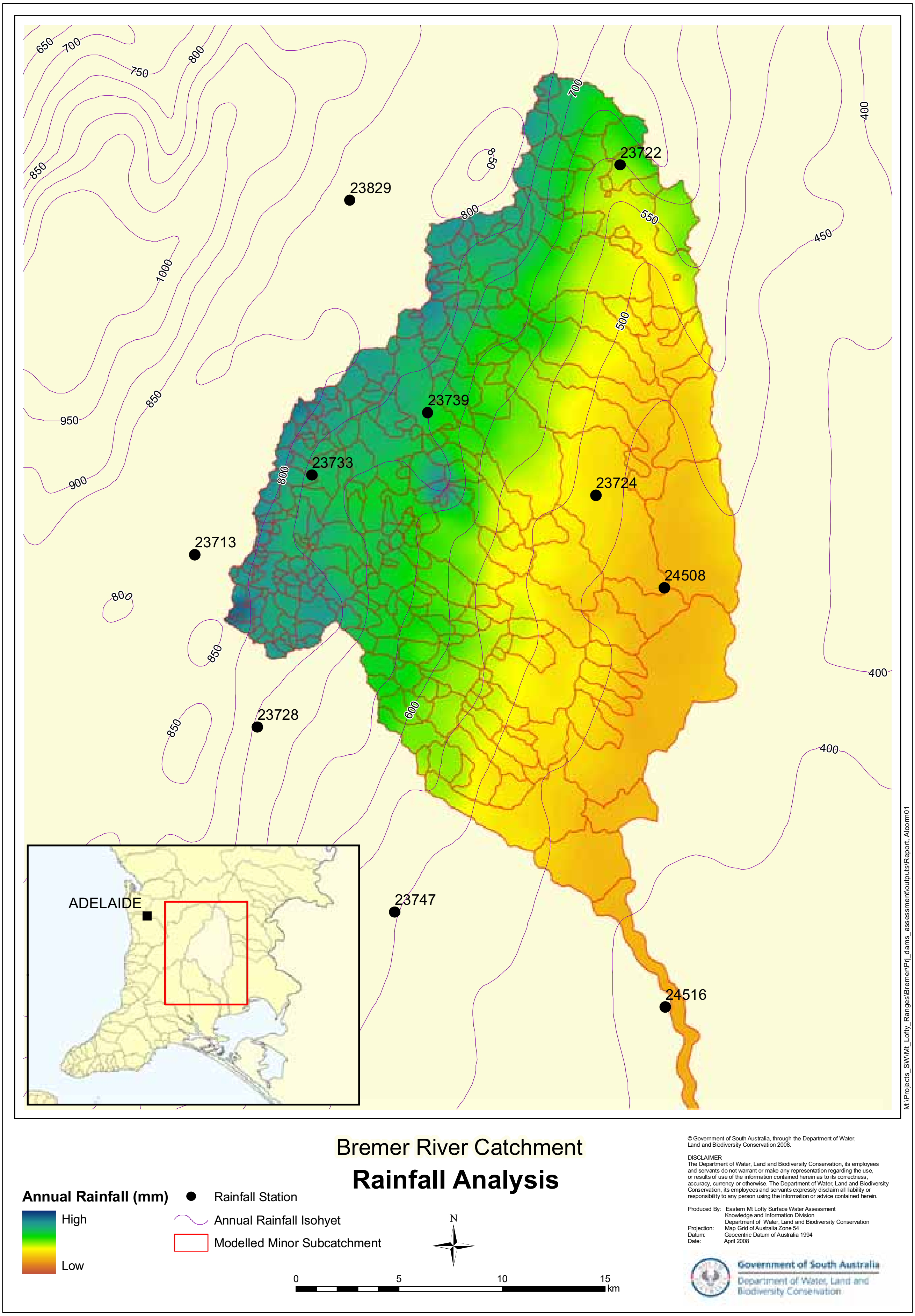


Figure 8 Rainfall analysis — spatial distribution of rainfall and stations used in modelling

Residual mass curves for all stations are shown in Figure 10. All stations appear to show the same upward trend from the beginning of the record (1895) to around the late 1920s, indicating a wetter than average period. From the 1960s onwards, most stations exhibit a downward trend, indicating a steady decline in rainfall.

There are a few notable exceptions. Previous hydrological studies conducted within the Mount Lofty Ranges have identified these trends for other rainfall sites (Heneker 2003; Savadamuthu 2006), which may indicate a decreasing trend for past 30 years within the high rainfall areas of the Mount Lofty Ranges. Langhorne Creek station (24516) for example, does not appear to exhibit the same strength of trend. Langhorne Creek lies not in the Mount Lofty Ranges proper, but on the plains, and as such may not be directly affected by changes to rainfall in the hills.

3.2 SPATIAL DISTRIBUTION OF RAINFALL

Although rainfall records from the ten sites are spread evenly throughout the catchment, it is desirable to estimate what proportion of the rain falling at a site might be some distance from the station. The spatial distribution of rainfall varies markedly over the catchment, decreasing in a northwest to southeast direction.

A rainfall surface with resolution of 0.01 degrees (~1 km^2) was developed by the Bureau of Meteorology (BoM) (Fawcett et al. 2006) for DWLBC. This dataset used a total of ~800 rainfall stations in southeastern South Australia to determine climate averages at a monthly and annual time step for the period 1971–2000. These averages were then used to create the smoothed rainfall grid.

The values in the grid are then used to determine the proportional rainfall falling on each sub-catchment for input into the hydrological model. It assumes that the number of rain days at a sub-catchment is the same as the nearest station. The difference between the grid value and the value at the nearest rain station are converted to a rainfall factor which defines this proportion. This process is described in Figure 11. Thus, each modelling sub-catchment is assigned a rainfall factor which has been compared to the nearest or most appropriate rainfall station. The rainfall stations used for each minor sub-catchment in the model are shown in Figure 12.

3.3 STREAMFLOW

Streamflow data within the Bremer River Catchment have been collected routinely since the mid-1970s. There are a number of long-term gauging stations, as well as shorter term gauging stations and water monitoring stations. All sites within the upper catchment (upstream of the confluence of the Bremer River and Rodwell Creek) are presented in Figure 13 and Table 6.

Gauging stations are usually solid structures, such as a concrete weir, or can be a stabilised rock bar with a modified ‘V‘ section to control the height of flow within a pool where the water is measured. Most of the state’s existing gauging networks were established ~30 years ago, and many are still operational.

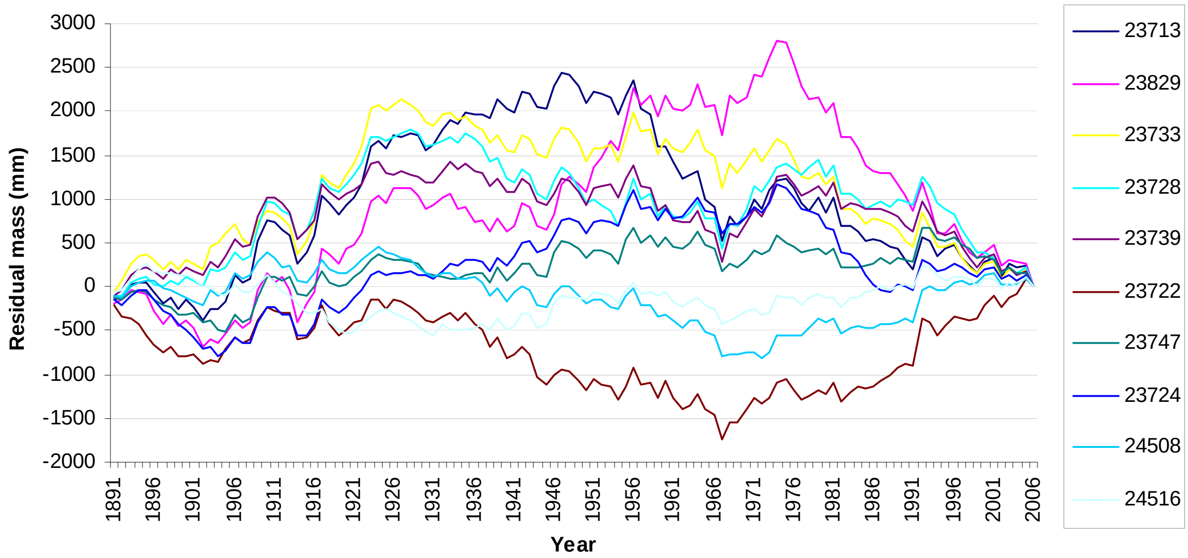


Figure 9 **Residual mass curves – all stations used in the Bremer River model, 1895–2006**

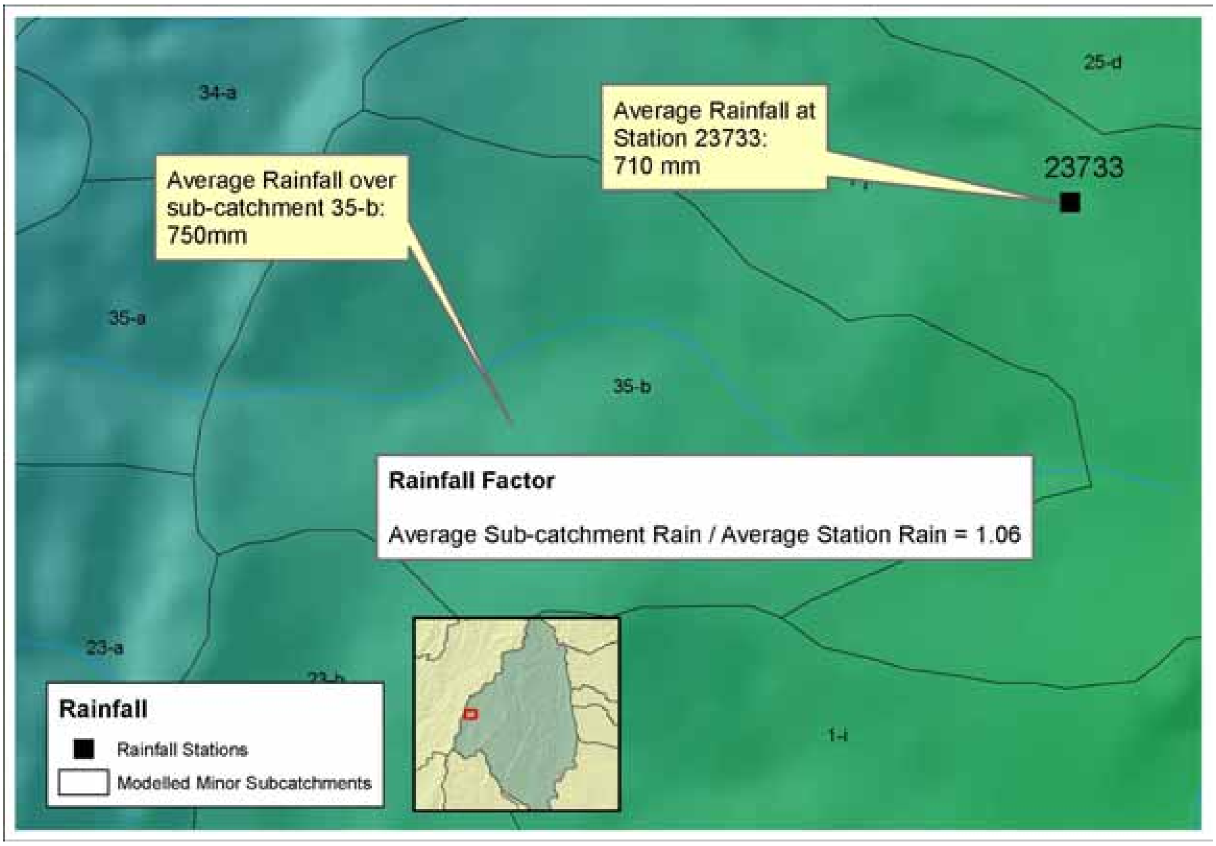


Figure 10 **Rainfall analysis – spatial adjustment of rainfall for modelling the Bremer Catchment**

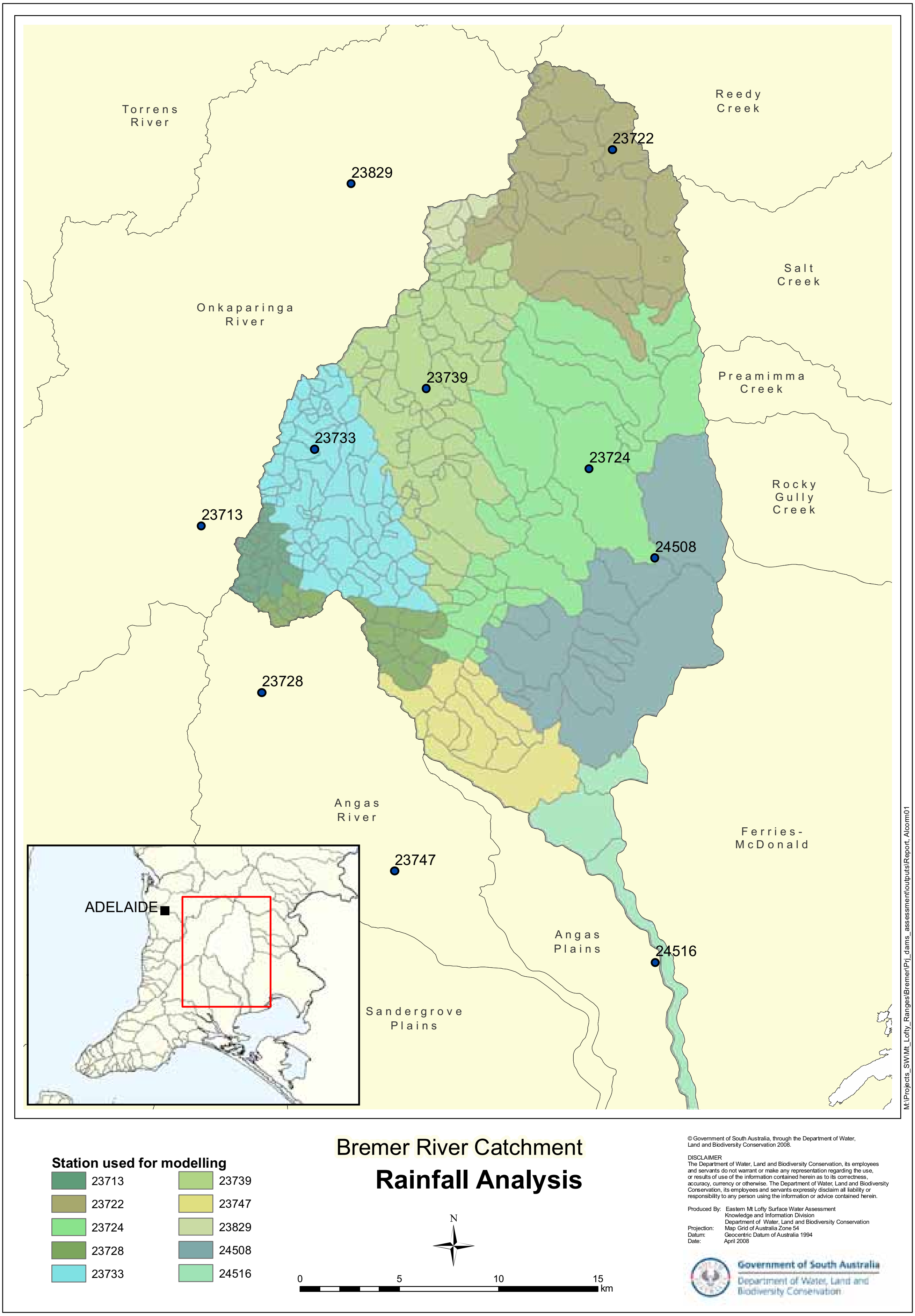


Figure 11 Rainfall analysis – rainfall station used for each minor sub-catchment

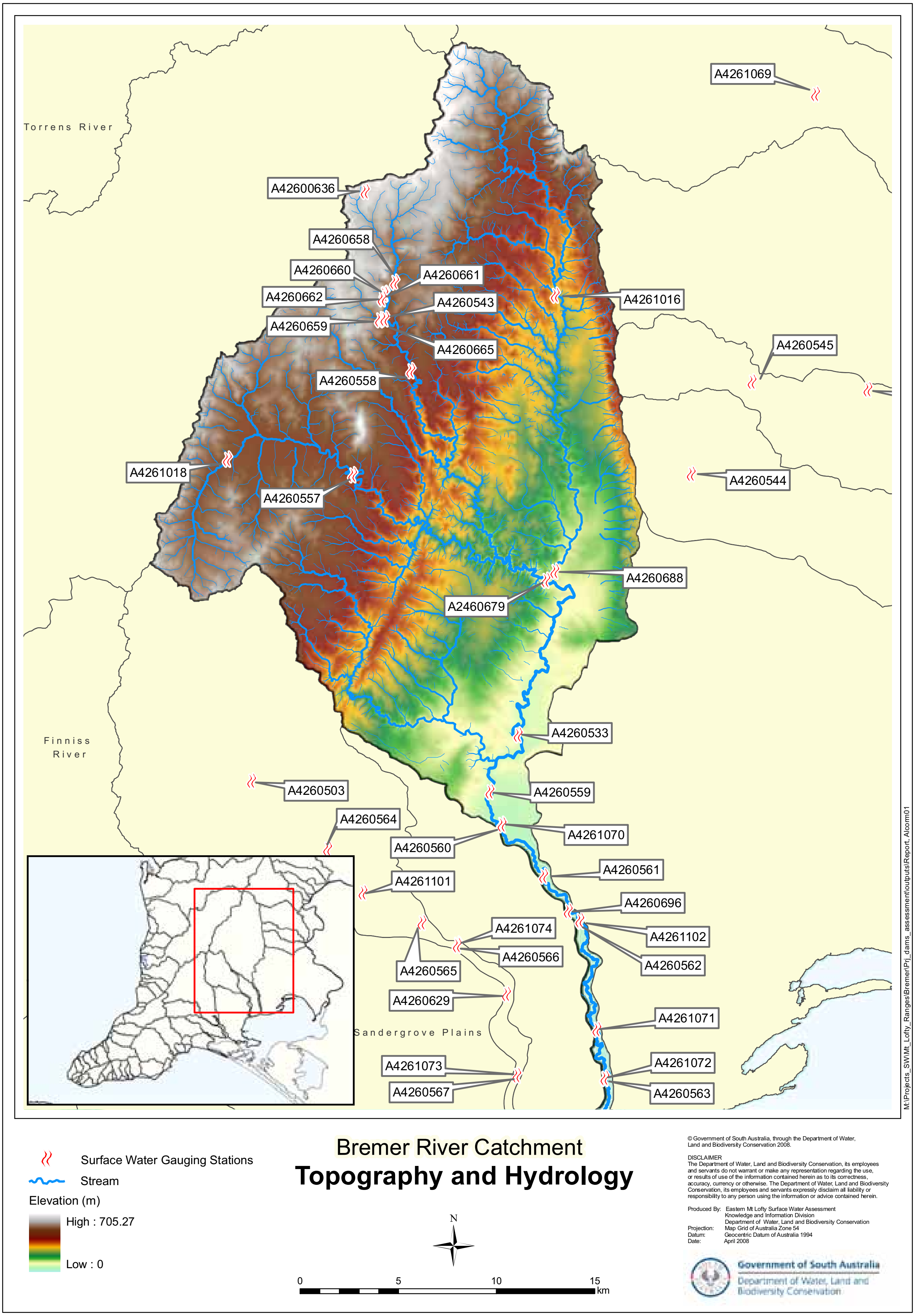


Figure 12 Topography and water monitoring stations in the Bremer River Catchment

Table 6 Water monitoring sites in the Bremer River Catchment

Site no.	Site name	Opened	Closed	Sub-catchment
A4260533	Bremer River at near Hartley	May-1973		Lower Bremer River
A4260557	Mount Barker Creek at D/S Mt Barker	Apr-1979		Upper Mount Barker Creek
A4260558	Dawesley Creek at Dawesley	Jun-1978		Dawesley Creek
A4260636	Bird-In-Hand Sewage Treatment Works	Mar-1991	Jan-1993	Dawesley Creek
A4260659	Dawesley Creek at D/S Brukunga Mine	Jul-1993		Dawesley Creek
A4260659	Dawesley Creek at U/S Brukunga Mine	Jul-1993		Dawesley Creek
A4260660	Days Creek at Brukunga Mine	Aug-1993		Dawesley Creek
A4260662	Jane Creek at Brukunga Mine	Aug-1993		Dawesley Creek
A4260679	Mt Barker Creek at U/S Bremer River Confluence	Jun-1997		Lower Mount Barker Creek
A4260688	Bremer River at U/S Mt Barker Creek Confluence	Oct-1997		Upper Bremer River
A4261018	Mt Barker Creek at Western Flat Creek	2003		Upper Mount Barker Creek

Monitoring stations usually consist of a water-level measuring device connected to a logger, which will either continuously or periodically record the water level in an existing pool or river reach. Some of these monitoring sites have now had theoretical ratings developed in an effort to add value to data sets of some considerable time period. Theoretical ratings should in general be used with caution, until proper validation of the rating has been attempted through the collection of streamflow gaugings. These sites are considered to be secondary data sources for the purposes of this investigation. See section 4.4 for a discussion on use of primary and secondary data in calibration of the rainfall–runoff model.

Only four sites were utilised in the calibration of the model — A4260533 (Bremer River), A4260557 (Upper Mount Barker Creek), A4260558 (Dawesley Creek), and A4260636 (Bird-In-Hand).

Several monitoring sites within the Dawesley Creek sub-catchment were established to monitor the effects of the Brukunga Mine on the water quality of Dawesley Creek. The mine was operational during 1955–1972 and is still undergoing remediation for the treatment of acid leachate that seeps into the creek. The hydrology of the Brukunga Mine site is the subject of other investigations and is not further elaborated here. Calibration of the Dawesley Creek model was carried out using streamflow data from the most downstream gauging station (A4260558).

The Mount Barker Creek sub-catchment is significant in the EMLR in that it contains the major urban town of Mount Barker. It also includes the small town of Littlehampton.

In the headwaters of the catchment, the land is predominantly rural in nature, not unlike the rest of the EMLR, but the town of Mount Barker lies approximately in the middle of Upper Mount Barker Creek sub-catchment (Fig. 3). This sub-catchment is monitored for streamflow at station A4260557 which accounts for an urban flow contribution for both Mount Barker and Littlehampton.

Both towns have water supplied by SA water, and have effluent and stormwater outflows. Effluent from both towns is routed through the Mount Barker Creek Sewage Treatment and Effluent Disposal System (STEDS), which is treated before being discharged through the

Laratinga Wetlands and ultimately to Mount Barker Creek upstream of A4260557. Some water is extracted for irrigation purposes prior to being discharged the creek.

3.4 SEWAGE TREATMENT AND EFFLUENT DISPOSAL SYSTEMS (STEDS) AND CATCHMENT INFLOWS

Currently in the Upper Bremer Catchment there are three main effluent disposal schemes in place—Mount Barker – Littlehampton (Fig. 15), Nairne–Brukunga, and Bird-In-Hand.

3.4.1 MOUNT BARKER–LITTLEHAMPTON SCHEME

Servicing the towns of Mount Barker and Littlehampton, this scheme consists of a pump station, emergency storage basin, two facultative oxidation lagoons, dissolved air flotation and continuous micro-filtration. The effluent is treated to a Class A standard before being routed through the Laratinga Wetland system.

Discharge from the wetland system is to Mount Barker Creek, with a proportion currently being pumped to a private irrigation system.

It is estimated that the current inflow to the scheme is ~1.9 ML/d based on a per-capita figure of 215 L/person/d (this figure includes a per-capita industrial usage figure; the usual figure for an urban centre is estimated at 140 L/person/d).

Data were obtained from the Environment Protection Authority (EPA) for station outflows for the years 2001–05 (Fig. 14). These data were then used to create an extended dataset to cover the expected span of the modelling. An average monthly outflow distribution was created and extended back to 1970 in order to complete the modelling. This study made no assumptions regarding changing population during that time. Irrigation off-take, during the period July 2002 to June 2003 was not recorded, so discharges from the Laratinga Wetland may be overestimated during that period.

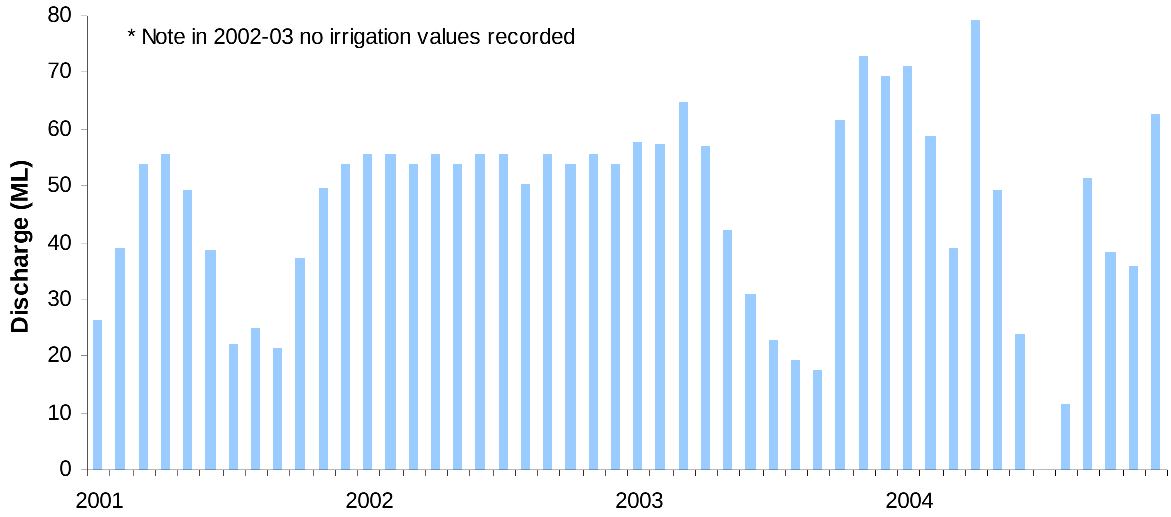


Figure 13 Mt Barker Waste Water Treatment Plant effluent discharge to wetlands

Figure 14 Mount Barker Wastewater Treatment Plant and Laratinga Wetlands

3.4.2 NAIRNE–BRUKUNGA SCHEME

Flow comes from a sewerage system at Brukunga to a lagoon system downstream of the town of Nairne. It is held here in a series of lagoons before being discharged to Nairne Creek. The outflow from this system was assumed to be negligible and was not explicitly accounted for in this study.

3.4.3 BIRD-IN-HAND TREATMENT WORKS

The Bird-in-Hand Treatment Works services the towns of Woodside, Lobethal and Charleston (Fig. 16). Effluent is treated through a series of ponds before being released into the very upper reaches of the Dawesley Creek sub-catchment.

Figure 15 Bird-in-Hand effluent ponds in the headwaters of the Dawesley Creek sub-catchment

The Bird-in-Hand Treatment Works has a combination of measured inflow and measured and estimated outflows for two main periods. During 1991 and 1992, flow was measured via a ‘V-notch’ weir at the outflow point to Dawesley Creek. Inflow to the plant was measured by mag-flow meter from 1996–2001, and outflows estimated by pump run times from 2001 onwards.

A daily dataset was derived from a combination of measured and estimated inflows, as well as outflows.

Where inflows were used, evaporation from the holding ponds was calculated to produce an outflow volume for the month. Monthly data obtained from SA Water can be seen in Appendix F.

3.4.4 DATA INPUTS TO WATERCRESS MODEL

Using the above data, estimates for daily flows as inputs to the model were calculated. This was done by firstly creating a monthly distribution based on the limited records available from the Mount Barker STEDS and estimates made for the Nairne–Brukunga STEDS. Due to the limited estimated record available from the EPA, estimates back to 1970 were made and proportioned between the two schemes. The monthly distribution was then redistributed to a daily flow value by simply dividing by the number of days in the month.

Mount Barker STEDS outflows were then routed through a simulated storage (Laratinga Wetlands) before being discharged to Mount Barker Creek.

4. SURFACE WATER MODELLING

4.1 OVERVIEW

Hydrologic models are conceptual models that represent the various components of the hydrologic cycle (e.g. rainfall, interception, evaporation, infiltration, surface runoff, groundwater recharge and baseflow) and the links between them. The components and the links of the hydrological cycle are represented by mathematical functions that are built into a model by using computer-programming languages. The models are built to simulate catchment conditions, to generate long-term data, and to enhance further understanding of the hydrological behaviour of catchments. They are further used for assessment of the impacts of various changes and activities within the catchment.

In this study, the hydrological model used was a rainfall–runoff water balance model.

4.2 METHODOLOGY

WaterCRESS (Cresswell 2002), a PC based water-balance modelling platform, was used for construction of the model in this study. This modelling platform incorporates some of the most widely used models in Australia (e.g. AWBM, SIMHYD and WC-1). WaterCRESS allows the incorporation of different components in its water balance models, such as:

- Demand components, which include town and rural demands
- Catchment components, which include rural and urban catchments
- Storage components, which include reservoir, aquifer, tank, and off-stream dam
- Treatment components, which include sewage treatment works and wetlands
- Transfer components, which include weir and routing components.

A model is then constructed as a series of ‘nodes’, each being one of the components mentioned above. The nodes are then linked based on the drainage direction to form one major catchment.

4.3 MODEL CONSTRUCTION

4.3.1 MODEL NODES

Using the criteria described in section 2.3, the Bremer River Catchment was divided into 278 rural catchment nodes.

The model chosen for this analysis was WC-1 (Cresswell 2002), due to its suitability for modelling ephemeral streams, such as those found in the Mount Lofty Ranges, and its use in previous technical investigations in this series. The WC-1 model is described in greater detail in Appendix C.

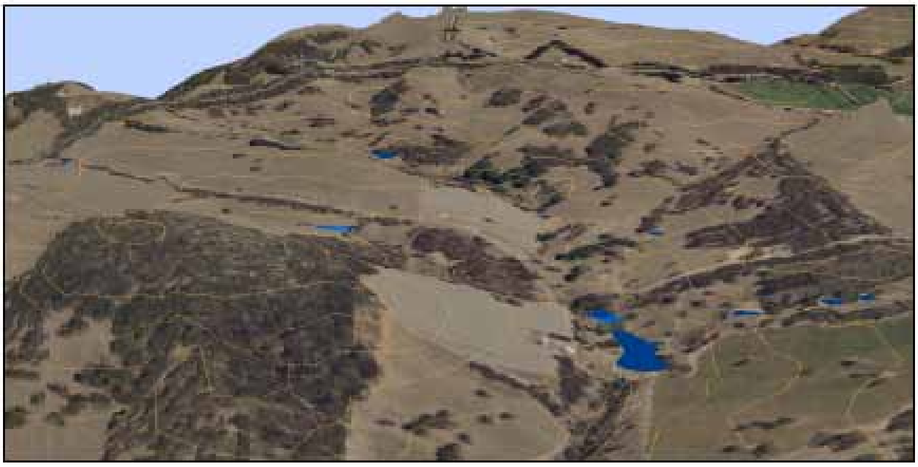


Figure 16a – Adding contours and farm dams to catchment map

Figure 16b – Delineating sub-catchments based on the layout of the catchment

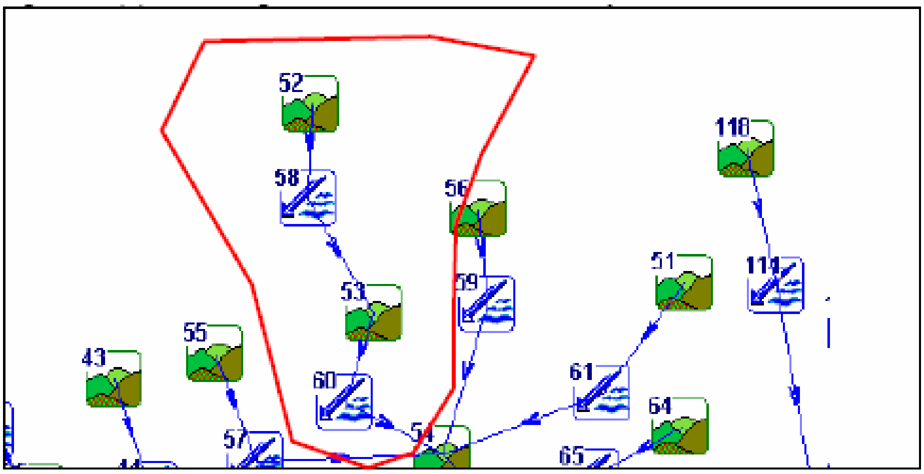


Figure 16c – Converting the digitised sub-catchment map into WaterCRESS model

Figure 16 Representation of sub-catchment and dam nodes in WaterCRESS Model

4.3.2 CATCHMENT NODES

Catchment nodes incorporate information derived from the land-use analysis outlined in section 2.2. This information generally includes:

- area
- nearest rainfall station and corresponding rainfall adjustment factor
- model catchment parameters
- model type — WC-1 is the model type used here (see Appendix C for description of model parameters)
- spatial location.

These data are migrated from the Geographic Information System (GIS) format into the model using an automated procedure developed to minimise error due to the large scale of this model.

The WaterCRESS platform allows for multiple catchment parameter sets to account for differences in hydrologic properties across the catchment. This is particularly useful for the Bremer River model due to the varied nature of the catchment. Three different parameter sets were used to describe the catchment area above the three main calibration points. For ungauged areas, the most appropriate catchment set was selected after calibration of gauged sub-catchments, based on various factors including soil properties, rainfall extent and topography. This is essentially a subjective, qualitative approach, which, however, is necessary in the absence of quality streamflow data for all the major sub-catchments.

4.3.3 URBAN NODES

Urban nodes representing the towns of Mount Barker, Littlehampton, Nairne and Brukunga are included in the model. Urban areas are calculated by digitising in GIS the extent of the towns and their surrounding impervious areas. Based on visual inspection, an impervious fraction coefficient is determined and multiplied by the area derived. This defines the actual impervious area, as the digitisation process does not differentiate between, for example, the backyard of a house and its driveway. The size of the coefficient is dependent on the scale and detail of digitisation, and the density of the urban or industrial development. This provides WaterCRESS an impervious area on which to run the urban model.

The urban model used within WaterCRESS is an 'Initial Loss – Continuing Loss' (ILCL) model. It assumes that some amount of initial loss in the event of rainfall will first occur (e.g. when a small amount of rain falls on a roof, most will evaporate before becoming roof runoff to stormwater or a rainwater tank). Typical values for initial loss are 1 mm for roof runoff and 2 mm for pavement and roads. These values may be altered but remain fixed in this model.

Continuing loss is determined by means of a loss coefficient (between 0 and 1), which determines the fraction of water that is removed. What is left is the effective rainfall which is available as runoff to the catchment.

4.3.4 DAM NODES

Each catchment node with farm dams was then linked to an off-stream dam node (Fig. 17). The input data for each off-stream dam node were:

- dam storage volume, which in this case was the cumulative storage capacity of all the dams in the minor sub-catchment
- nearest rainfall station and corresponding rainfall adjustment factor
- dam capacity to dam surface area relationship, for use in calculating surface evaporation at less than full supply level
- maximum daily diversion to the dam, which in this case was the maximum capacity of the dam
- fraction of total catchment runoff diverted to the dam.

The fraction of catchment runoff diverted to the dam was dependent on the location of the dam(s) and the probable catchment runoff captured by the dam(s). For example, this fraction was 1.0 if there was a large on-stream dam located on the downstream end of the catchment. It would be considered a controlling dam to control or block the runoff from the entire sub-catchment. This fraction was reduced when the total catchment storage was made up of numerous smaller dams spread throughout the catchment or when the dams were truly off-stream.

Annual water usage from all dams was assumed to be 30% of the total dam capacity for a stock and domestic dam, and 50% for an irrigation dam (Fig. 6). This rate of water usage was found to allow for some carryover of storage to following years in previously calibrated models for other catchments in the Mount Lofty Ranges. This is the maximum demand attached to the dam and may not be achieved in any given year depending on the supply available over the year. A recent study of over 700 dams across the Mount Lofty Ranges supports this figure of 30% as an average water use from farm dams (McMurray 2004a).

4.3.5 ROUTING NODES

Due to the nature of the daily time step model used in this investigation, it is necessary to route flows through the system. Despite the limitations in modelling daily flows accurately, increased reliance is being placed on models for accurate daily output. Modelled daily output has been used to identify and quantify environmental water requirements (MREFTP 2003). However, due care must be taken such that the temporal scale is appropriate for the intended use.

Routing nodes have been used in this model in areas where representation of the catchment was limited to only the use of a rural catchment node (i.e. where there are long stream lengths with no intercepting features). Addition of routing nodes enabled flows to be delayed where necessary, to achieve a better representation of the daily observed record.

4.3.6 STREAM LOSS NODE

Upon inspection of the flow frequency curves for the gauging station at Hartley and other upstream stations (A4260679, A4260688, A4260557), it is apparent that between the confluence of the Bremer River and Mount Barker Creek and Hartley, there is a significant loss component through the stream bed. In order to compensate for this it is necessary to introduce a loss component into the model.

For this study, stream losses were simulated using a weir node to divert flows below a certain threshold at a specified rate. Derivation of the threshold and rate formed part of the calibration process, and a trial and error method was used. Following model calibration at the gauging at Hartley, it was estimated that losses in that reach are on average 350 ML/y, but vary depending on upstream flow each year. For example, using a threshold measure would result in diversion of more lower magnitude flows during a year.

4.4 MODEL CALIBRATION

Model calibration involves comparing the runoff generated from the model against recorded streamflow. The basic process is to vary the catchment parameter values of the WC-1 model until good representation of the recorded data is achieved.

As noted in section 3.3, there have been multiple continuous recordings made within the Bremer River Catchment, but for varied time frames and of various quality. The calibration data used here may be defined as either primary or secondary. Thus, the calibration is carried out in the following sequence:

1. Calibrate the most upstream sub-catchments that have streamflow data (primary data)
2. Assign regional parameter sets to ungauged upper catchments
3. Calibrate downstream sites (primary data)
4. Assess secondary streamflow sites for calibration and adjust parameters if necessary
5. Assign regional parameter sets to remaining ungauged catchments
6. Iterate from step 1, adjusting parameters as necessary to achieve a good fit to all stations, with a higher weighting on the primary stations.

Calibration at each step above was carried out with a combination of methods.

1. Initially, regional catchment parameter estimates were gathered from hydrologic models developed in the same region. Using these parameters gave an initial starting point for the calibration process.
2. Using a genetic algorithm (GA) calibration tool built into the WaterCRESS platform, various parameters were coupled and optimised until suitable calibration statistics were found.
3. Finally, fine adjustment of parameters was applied in order to achieve the best calibration possible.

Using the GA tool to optimise the parameters was initially helpful but did not fully account for some of the requirements of the modelling process. For example, while it is possible within the GA to optimise to different objective functions and use several error models, it was necessary to visually fit some aspects of the calibration output, such as the difference in flow duration curves. Optimisation of low-flows is an imperative part of model requirement and as such may require more weight than, for example, monthly flow totals. Overall, the model parameters were fitted using both automated and visual fitting methods to ensure best optimisation for the expected use of the model and model output.

4.4.1 PRIMARY CALIBRATION DATA

Primary data include data from those sites with long periods of continuous, high quality data collection. Data from these sites were used to carry out the initial calibration.

A4260557: 1979–2007 High quality data

Used to calibrate the Upper Mount Barker Creek sub-catchment for the catchment hydrologic properties and also the urban drainage component. Calibration of the urban nodes required inspection of summer flow peaks that may not have produced a catchment runoff response. Calibration of urban flows at a daily time scale is difficult owing to the quick response from urban areas to produce runoff.

A4260558: 1979–2007: High quality data

Used to calibrate the Dawesley Creek sub-catchment upstream of Dawesley. This is the most downstream gauge of the sub-catchment. Although there are other upstream sites, mostly established to monitor the impact of runoff from the rehabilitated Brukunga Mine site, it was decided to calibrate the model at a sub-catchment scale. Numerous studies have been completed for the site in the past and it was not the intention of this model to replicate these.

Calibration at a finer scale within this catchment would have been unnecessarily complex, owing to the Dawesley Creek diversion project and the inclusion of synthetic flow inputs from the Bird-in-Hand Treatment Works.

A4260533: 1973–2007: High quality data

Used to calibrate the remaining gauged catchments, most notably the Upper Bremer River sub-catchment, but also containing the as yet unquantified flow from the Nairne Creek and Lower Mount Barker Creek sub-catchments. This station contains the longest period of data, dating back to 1973, and is still operational. The calibration period though was set to be the same as the previous two gauging stations.

4.4.2 SECONDARY CALIBRATION DATA

Secondary data include that collected over shorter time periods, or of lesser quality. For example, two sites near the confluence of the Bremer River and Mount Barker Creek that were originally set up only as water-level monitoring sites were recently extended to include a rating to estimate streamflow. These data are of shorter duration (1997–present), and are only backed up by a couple of streamflow gaugings.

Station A4261018 (Western Flat Creek at U/S Mt Barker) was installed in 2002 so it also has a relatively short data record. Data from this site were only used as a secondary check on the calibration parameters which were assumed for the entire Upper Mount Barker Creek sub-catchment.

4.4.3 UNGAUGED CATCHMENT PARAMETERS

Of all the sub-catchments in the Bremer River Catchment, the Upper Mount Barker Creek and Dawesley Creek sub-catchments are completely gauged at the end of the catchment. Nairne Creek, Red Creek and Rodwell Creek sub-catchments are completely ungauged. The Upper Bremer River and Lower Mount Barker Creek have only a provisional rating, which is only used in secondary calibration of the model. Using the gauging station at Hartley to determine sub-catchment parameters for the Nairne, Upper Bremer, and Lower Mount Barker is problematic because the flows at Hartley are affected by all three sub-catchments. The simplest case would be to calibrate at that point and assign the same parameter values for all ungauged sub-catchments upstream. However, this would be inappropriate due to the difference in hydrologic characteristics of the sub-catchments.

Analysis of available soil data makes it possible to group sub-catchments with similar hydrologic properties. There are many measured soil properties available. The following three measures were investigated here to determine similarity of catchment properties for regional parameterisation.

Surface texture: A measure of the approximate clay content of the soil (Table 7).

Table 7 Soil attribute – surface texture

Attribute class	Surface texture	Approximate clay content
S	Sand	Less than 5%
LS	Loamy sand, clayey sand	5–10%
SL	Sandy loam, fine sandy loam	10–20%
L	Loam, silty loam, light sandy clay loam	About 25%
SCL	Sandy clay loam	20–30%
CL	Clay loam, silty clay loam, fine sandy clay loam	30–35%
CN	Non-cracking clay	More than 35%
CC	Cracking clay	More than 35%
X	Not applicable	

Available water-holding capacity: The approximate depth of a soil, estimated from such attributes as soil texture structure and stone content (Table 8).

Potential root-zone depth (Crop Type CC): Represents to potential root zone depth of such hardy crops as grapes, vines and olives (Table 9). This depends on such attributes as soil physical condition, hardpan, soluble salts, boron, alkalinity, acidity and sodicity.

Table 8 Soil attribute – available water-holding capacity

Attribute class	Approximate available water-holding capacity
1	More than 100 mm
2	70–100 mm
3	40–70 mm
4	20–40 mm
5	Less than 20 mm
X	Not applicable

Table 9 Soil attribute – potential root zone depth

Attribute class	Average potential root-zone depth — Crop type CC
1	More than 100 cm
2	80–100 cm
3	60–80 cm
4	50–60 cm
5	40–50 cm
6	30–40 cm
7	20–30 cm
8	Less than 20 cm
X	Not applicable

Analysis of each type of classification was carried out for each sub-catchment. The decision on what constitutes ’like‘ sub-catchments was subjective due to the nature of the data and the three soil properties chosen for measurement. Likewise, analysis based on visual inspection of the spatial data alone may be misread, depending on the intended scale of use. At a scale of 1:250 000 as seen here (Fig. 18), a subjective qualitative judgment is probably appropriate for the purpose of this model.

Figure 18 shows the spatial extent of the soil properties described above.

Nairne Creek sub-catchment was therefore assigned the same sub-catchment parameter set as the Upper Mount Barker Creek sub-catchment, due to its similarities in rainfall, topography, and soil properties. Lower Mount Barker Creek was bisected and the upper half was given the sub-catchment parameters as for Dawesley Creek, while the lower half was assumed to be the same as the Upper and Lower Bremer River sub-catchments.

Likewise, the upper half of Rodwell Creek was assumed to have the same parameters as Dawesley Creek sub-catchment, and the lower half of Rodwell Creek and Red Creek were both assigned the Upper and Lower Bremer parameter set. It is this parameter set that was then calibrated to fit the flows at the Hartley gauging station.

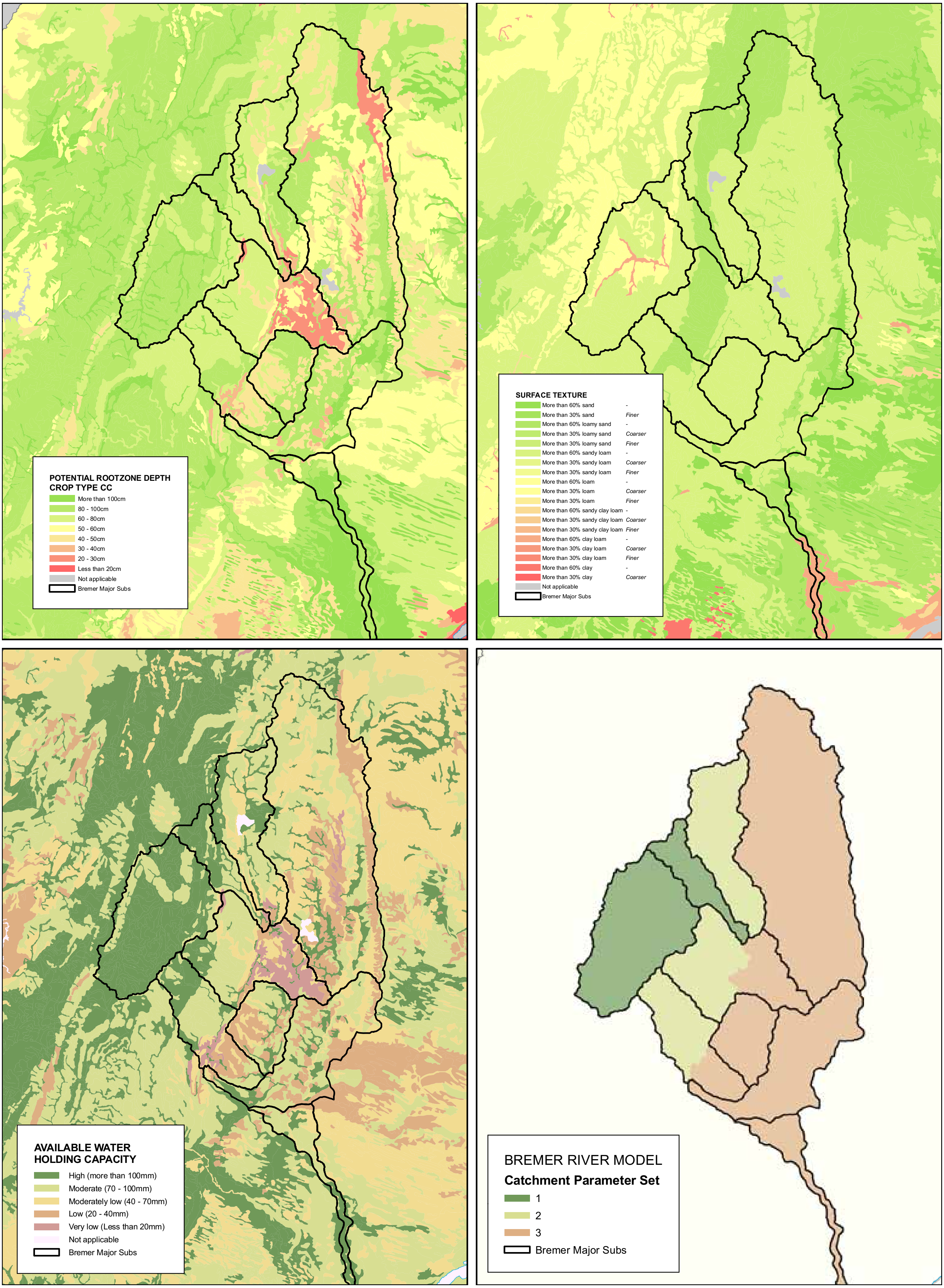


Figure 17 Bremer River Catchment soil physical properties and model parameterisations

4.4.4 CALIBRATION STATISTICS

For each of the three primary data sources the data were calibrated with the aim of achieving the best fit using the following three statistics:

- Percentage difference from mean and median
- Coefficient of Determination (R2)
- Coefficient of Efficiency (E).

Calibration statistics and the methods used to determine values are described in Appendix A.

4.4.5 CALIBRATION RESULTS

4.4.5.1 Upper Mount Barker Creek Sub-catchment

Table 10 Calibration statistics for Upper Mount Barker Creek sub-catchment

Upper Mount Barker Creek	Annual		Monthly		Daily	
	Modelled	*Observed*	*Modelled*	*Observed*	*Modelled*	*Observed*
Mean	6252.0	6396.9	520.7	532.2	17.1	17.5
Median	5409.1	5502.4	124.8	129.3	3.0	3.1
R^2	0.85		0.83		0.76	
E	0.84		0.82		0.75	
% Volume Difference	2.26		2.15		2.19	

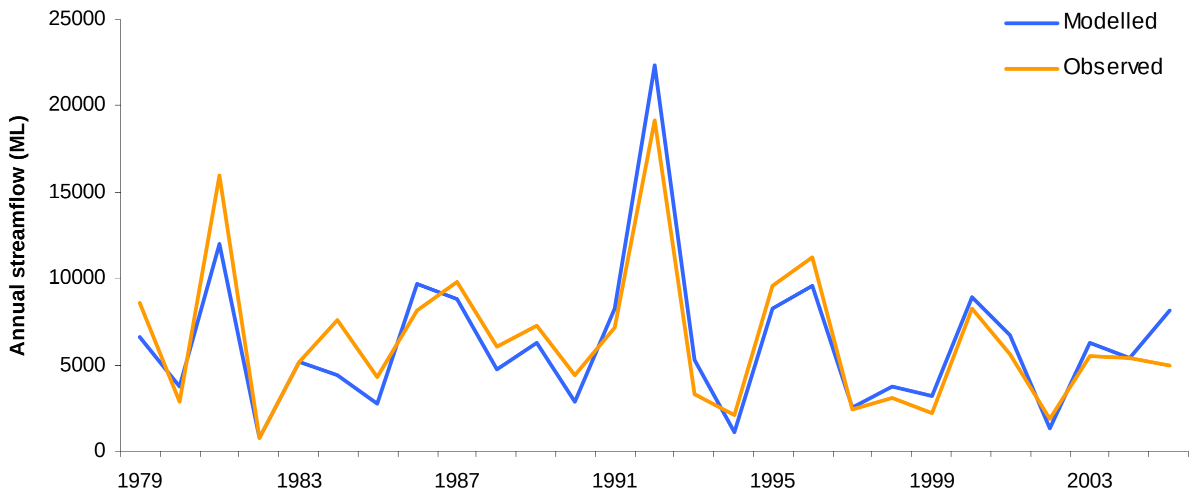


Figure 18 Upper Mount Barker Creek sub-catchment annual calibration chart

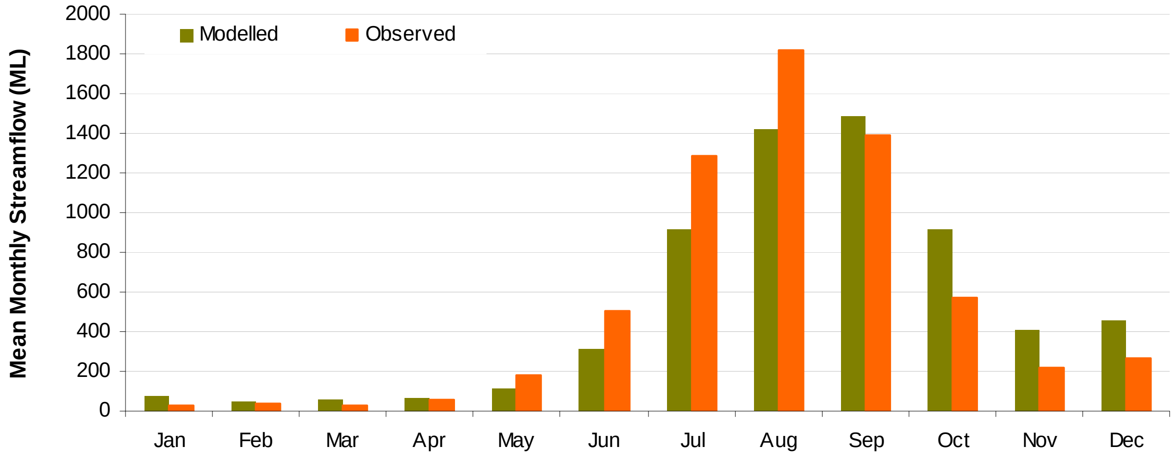


Figure 19 Upper Mount Barker Creek sub-catchment mean monthly streamflow calibration chart

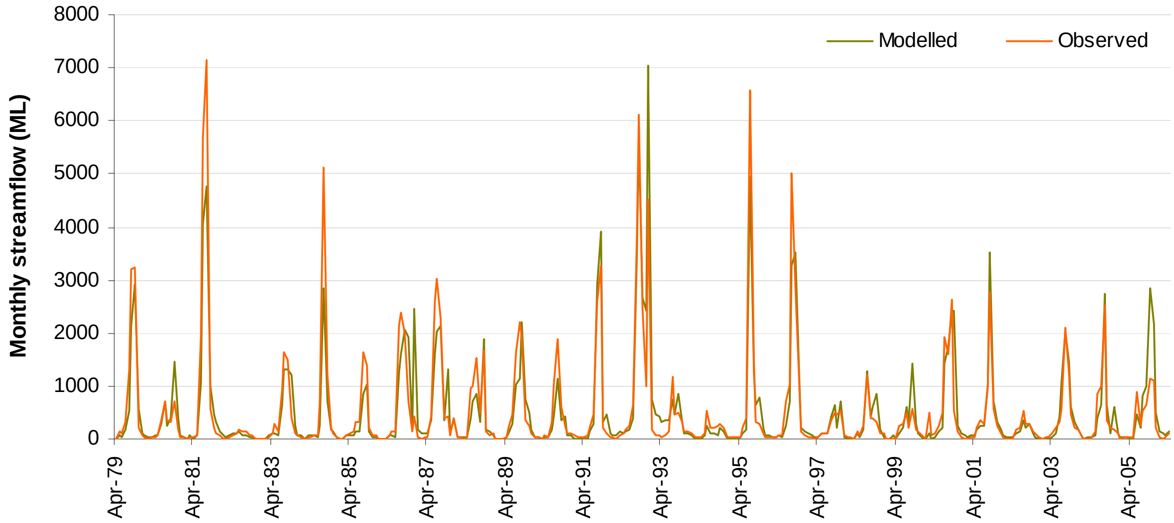


Figure 20 Upper Mount Barker Creek sub-catchment monthly streamflow calibration chart

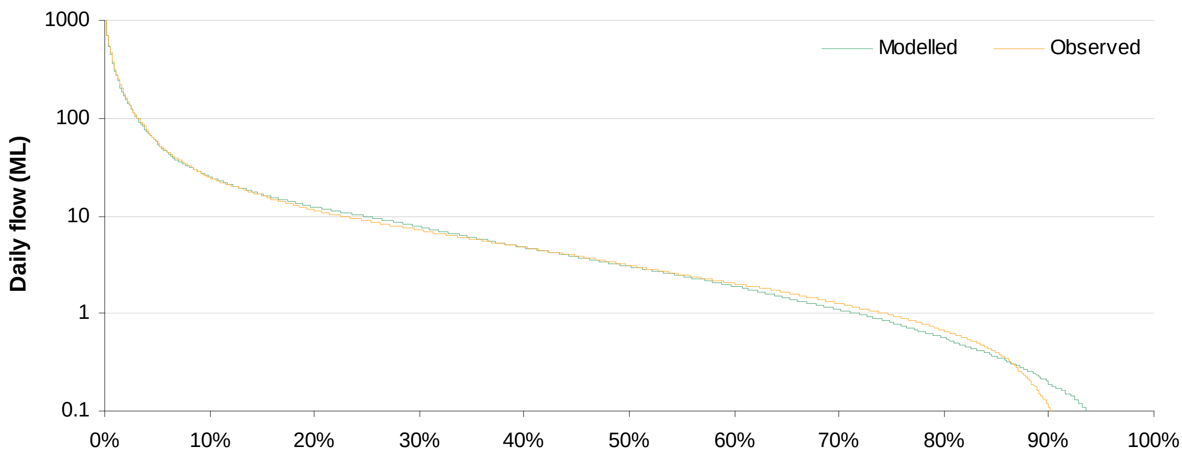


Figure 21 Upper Mount Barker Creek sub-catchment calibration daily flow duration curve

4.4.5.2 Dawesley Creek Sub-catchment

Table 11 Calibration statistics for Dawesley Creek sub-catchment

Dawesley Creek	Annual		Monthly		Daily	
	Modelled	*Observed*	*Modelled*	*Observed*	*Modelled*	*Observed*
Mean	2621.0	2494.6	218.1	207.2	7.0	6.6
Median	2427.7	2300.4	26.3	33.2	0.7	0.8
R^2	0.74		0.77		0.69	
E	0.72		0.77		0.6	
% Volume Difference	3.18		3.1		3.1	

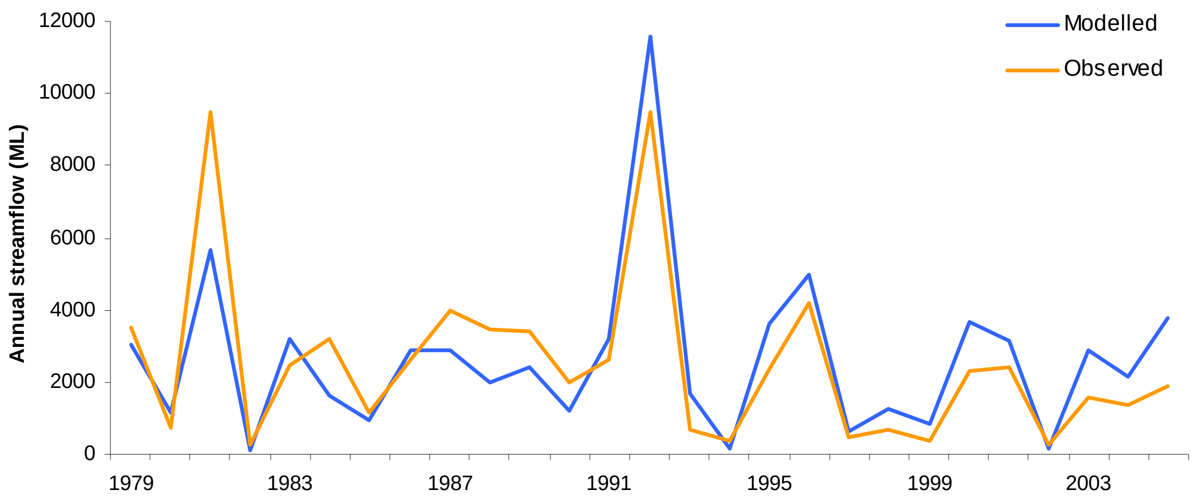


Figure 22 Dawesley Creek sub-catchment annual calibration chart

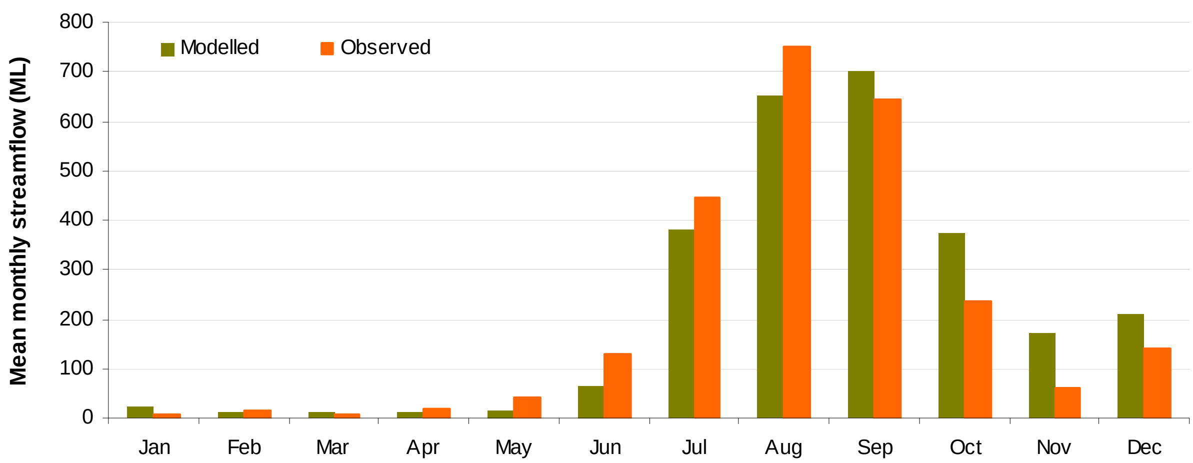


Figure 23 Dawesley Creek sub-catchment mean monthly streamflow calibration chart

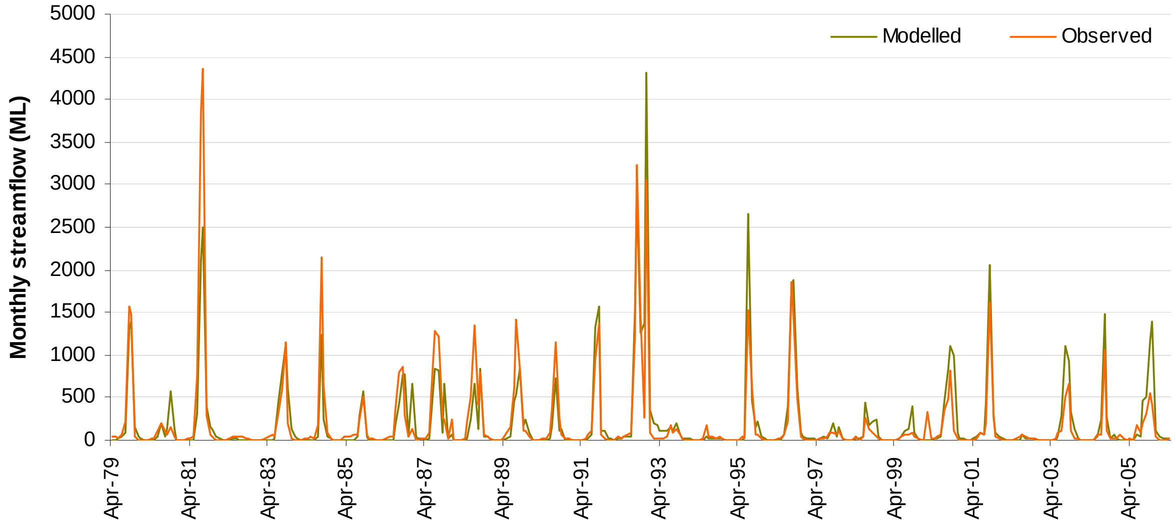


Figure 24 Dawesley Creek sub-catchment monthly streamflow calibration chart

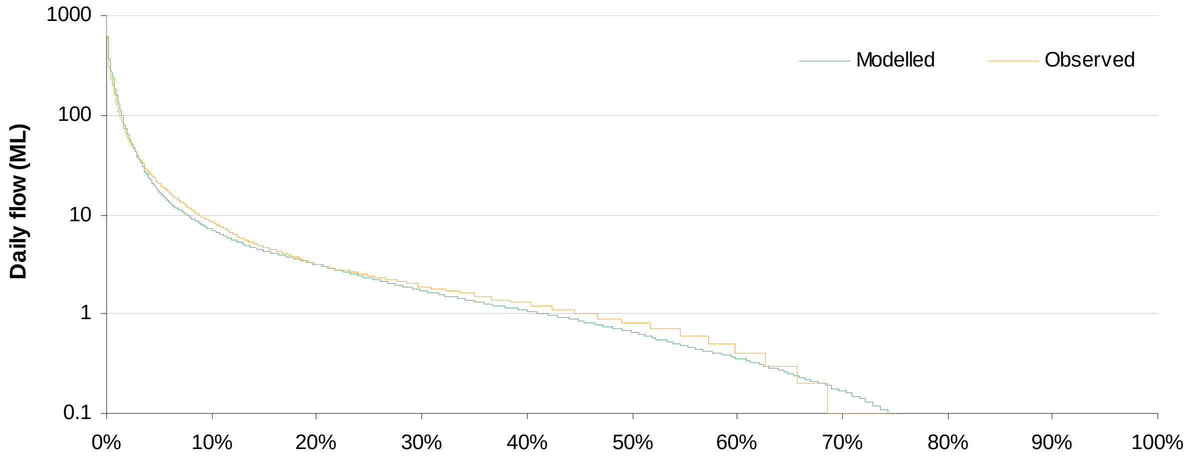


Figure 25 Dawesley Creek sub-catchment calibration daily flow duration curve

4.4.5.3 Bremer River at Hartley

Table 12 Calibration statistics for Bremer River at Hartley

Bremer River At Hartley	Annual		Monthly		Daily	
	Modelled	*Observed*	*Modelled*	*Observed*	*Modelled*	*Observed*
Mean	16746.8	16647.8	1365.0	1348.7	44.7	44.2
Median	13927.4	13160.3	141.9	135.8	3.5	2.5
Confidence Level (95.0%)	5987.1	5450.9	339.7	328.1	4.6	4.1
R^2	0.83		0.81		0.74	
E	0.79		0.82		0.67	
% Volume Difference	0.6		1.21		1.21	

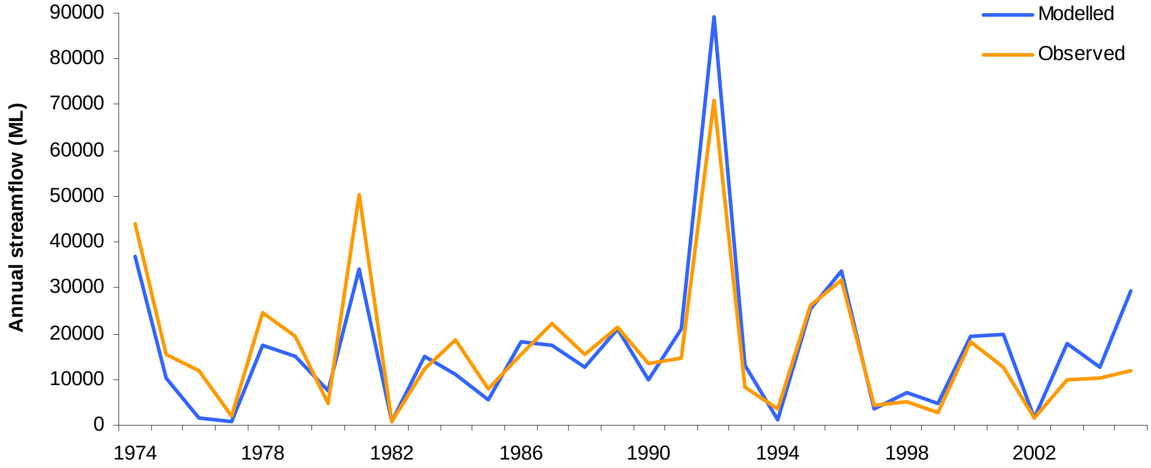


Figure 26 **Bremer River annual streamflow calibration chart**

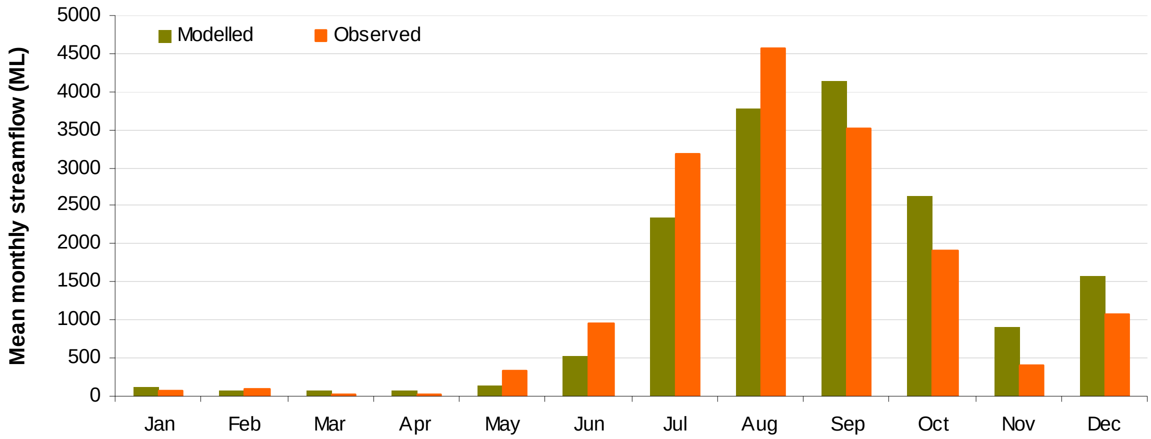


Figure 27 **Bremer River mean monthly streamflow calibration chart**

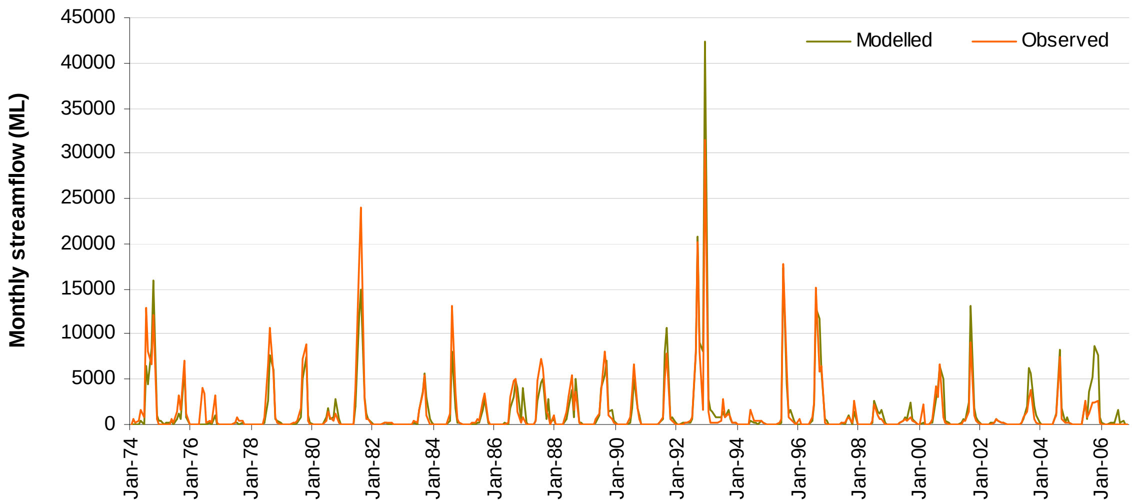


Figure 28 **Bremer River monthly streamflow calibration chart**

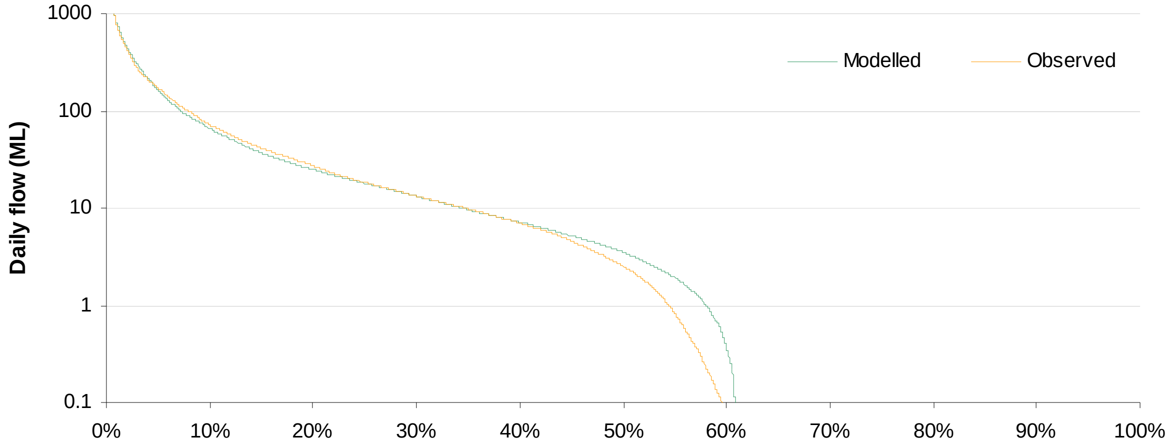


Figure 29 Bremer River calibration daily flow duration curve

Calibration at all three gauging stations was firstly carried out for the same time period (1980–2005) in order to correctly weight the observations and modelled outputs to the same range. This model is primarily intended to be able to reproduce the catchment yield over a long period of time (30 years). Therefore, calibration of different parts of the model to different time periods is undesirable due to the expected use of the model.

Note that the calibration of annual yield, whilst showing good calibration statistics, will not necessarily reproduce the exact yield for a given year. However, it is a reasonable expectation of the model to reproduce a good approximation of the 30-year average and median flows.

Monthly and daily flow calibration is generally a more difficult task, but a reasonable result was obtained. Daily flow calibration at Hartley (Bremer River) was the most difficult as it relied on correct calibration of the upstream catchments, correct assumptions about the catchment parameter sets for the ungauged catchments (Nairne Creek, Lower Mount Barker Creek, Upper and Lower Bremer River), and finally a reasonable estimate of stream loss in the Lower Bremer River sub-catchment.

5. SCENARIO MODELLING

5.1 RAINFALL–RUNOFF RELATIONSHIP

5.1.1 ANNUAL RUNOFF COEFFICIENT

The relationship between rainfall on a catchment and the resultant runoff can be described in a number of ways. The simplest way is to use a linear runoff coefficient where:

Runoff coefficient = mean annual runoff (mm) / mean annual rainfall (mm).

Runoff coefficients are given for each of the modelled sub-catchments in Table 13 below.

Table 13 Runoff coefficients – Bremer River sub-catchments

Bremer River Sub-catchments	Annual rain (mm)	Annual runoff (ML)	Area (km^2)	Annual runoff (mm)	Runoff coefficient
Upper Mount Barker Creek	740	5968	86	70	11%
Nairne Creek	674	1538	23	66	11%
Dawesley Creek	663	2941	56	53	9%
Lower Mount Barker Creek	537	1306	65	20	4%
Upper Bremer River	516	5107	195	26	5%
Lower Bremer River	429	130	68	2	1%
Rodwell Creek	582	976	45	22	5%
Red Creek	489	207	29	7	2%
Total Bremer River Catchment	579	19 493	567	34	7%

5.1.2 TANH CURVES

Another method used to represent the relationship is to plot runoff and rainfall against each other and fit a tanh hyperbolic function (equation 4). This method, as described by Grayson et al. (1996, pp.77–83), can more appropriately define runoff based on different rainfall. The non-linear nature of this relationship means that for higher rainfall events the runoff is more likely to be much higher than if a standard runoff coefficient was used. In most cases this can be 3–4 times higher. Tanh curves are described in more detail in Appendix B.

Equation 4:

$$Q = (P - L) - F \times \tanh[(P - L)/F]$$

where: Q = runoff (mm)

P = rainfall (mm)

L = notional loss (mm)

F = notional infiltration (mm).

The tanh relationship is normally used for annual and winter (May to November) runoff relationships, but it can be used for months or seasons. It is presented here for both annual runoff (Table 14) and winter (May to November, Table 15) adjusted runoff.

Table 14 Annual tanh (current) coefficients used for each Bremer River sub-catchment

Sub-catchment	L	F
Upper Mount Barker Creek	130	1000
Nairne Creek	100	950
Dawesley Creek	230	670
Lower Mount Barker Creek	210	890
Upper Bremer River	140	900
Lower Bremer River	220	1500
Rodwell Creek	375	420
Red Creek	275	850

Table 15 Winter adjusted (May–November 'no-dams') tanh coefficients used for each sub-catchment

Sub-catchment	L	F
Upper Mount Barker Creek	130	650
Nairne Creek	170	535
Dawesley Creek	195	480
Lower Mount Barker Creek	130	665
Upper Bremer River	95	620
Lower Bremer River	165	740
Rodwell Creek	150	515
Red Creek	125	945

Interpretation of the following tanh curves should be approached with caution. In Figure 32 for example, curves for each major sub-catchment are presented showing a scale of zero up to 1000 mm annual rainfall. However, it should be noted that the coefficients for most of the curves were derived for rainfall amounts significantly less than 1000 mm. It must therefore be emphasised that the curves should be interpreted only within the meaningful range of runoff for a particular region. For example, the rainfall range of Red Creek sub-catchment is only between 400–500 mm.

Tanh curves showing modelled data points for the individual sub-catchments, from which the tanh coefficients are derived, are provided in Appendix B.

Tanh curves for adjusted flow are shown in Figure 32. These curves show the range of expected winter runoff for the adjusted condition (with farm dams removed).

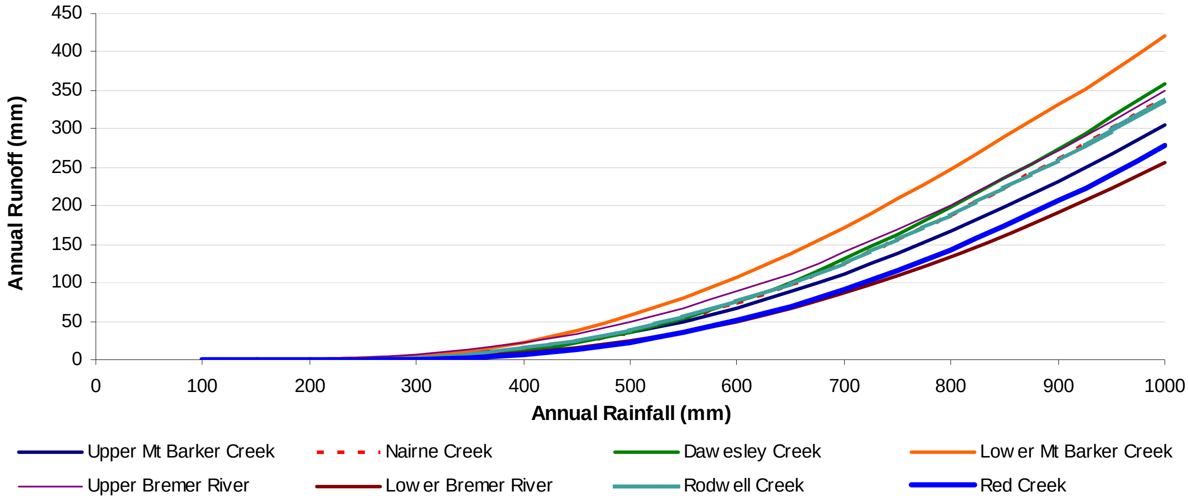


Figure 30 Annual tanh curves for each Bremer River sub-catchment

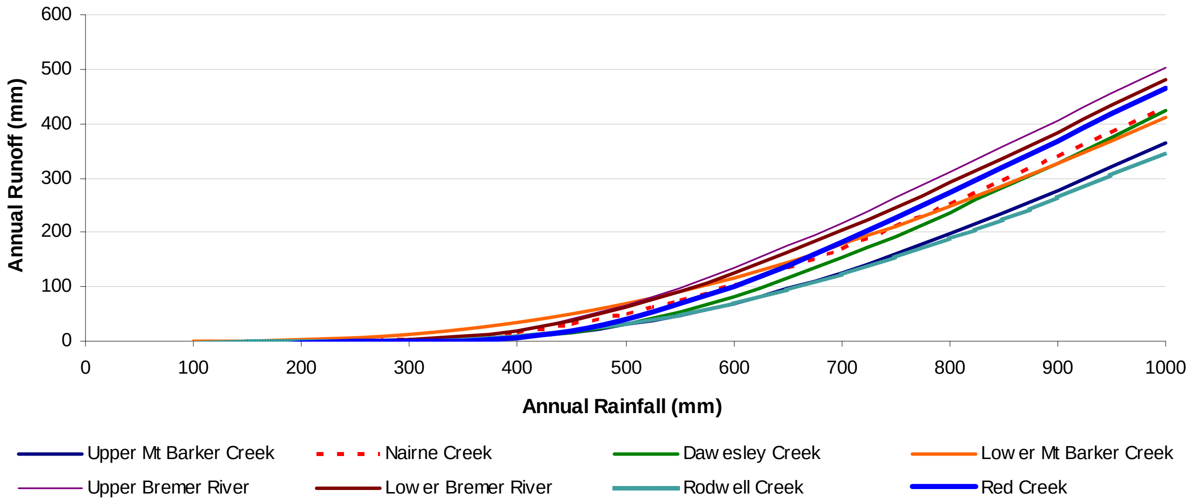


Figure 31 Winter (May–November) tanh curves for each Bremer River sub-catchment

5.2 CURRENT SCENARIO VERSUS "NO DAMS" SCENARIO

The purpose of this scenario is to assess the possible impacts that the development of farm dams may have had on the catchment. This is achieved by:

1. Modelling the current situation
2. Deriving a set of catchment hydrologic characteristics
3. Removing the dams from the model
4. Assessing the change in flows.

This scenario is also essential in determining the allowable level of farm dam development as defined in the catchment plan, as the rule requires an estimate of surface water flows before the development of the catchment.

It should be noted here that the calibrated model and its output makes no assumptions about land or water-use change over the period of assessment. Whilst it may be the case that, for example, the number of farm dams has increased considerably over the past 30 years, a constant level has been assumed. Regardless of any assumptions about land cover or land-use change, this flow describes flows from a catchment in its current state, with the impact of farm dams removed.

5.2.1 ANNUAL FLOWS

The reduction in mean annual flows can be directly attributed to the effect of farm dams capturing and using water, either through evaporation or irrigation (usage) demand (Fig. 33, Table 16). It follows that the largest impacts are seen in the sub-catchments with the greatest farm dam density as a proportion of runoff. The effect here is also amplified in sub-catchments such as Rodwell Creek, which has high development and lower average rainfall. It shows the largest impacts with 23% of annual streamflow being removed by farm dams. Mount Barker is the next most impacted with a 14% reduction in the mean annual streamflow. The lower reduction in streamflow compared to Rodwell Creek is due to the sub-catchment being in a higher rainfall area, despite also having high levels of development. Overall for the Bremer River Catchment, upstream of the plains, the reduction in mean annual streamflow is estimated to be 10% or ~2200 ML.

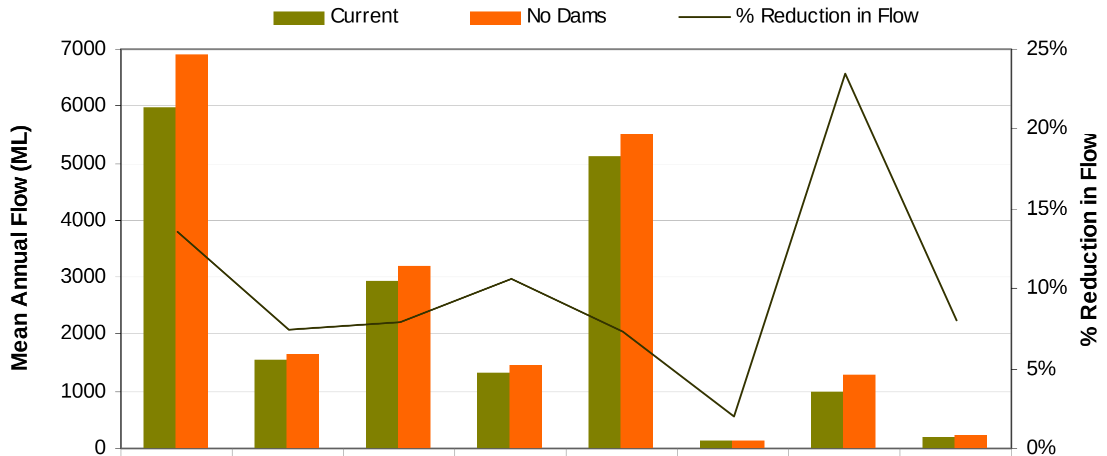
Table 16 Reduction in flow percentiles (exceeded)

Percentile (exceeded)	Mount Barker Creek			Bremer River			Total Bremer River		
	Current	*Adjusted*	*Reduction*	*Current*	*Adjusted*	*Reduction*	*Current*	*Adjusted*	*Reduction*
10th	47.5	53.1	11%	17.3	21.6	20%	68.6	78.6	13%
20th	20.9	25.3	17%	3.9	6.2	36%	25.8	32.3	20%
30th	12.3	16.6	26%	0.5	2.3	80%	13.0	19.1	32%
40th	7.7	11.5	33%	0.0	0.6	100%	7.1	12.2	42%
50th	5.1	8.3	39%	0.0	0.0	0%	3.5	8.1	57%
60th	3.3	6.0	45%	0.0	0.0	0%	0.4	4.8	92%
70th	1.9	4.2	54%	0.0	0.0	0%	0.0	2.1	100%
80th	0.8	2.5	67%	0.0	0.0	0%	0.0	0.0	100%
90th	0.1	0.9	91%	0.0	0.0	0%	0.0	0.0	0%

5.2.2 MONTHLY FLOWS

Reductions in flows for each month (as a percentage of mean monthly flow) are given below for each sub-catchment. Most sub-catchments exhibit the same pattern of flow reduction, with summer and autumn flows being most impacted due to most dams being empty and unable to spill. The effects on winter months, although relatively diminished, are still significantly reduced. For example, in Upper Mount Barker Creek, even September flows (the highest modelled month) are reduced by 5%.

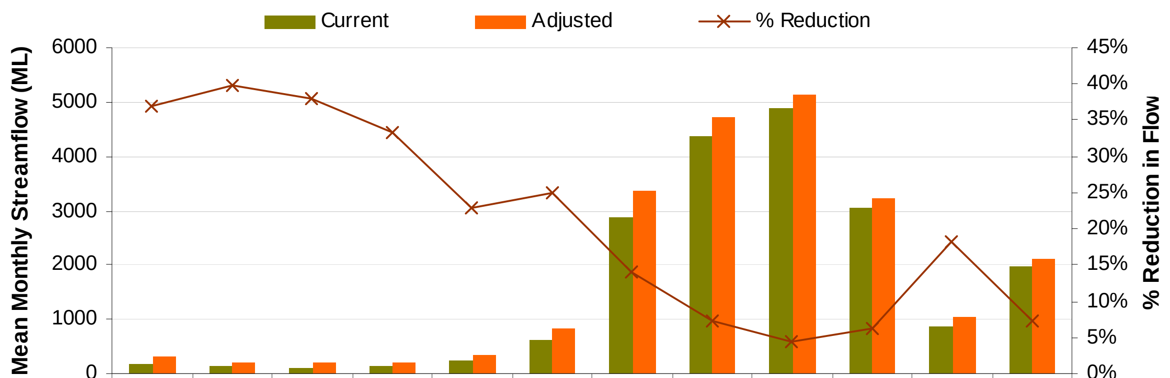
Notably, December flows in all catchments exhibit the effects of two extreme flow months in 1986 and 1992. The relative proportion of flows in that month are more pronounced in the drier sub-catchments of the Lower Bremer River and Red and Rodwell Creeks, but the effect of farm dams is less than in those catchments with higher rainfall and farm dam densities.



	Upper Mt Barker Ck	Nairne Ck	Dawesley Ck	Lower Mt Barker Ck	Upper Bremer River	Lower Bremer River	Rodwell Ck	Red Ck
Current	5968	1538	2941	1306	5107	130	976	207
No Dams	6903	1661	3192	1461	5511	133	1274	225
% Reduction in Flow	14%	7%	8%	11%	7%	2%	23%	8%

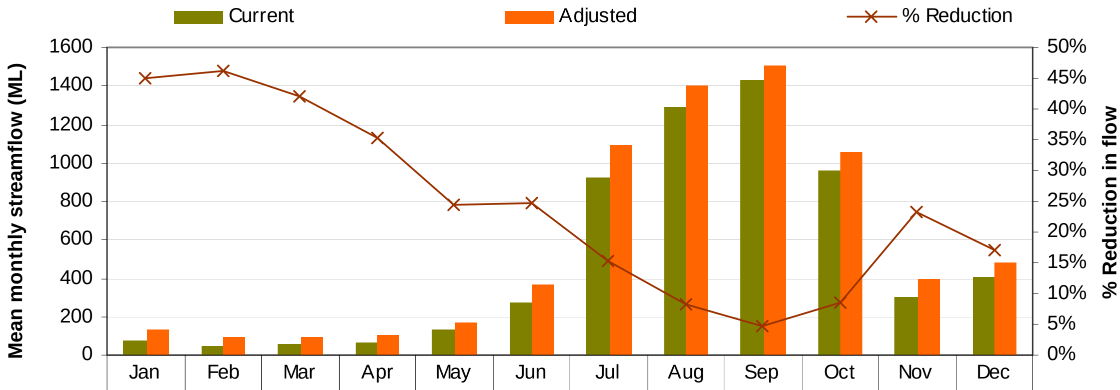
Figure 32 Reduction in mean annual flow due to farm dams (1974–2003)

Reductions in mean monthly streamflow are presented for the total Bremer River (Fig. 34), Upper Mount Barker Creek (Fig. 35), Nairne Creek (Fig. 36), Dawesley Creek (Fig. 37), Upper Bremer River (Fig. 38), and Rodwell Creek (Fig. 39). Remaining sub-catchment results are provided in Appendix C.



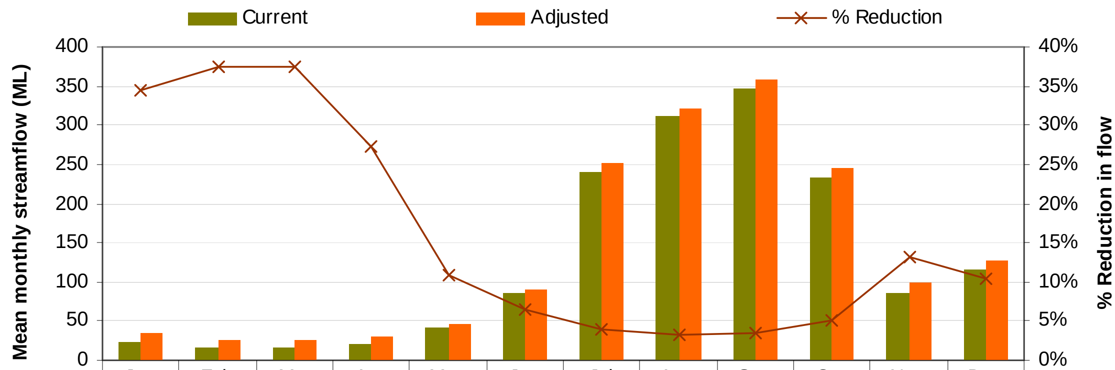
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	188.9	124.0	118.8	138.4	259.9	633.0	2881.5	4380.5	4906.8	3036.3	852.7	1972.2
Adjusted	299.4	205.5	191.9	207.2	336.7	842.7	3356.6	4721.7	5130.8	3241.9	1041.2	2127.6
% Reduction	37%	40%	38%	33%	23%	25%	14%	7%	4%	6%	18%	7%

Figure 33 Reduction in mean monthly streamflow – total Bremer River Catchment



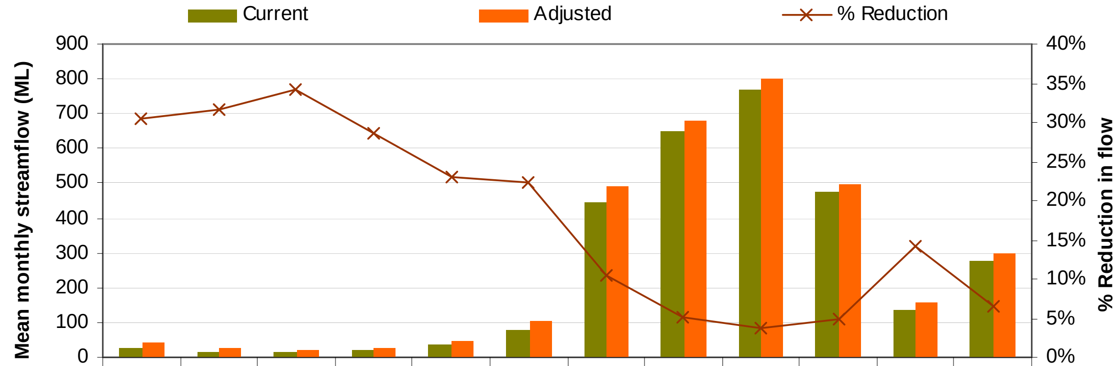
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	74.5	50.0	56.2	69.4	128.0	276.1	923.2	1290.1	1433.1	960.7	305.5	401.6
Adjusted	135.5	92.9	97.1	107.1	169.1	366.7	1090.7	1406.8	1506.1	1050.3	397.6	483.3
% Reduction	45%	46%	42%	35%	24%	25%	15%	8%	5%	9%	23%	17%

Figure 34 Reduction in mean monthly streamflow – Upper Mount Barker Creek sub-catchment



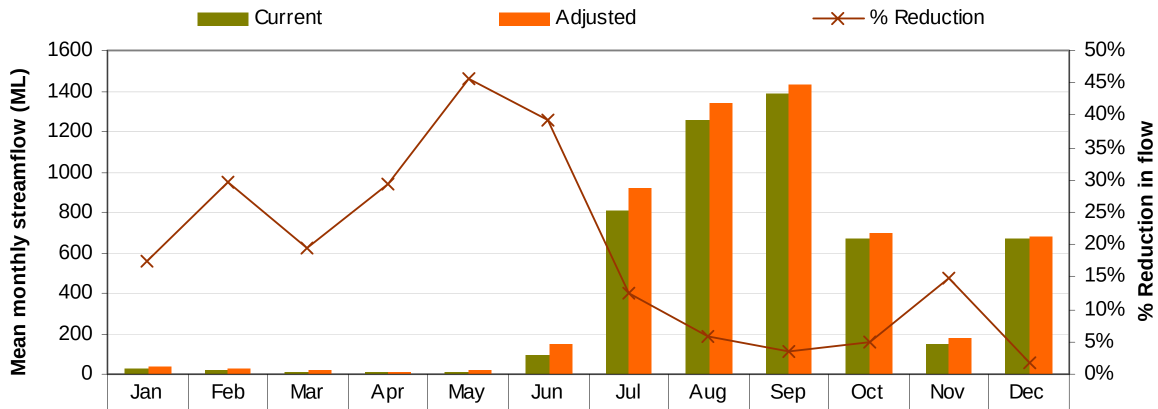
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	22.9	16.4	16.4	21.8	41.9	84.8	241.3	311.6	346.7	233.5	86.3	114.7
Adjusted	34.9	26.2	26.1	30.0	47.1	90.6	251.3	322.0	359.4	246.2	99.5	128.1
% Reduction	35%	37%	37%	27%	11%	6%	4%	3%	4%	5%	13%	10%

Figure 35 Reduction in mean monthly streamflow – Nairne Creek sub-catchment



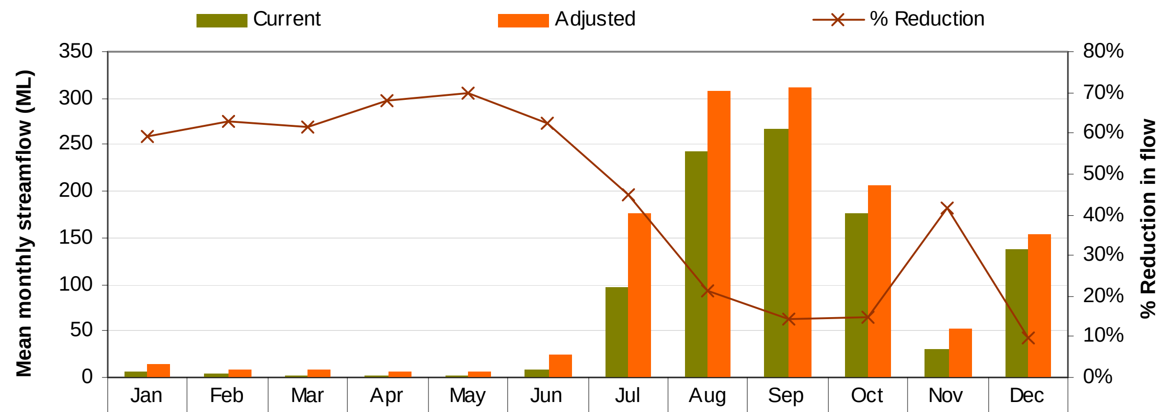
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	28.5	17.2	14.5	19.0	34.3	79.7	442.2	647.8	769.9	474.3	134.6	278.8
Adjusted	41.0	25.1	22.0	26.6	44.7	102.6	494.1	681.9	799.8	499.0	156.8	298.3
% Reduction	30%	32%	34%	29%	23%	22%	11%	5%	4%	5%	14%	7%

Figure 36 Reduction in mean monthly streamflow – Dawesley Creek sub-catchment



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	32.5	19.7	11.7	6.7	9.8	91.2	805.9	1260.1	1384.9	666.2	150.5	668.1
Adjusted	39.3	28.0	14.6	9.4	18.0	150.0	920.1	1338.6	1433.0	701.7	176.9	681.0
% Reduction	17%	30%	20%	29%	46%	39%	12%	6%	3%	5%	15%	2%

Figure 37 Reduction in mean monthly streamflow – Upper Bremer River sub-catchment



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	6.1	3.3	2.8	1.9	2.1	9.0	96.8	243.2	266.5	175.4	30.6	137.8
Adjusted	15.1	8.8	7.3	5.9	6.9	23.8	175.9	308.4	310.6	206.3	52.5	152.8
% Reduction	59%	63%	62%	68%	70%	62%	45%	21%	14%	15%	42%	10%

Figure 38 Reduction in mean monthly streamflow – Rodwell Creek sub-catchment

5.2.3 DAILY FLOWS

Assessment of daily flows is important in assessing the impact of dams on environmental water requirements (EWRs). Figure 40 shows that impact on the Bremer River at the end of the modelled catchment in a daily flow frequency curve. The flow frequency curve describes the percentage of time that flows greater than that indicated on the y-axis can be expected. For example, a flow of greater than ~65 ML/d could be expected for only 10% of an average year. The reduction of flows at the 50th percentile (median daily flow) is 58% due to the effect of farm dams.

Division of the catchment into two main sections for daily flow analysis is appropriate at this scale due to the necessity of a subtractive measure to determine flow for receiving sub-catchments. For this purpose, the flows have been separated at a daily time scale at the confluence of Mount Barker Creek and Bremer River. Figure 41 indicates the impact of farm dams on the flow duration curve for Mount Barker Creek, upstream of the confluence with the Bremer River (i.e. at station A4260679; Fig. 12). The flow record therefore includes the flows from not only Mount Barker Creek, but also Nairne and Dawesley Creeks. The curve indicates a reduction in the median daily flow of ~40%.

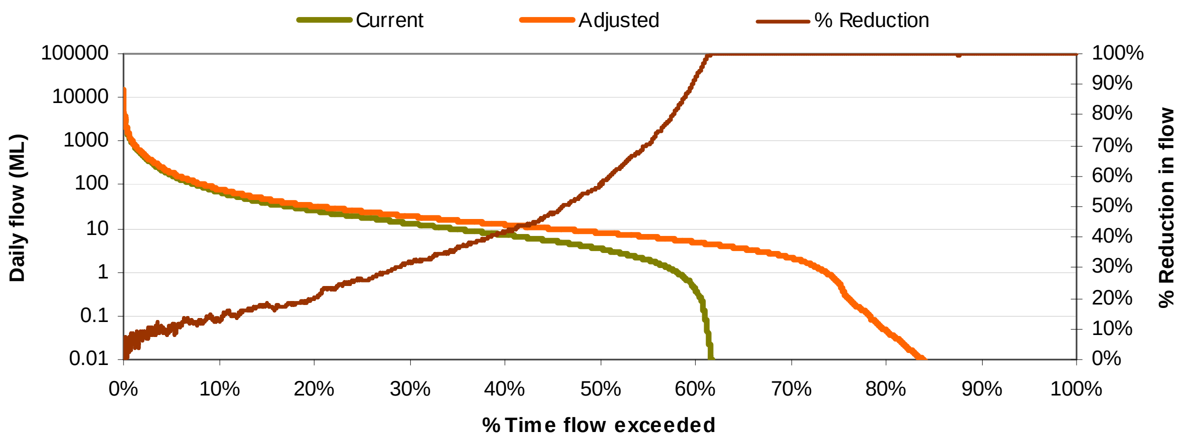


Figure 39 **Daily flow frequency curves showing the effect of farm dams on daily flow regime**

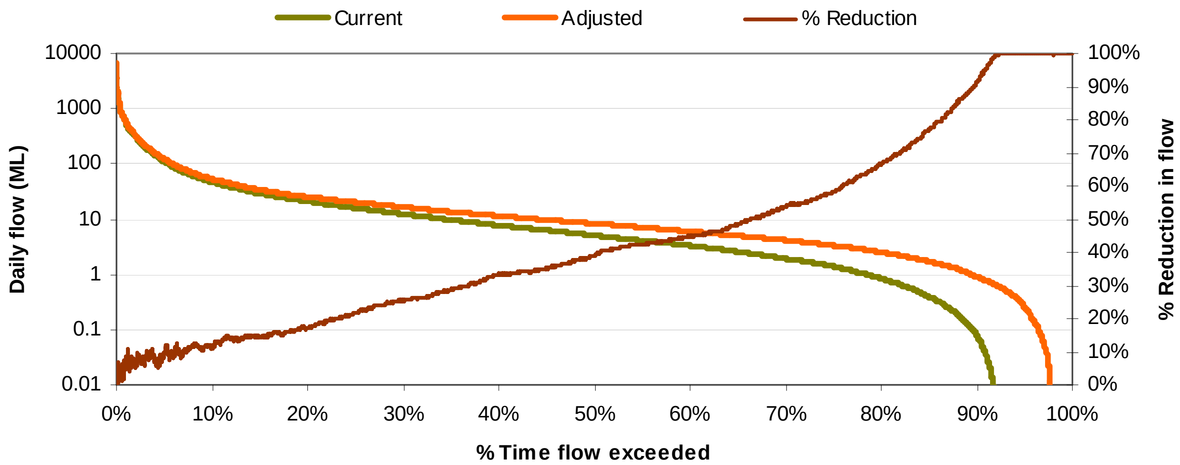


Figure 40 **Flow duration of Mount Barker Creek, upstream of Bremer River confluence**

The flow duration curve in Figure 42 shows the impact of farm dams on the combined sub-catchments of Upper Bremer River, Lower Bremer River, Red Creek and Rodwell Creek. Daily flow data are derived by subtracting the flow record from Mount Barker Creek upstream of the confluence with the Bremer River. The effect of such reduction of the flow record is to produce the daily flow characteristics without the influence of the upstream catchments.

The flow duration curve highlights the drier nature of these sub-catchments. Under current conditions runoff is only produced on average ~32% of the year, whereas under 'natural' conditions runoff would have been produced for ~45% of the year.

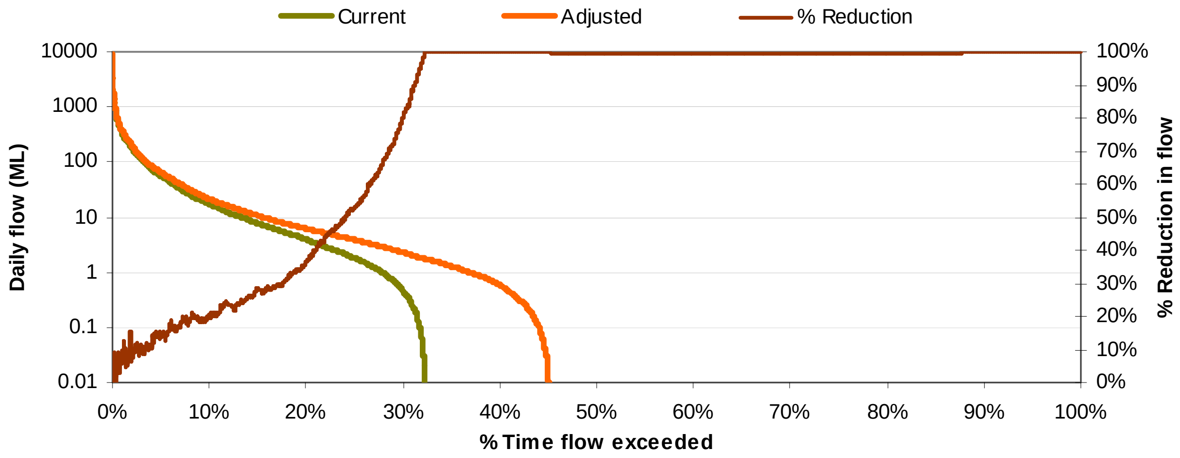


Figure 41 **Flow duration of Bremer River with flows from Mount Barker Creek removed**

6. SUMMARY AND CONCLUSIONS

This report describes the methodology and outcomes of a hydrological study of the Bremer River Catchment. It examines the surface water flow regime of the catchment and the likely impacts of farm dams on its hydrology.

6.1 SUMMARY OF DATA INPUTS

6.1.1 RAINFALL AND EVAPORATION DATA

Rainfall and evaporation data are the main drivers of streamflow within the model, and accurate daily read data are essential in attempting to replicate a complex natural system. The desired accuracy of the data required for the model will depend ultimately on the expected use or outcome of the model.

Daily data were obtained from the SILO rainfall archive 'Patched Point Dataset' which uses spatial interpolation methods to infill missing data and disaggregate accumulated data. Despite some discrepancies in daily totals in the record when compared to other methods of infill and disaggregation, monthly and annual totals were considered to be comparable to those methods. The spatial distribution of data available was good for this study, but it is noted that other catchment areas in the Mount Lofty Ranges may not be adequately covered.

A similar spatial interpolation technique is used for evaporation data, which is necessary due to the sparse nature of pan evaporation recording locations across the Mount Lofty Ranges.

6.1.2 STREAMFLOW DATA

Streamflow and water level monitoring are carried out extensively in the Bremer River Catchment. Records vary from 32 years (at Hartley) to five years (at Western Flat Creek). Two water level monitoring sites (at Mount Barker Creek and Bremer River upstream of the confluence) have recently had streamflow ratings applied in an effort to add value to what is now a ten-year data set. Only limited streamflow gaugings have been conducted for these sites to verify the rating and, as such, they were not used explicitly in the calibration of the model.

6.1.3 FARM DAM DATA

The collection of farm dam data for this study comprised three main components:

1. Digitising of farm dams from aerial photography onto a GIS coverage to obtain numbers and spatial distribution of development.
2. Estimation of farm dam volumes from the GIS coverage using a relationship developed by McMurray (2004b).

3. Collection of specific information about usage, and better estimates of farm dam sizes, through the Land and Water Use Survey conducted by the Department of Water, Land and Biodiversity Conservation (DWBLC), such as measuring dam wall height and applying a formula based on dam shape.

It is hoped that through the extensive DWLBC survey, more accurate information about farm dam capacity will be available to enhance the water allocation planning process.

6.2 CATCHMENT MODELLING

6.2.1 MODEL CALIBRATION

Calibration at all three gauging stations was firstly carried out for the same time period (1980–2005) in order to correctly weight the observations and modelled outputs to the same range. Calibration results however, are presented at the full length of the available streamflow data. This model is primarily intended to be capable of reproducing the catchment yield over a long period of time (30 years).

Note that the calibration of annual yield, whilst showing good calibration statistics, will not necessarily reproduce the exact yield for a given year. However, it is a reasonable expectation of the model to reproduce a good approximation of the 30-year average and median flows.

Monthly and daily flow calibration is generally a more difficult task, but a reasonable result was obtained. Daily flow calibration at Hartley (Bremer River) was the most difficult as it relied on correct calibration of the upstream catchments, correct assumptions about the catchment parameter sets for the ungauged catchments (Nairne Creek, Lower Mount Barker Creek, Upper and Lower Bremer River), and a reasonable estimate of stream loss in the Lower Bremer River sub-catchment.

6.2.2 MODELLING RESULTS

6.2.2.1 Dam development limits

An assessment of farm dams was made against the RMCWMP limit (the '30% limit').

- Under the 30% limit, current development indicates that the Upper Mount Barker Creek, Dawesley Creek and Rodwell Creek sub-catchments are over-developed.

6.2.2.2 Scenario modelling

Reduction in flows due to farm dams was assessed at annual, monthly and daily time scales. Annual reductions in flows were found to be highest in sub-catchments with the highest farm dam density.

- Rodwell Creek recorded the largest reduction in streamflow due to dams, at 23% of the mean annual.
- Mount Barker Creek, despite having a higher rainfall and a significant baseflow component, recorded a 14% reduction in the mean.

- Total reduction in flows across the whole catchment is 10% of mean annual streamflow (2200 ML).
- The mean monthly reduction in flows followed the same seasonal pattern in all the sub-catchments.
- Flow reductions were highest in the summer and autumn months, but even winter months were significantly impacted in the highly developed sub-catchments.
- Upper Mount Barker Creek sub-catchment for example, records a reduction in mean September streamflow of 5%. This is the modelled peak month for the 30-year period.
- Daily flows at a sub-catchment scale indicate a reduction in the median daily flow (50th percentile) of:
  - 39% for Mount Barker Creek sub-catchment
  - 57% for the Bremer River Catchment (with flow from Mount Barker Creek sub-catchment removed and including Red and Rodwell Creek sub-catchments).

7. RECOMMENDATIONS

The following section lists the main recommendations for the management of surface water resources in the Bremer River Catchment.

7.1 TECHNICAL RECOMMENDATIONS

Improved catchment modelling depends on both quality streamflow data and climatological data. It is recommended that:

- Operation of all current gauging stations be continued to allow future monitoring of the outcomes of the current water allocation process.
- Streamflow gauging of recently updated water level monitoring sites be carried out at a range of flow levels in order to verify current ratings.
- Improvements be made to the monitoring network on the plains section of the catchment.
- In order to correctly assess the impact of farm dams, it may be necessary to improve the estimation of farm dam capacities. Accurately surveying farm dams in key positions within the catchment would greatly enhance the ability of the process to predict their impact.
- The use of sub-daily data would greatly improve current modelling and understanding of catchment hydrology. It is recommended that, where possible, data from relevant pluviometers be used to construct and calibrate catchment rainfall–runoff models.

7.2 ENVIRONMENTAL CONSIDERATIONS

The hydrological analysis in this study has highlighted a number of key concerns relating to the environmental flow regimes of the catchment. Although this study was not an attempt to define the environmental water requirements (EWRs), it provided some insight into the level of change within the catchment due to the impact of farm dams. Reductions in catchment yield, reduced flows during transitional seasons, and decreased low and medium flows will require various management mechanisms to ensure the sustainability of this resource. In this regard, it is recommended that:

- Further development of farm dams in the catchment be restricted until an appropriate Water Allocation Plan (WAP) is in place, and provision for suitable measures for water trading are made. Future development should then abide by existing rules as set out in the River Murray Catchment Water Management Plan (RMCWMP) (RMCWMB 2003).
- Following the adoption of a WAP, further monitoring of both quality and quantity of streamflow will be necessary to gauge any impacts or improvements due to the management options put in place.
- Best practice irrigation measures be encouraged in order to enhance the capability of the resource to cope with development.
- Under the current Notice of Prescription, stock and domestic dams are exempt from any management rules. This provides the catchment management board with little flexibility in terms of placing future restrictions on extraction, diversion or use. It is recommended that this decision be revisited at the review of the first WAP.

APPENDICES

A. CALIBRATION STATISTICS

Percentage difference from mean and median

This describes the difference between the observed mean and predicted mean values.

Coefficient of Determination (R^2)

This describes the proportion of the variance in the data that can be explained by the model. The range of values is 0–1.0, with the higher number (closer to one) describing a better fit.

$$R^2 = \left\{ \frac{\sum_{i=1}^{N} \left(O_i - \overline{O}\right)\left(P_i - \overline{P}\right)}{\left[\sum_{i=1}^{N} \left(O_i - \overline{O}\right)\right]^{0.5} \left[\sum_{i=1}^{N} \left(P_i - \overline{P}\right)\right]^{0.5}} \right\}^2$$

Where: The overbar indicates the mean for the period

N = number of observations

O = observed runoff

P = predicted (or modelled) runoff.

Coefficient of Efficiency (E)

Defined by Nash and Sutcliffe (1970) as the ratio of the mean square error to the variance subtracted from one. The values range from minus infinity to one. A value of one would describe a perfect fit. A value of zero would indicate that using the mean value for the time step would be an equally good predictor of the data, whereas a value of less than one denotes that the mean would be a better predictor than the model.

$$E = 1 - \frac{\sum_{i=1}^{N} \left(O_i - P_i\right)^2}{\sum_{i=1}^{N} \left(O_i - \overline{O}\right)}$$

Where: The overbar indicates the mean for the period

N = number of observations

O = observed runoff

P = predicted (or modelled) runoff.

B. TANH CURVES

The tanh function is a standard hyperbolic function that was used by Boughton (1966) as a simple rainfall–runoff relationship.

Calculation

$$Q = (P - L) - F \times \tanh[(P - L)/F]$$

where: Q = runoff (mm)

P = rainfall (mm)

L = notional loss (mm)

F = notional infiltration (mm).

The equation can be applied to any data but should be used for data where average storage of soil water is approximately constant (i.e. where the notional loss and infiltration might be expected to be similar). Annual data satisfies this requirement but monthly data will need to be separated into data for each month or at least for each season, and a different L and F derived for each month's (or season's) set.

Determination of F and L

The values of the notional loss (L) and notional infiltration (F) are determined by plotting monthly, seasonal or annual flow sets against the associated rainfall. A preliminary value of L is chosen from the data and F fitted either by trial and error, or with a curve-fitting technique. Similarly, the preliminary estimate of L can be changed to improve the fit. It is often simplest to plot the data in a spreadsheet and visually fit the parameters.

In the absence of a detailed hydrological model, the tanh curve may be used to estimate mean annual runoff for a given annual rainfall. In the case of determining the level of farm dam development in relation to the RMCWMP 30% limit, it is necessary to have curves showing the mean winter runoff for a given winter rainfall total. The curves shown below are derived from 30 years of modelled data and show both the annual and winter rainfall–runoff relationship.

Annual tanh curves

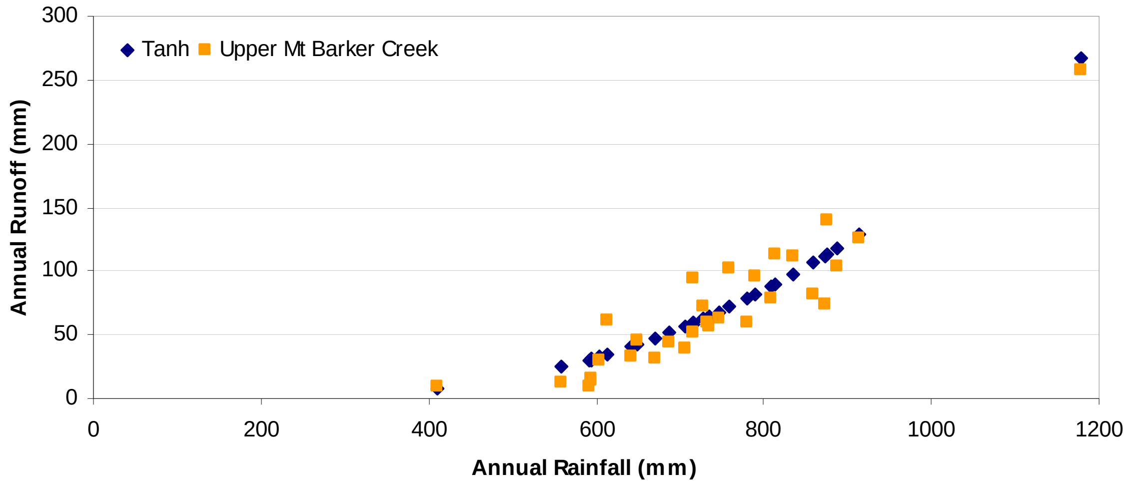


Figure B.1 Upper Mount Barker Creek sub-catchment annual tanh curve

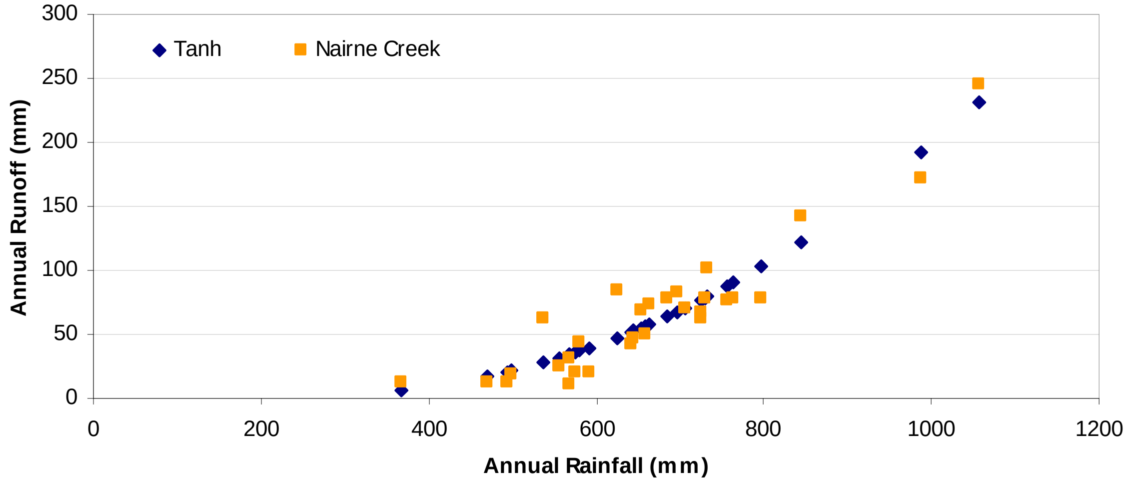


Figure B.2 Nairne Creek sub-catchment annual tanh curve

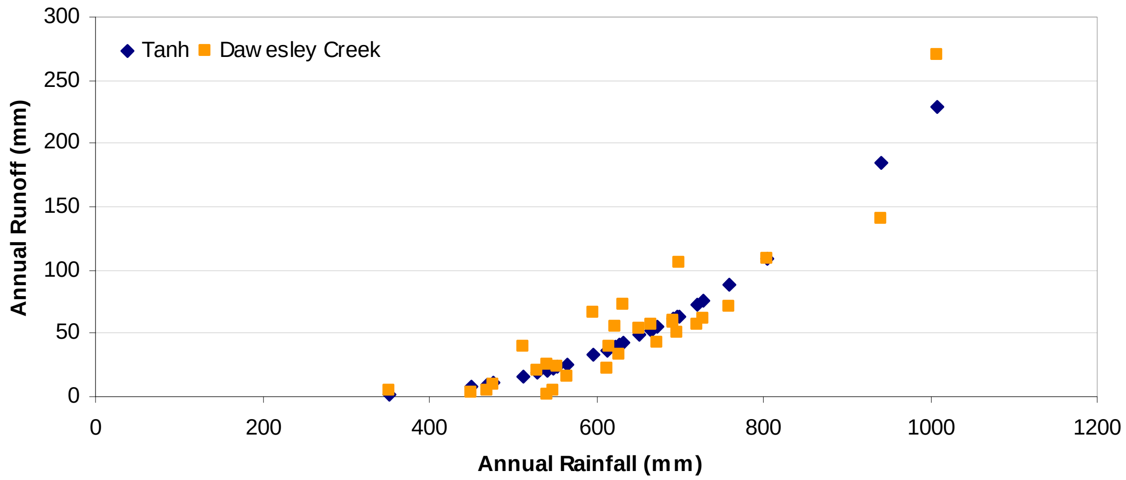


Figure B.3 Dawesley Creek sub-catchment annual tanh curve

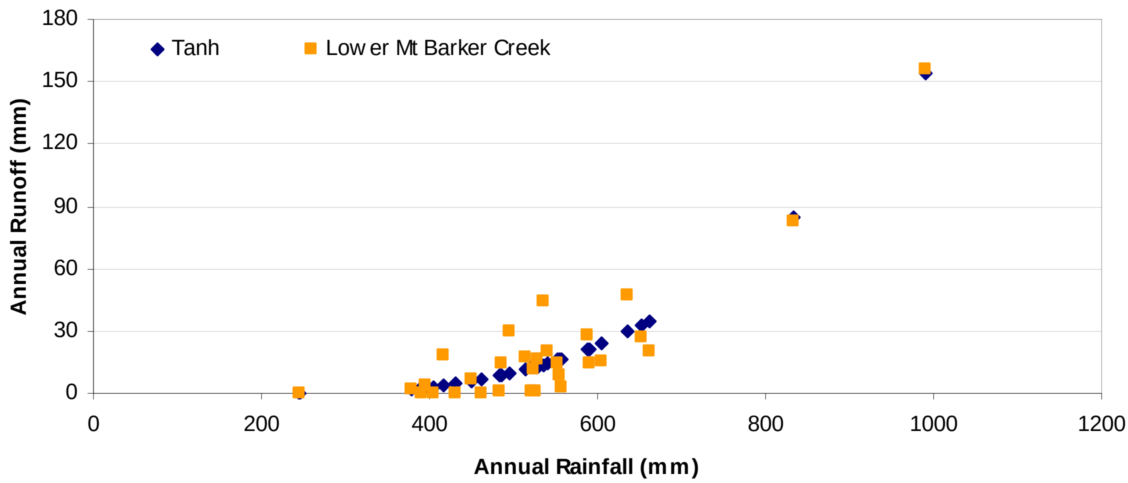


Figure B.4 Lower Mount Barker Creek sub-catchment annual tanh curve

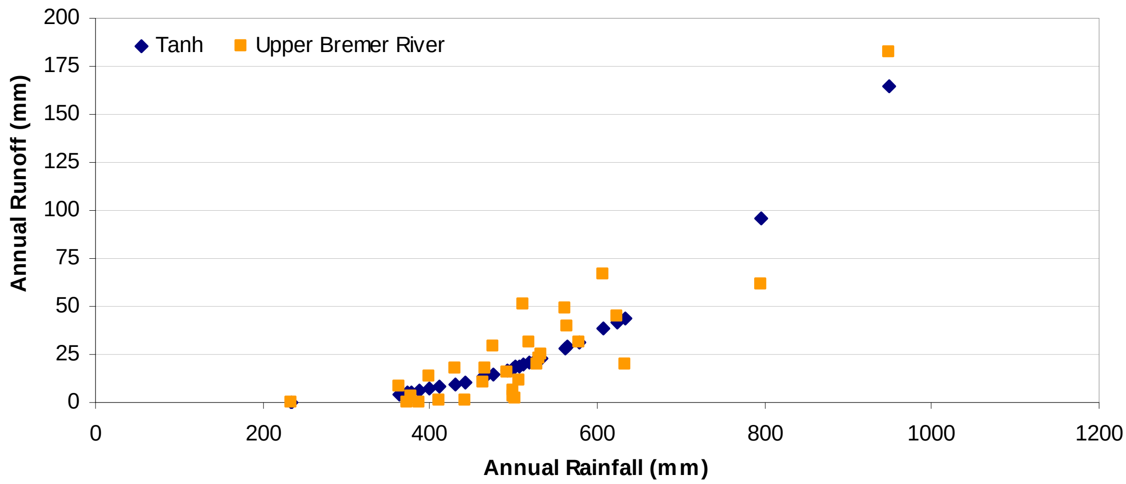


Figure B.5 Upper Bremer sub-catchment annual tanh curve

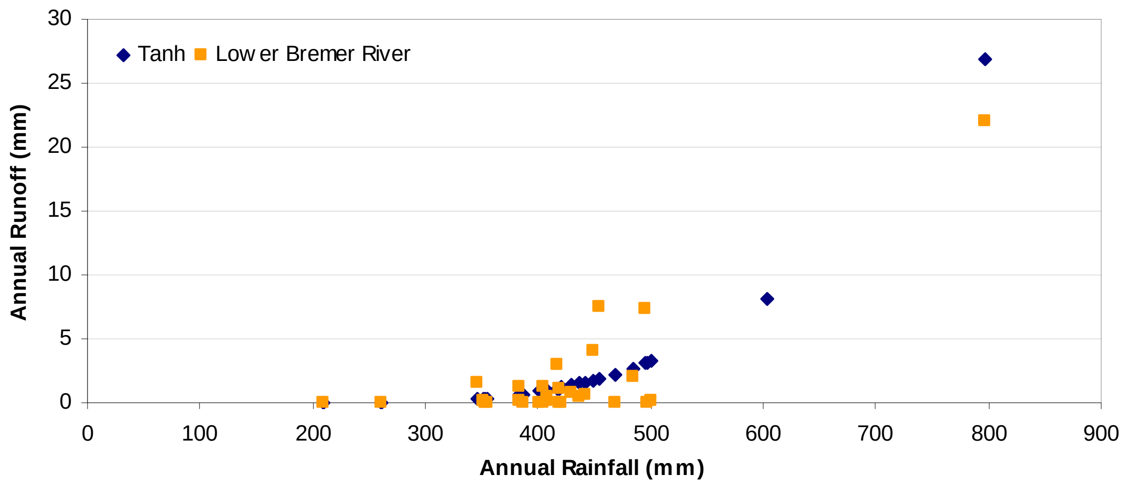


Figure B.6 Lower Bremer River sub-catchment annual tanh curve

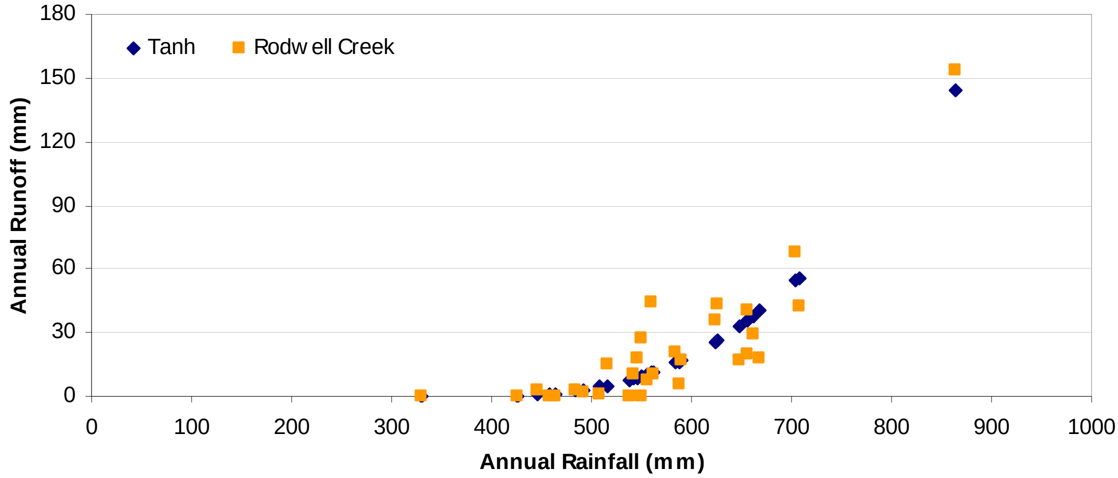


Figure B.7 Rodwell Creek sub-catchment annual tanh curve

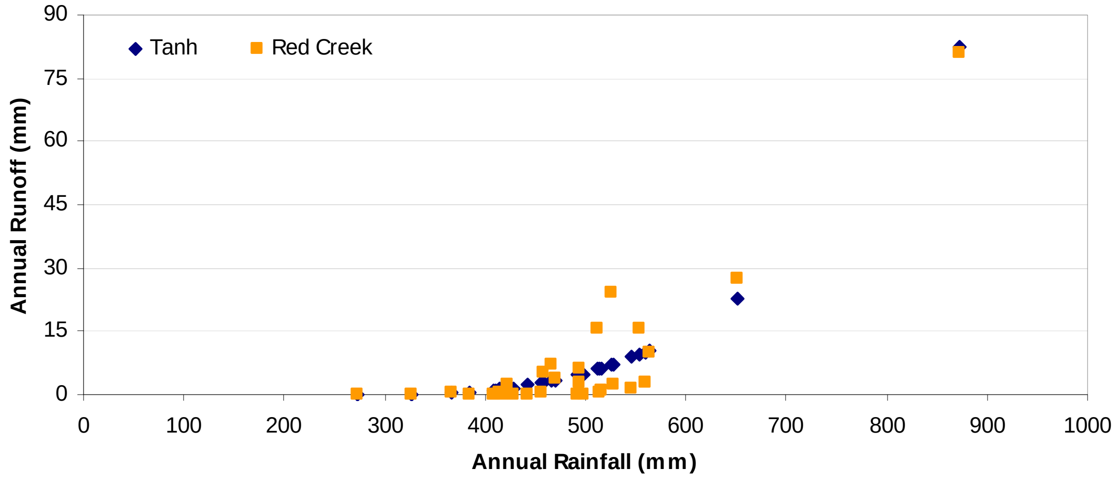


Figure B.8 Red Creek sub-catchment annual tanh curve

Adjusted winter tanh curves

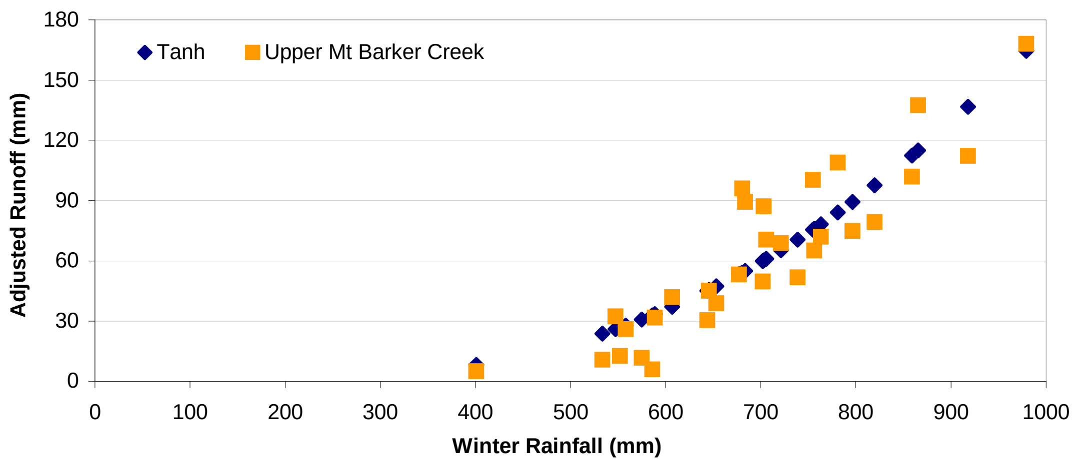


Figure B.9 Upper Mount Barker Creek sub-catchment adjusted winter tanh curve

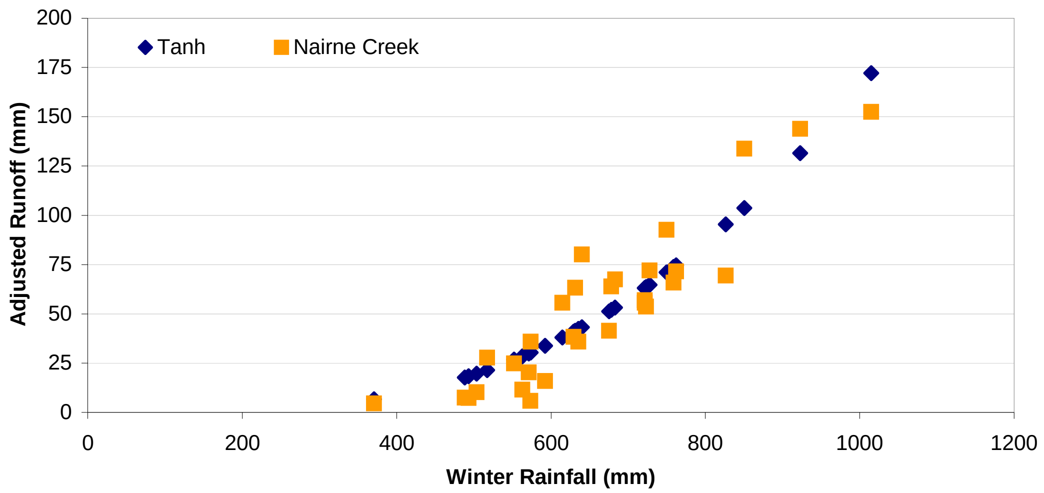


Figure B.10 Nairne Creek sub-catchment adjusted winter tanh curve

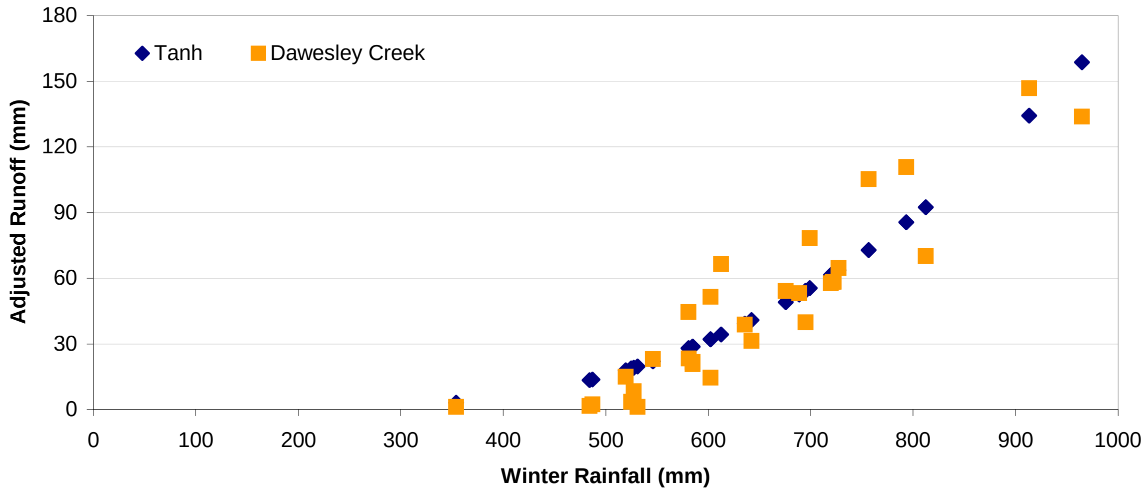


Figure B.11 Dawesley Creek sub-catchment adjusted winter tanh curve

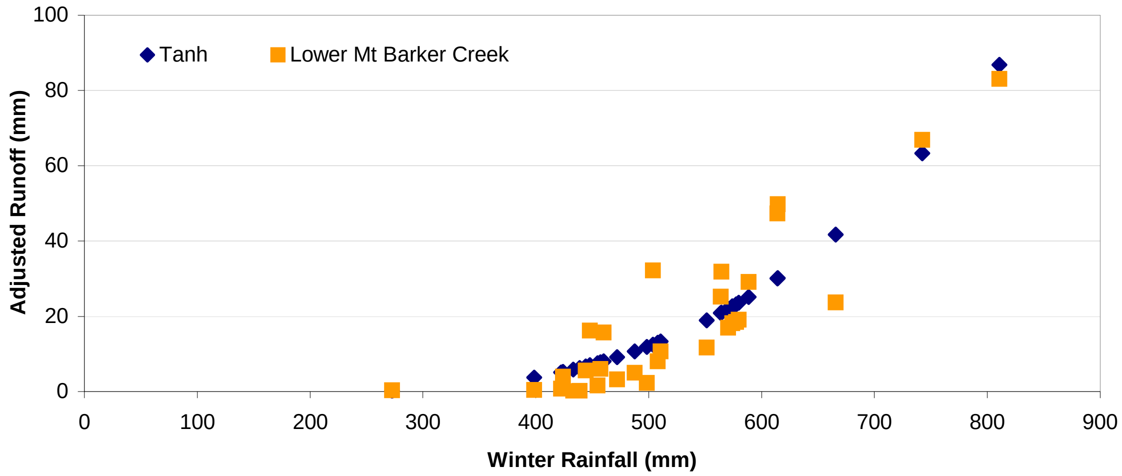


Figure B.12 Lower Mount Barker Creek sub-catchment adjusted winter tanh curve

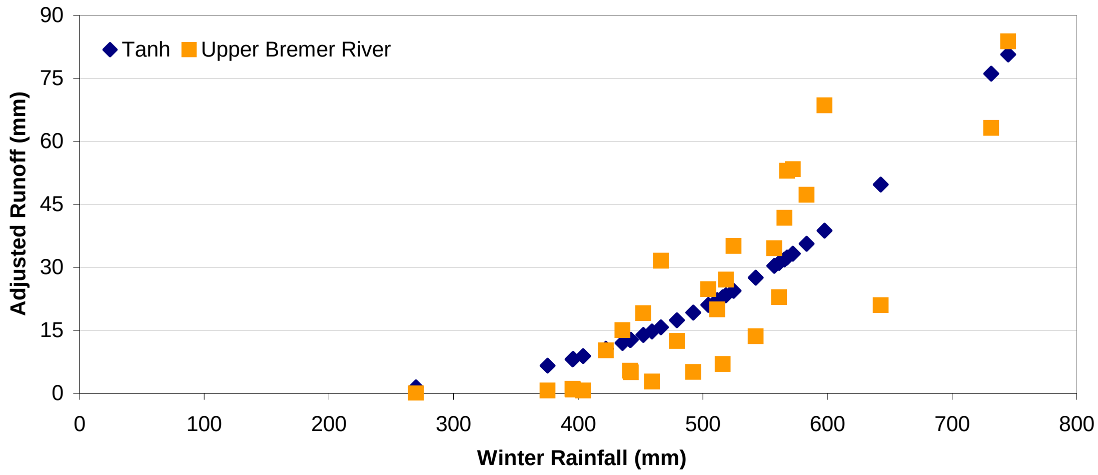


Figure B.13 Upper Bremer River sub-catchment adjusted winter tanh curve

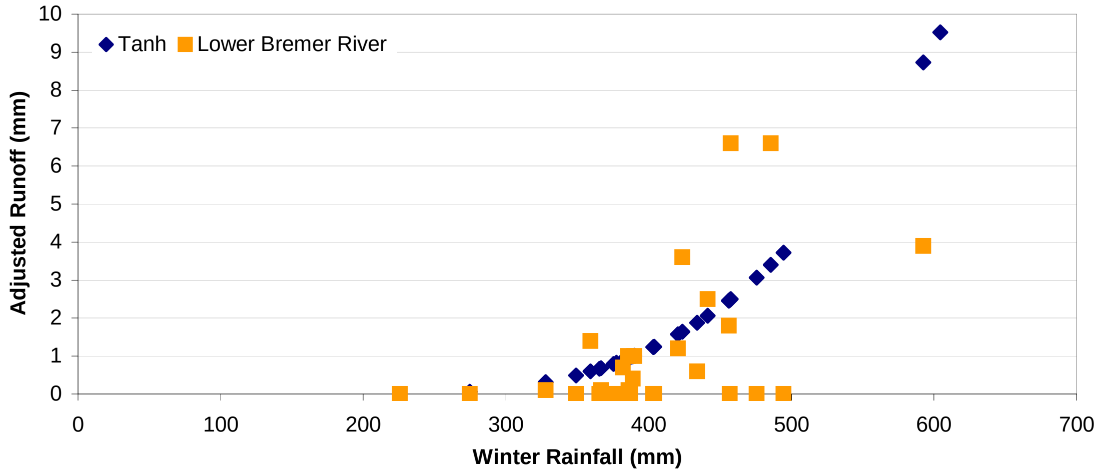


Figure B.14 Lower Bremer River sub-catchment adjusted winter tanh curve

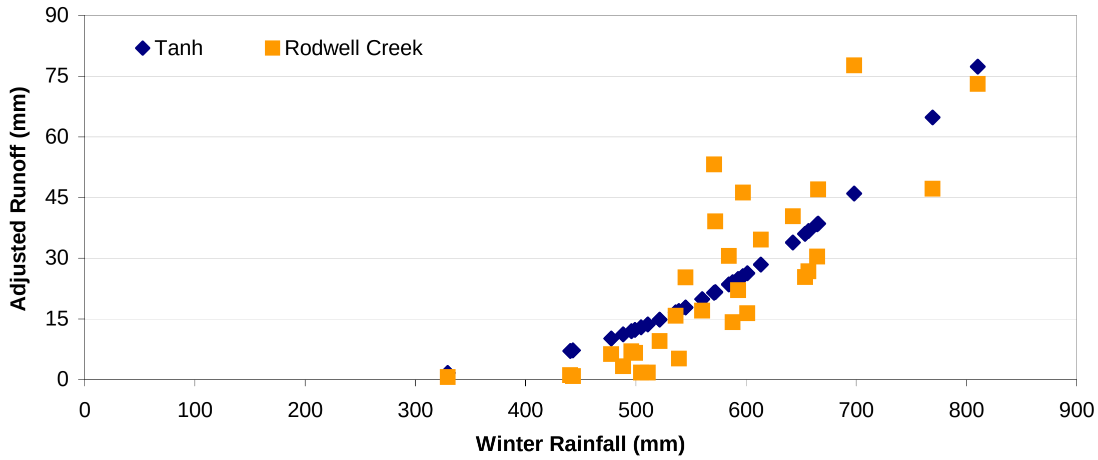


Figure B.15 Rodwell Creek sub-catchment adjusted winter tanh curve

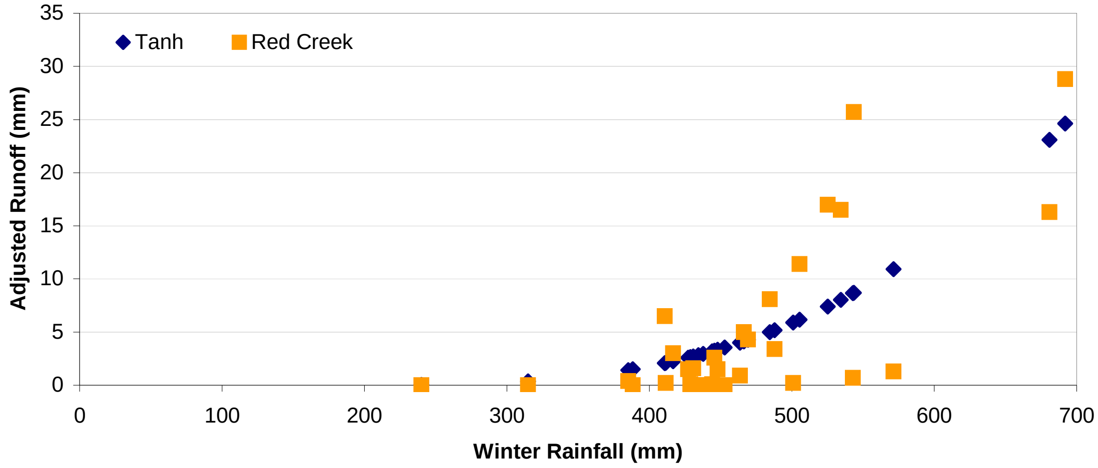


Figure B.16 Red Creek sub-catchment adjusted winter tanh curve

C. DESCRIPTION OF WC-1 MODEL

WC-1 is a water balance model developed by David Cresswell (2002) based on experience with South Australian rainfall–runoff calibration in the Mount Lofty Ranges, Barossa Valley and Mid North. The program was developed in 1988 to estimate the impact of farm dams in the Barossa Valley when it was found that most of the existing models tried were not able to reproduce the recorded runoff of South Australia's drier catchments. When annual rainfall lies in the range 450–650 mm, the estimation of runoff becomes a tricky exercise.

Model Concept

WC-1 is a ten-parameter model using three storages as shown in Figure C.1 to track interception, soil moisture and groundwater. The soil store is generally the main runoff producing component requiring four parameters for calibration.

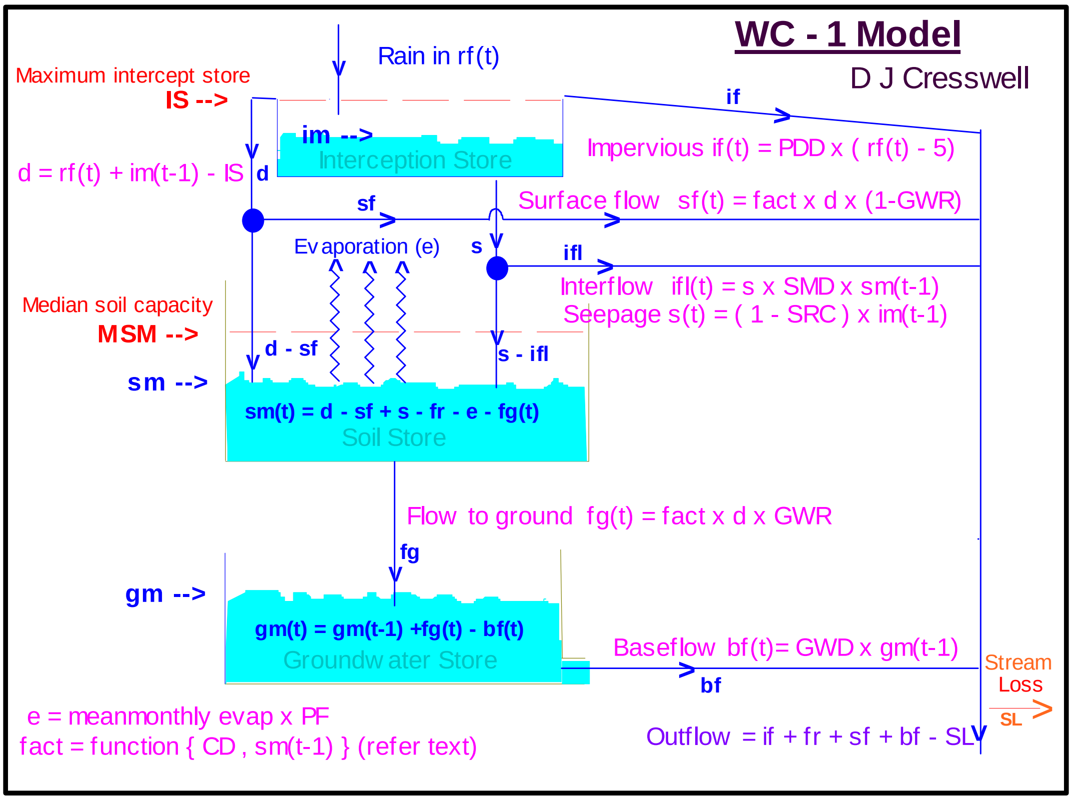


Figure C.1 Concept of WC-1 Model

Surface runoff (not including the groundwater contribution) is calculated with both a hortonian and saturated surface area component. The hortonian component is generally small and is calculated as the runoff from an impervious area that has a daily loss rate of 5 mm. The parameter PDD is used to input the fraction of the catchment contributing to runoff.

By far the greatest proportion of surface flow is generated by calculating the saturated surface area of the catchment. To do this, the model tracks the soil storage and calculates the area saturated based on the assumption that the soil moisture-holding capacity is normally distributed across the catchment. This is shown in Figure C.2.

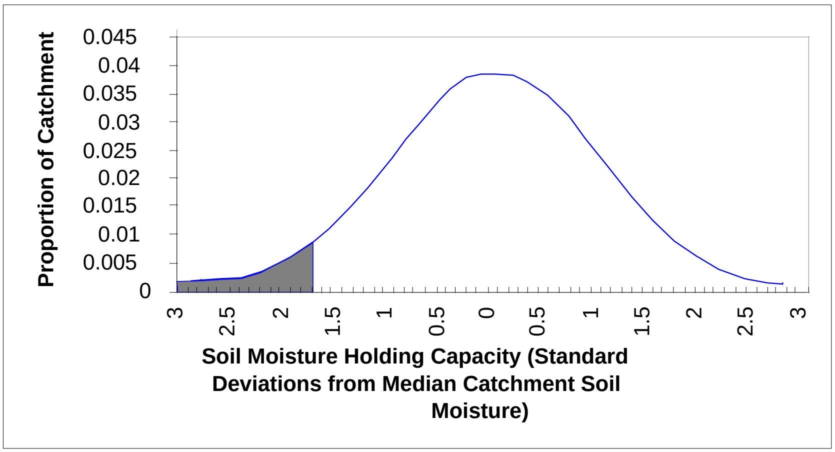


Figure C.2 Proportion of catchment contributing to runoff, calculated from soil moisture

To calibrate such a model two parameters are required—the median soil moisture of the catchment (MSM), and the catchment standard distribution (CD). Typically, these values are found to lie in the range 150–250 mm (MSM) and 20–80 mm (CD).

When dry, the soil moisture lies >3 standard deviations to the left of the median centre, and as the catchment wets up this moves towards the fully saturated catchment, which occurs at median soil moisture plus 3 standard deviations. At any point on the axis, the proportion of catchment assumed to be saturated is calculated as the area under the normal distribution curve.

For example, Figure C.2 indicates that when the soil moisture of the soil store reaches MSM-1.6xCD the area shaded is the proportion of the catchment contributing to the runoff. From normal distribution tables this is 5.5% of the catchment.

When the median soil moisture is reached, the proportion of catchment contributing to runoff is 50%, as shown in Figure C.3.

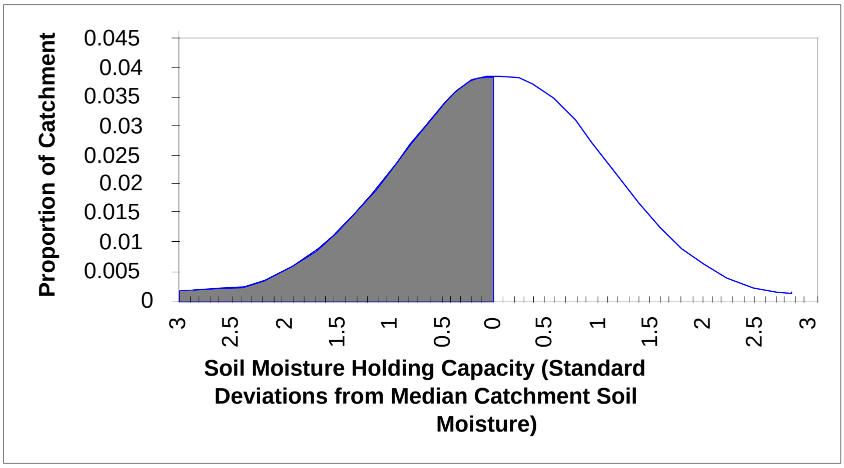


Figure C.3 Proportion of catchment contributing to runoff calculated from soil moisture

The shape of this relationship (Fig. C.4) is similar to a power curve but asymptotic to Y = 0 and Y = 1. Intuitively this is what is expected and overcomes the problem of the power curve that is required to be silled at 1.0.

The volume of water running off the catchment is then the product of the contributing area and the effective rainfall. Catchments in semi-arid areas show a capacity to retain quite significant rainfall events, requiring the use of an interception store for accurate simulation.

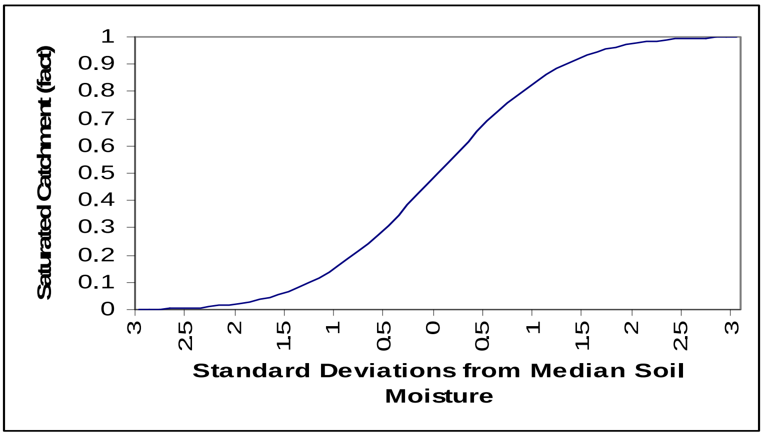


Figure C.4 Proportion of catchment contributing to runoff calculated from soil moisture

The effective rainfall is defined as the volume of water spilling the interception store.

The maximum interception store (IS) may typically range from zero to 30 mm and is tracked continuously within the model. Water may leave the interception storage either by overtopping the storage, thus becoming effective rainfall, or it may percolate slowly into the soil store where it contributes to an interflow component of flow. This percolation occurs at a rate calculated in a similar way to the Annual Precipitation Index (API).

The transfer rate is independent of season and is set by the soil wetness multiplier (SWM), typically to a value of 0.9. The value set is the proportion of the water held in the store (im(t)) which is retained to the next day. Seepage is calculated as:

$S = (1\text{-}SWM) \times im(t)$

During the wet season, the baseflows of the streams are seen to rise but the duration of such flows remains dependent on relatively continuous rain falling on the catchment. It is proposed that this baseflow return occurs due to the over-saturated areas of the catchment returning a fraction of this moisture back to the streams. As the catchment dries or during long spells of no rain, it is expected that this return will drop to zero.

This interflow is assumed in the model to be:

$Ifl = s \times SMD \times sm(t)$

SMD is the parameter defining the proportion returned to the stream.

The catchment response is therefore defined by the six parameters mentioned above but evaporation can potentially override all of these. In semi-arid catchments, choosing the correct evaporation rate is critical.

Models use various formulas ranging from linear to power functions to estimate the moisture loss from soils. Experimentation with the linear model was not found to improve the estimate of runoff and was discarded for the simpler constant model. Here, evapotranspiration is assumed to equal the pan factor multiplied by recorded daily evaporation. Typically a value of 0.6 to 0.7 is used for class A pan recordings.

Groundwater is simulated within the model using two parameters — GWR (recharge) and GWD (discharge). Both operate in a simple linear fashion.

Groundwater recharge is seen to have a greater relationship with streamflow than total rainfall. This suggests that groundwater recharge requires similar conditions to streamflow, hence the wetting up of the catchment, to occur. Tying recharge to streamflow simulates this, thereby assuming that the greater the saturated catchment-generated streamflow occurring, the more recharge occurs from the soil to the groundwater store.

The parameter GWR (Groundwater Recharge) is used to define the proportion passing to ground, and this may often be up to 20–30%.

Baseflow discharging from the groundwater store is simply a linear relationship defined by parameter GWD (Groundwater Discharge). No loss is assumed to occur from the groundwater store to external basins.

Summary of WC-1 Parameters

Medium soil moisture (MSM) — Represents the field capacity of the soil. Usually in the range of 150–300 mm. Increasing this value delays the early season initiation of runoff, decreases runoff by providing greater opportunity for evapotranspiration, and assists in keeping late season groundwater flows up.

Interception store (IS) — Represents the maximum initial abstraction from rainfall before any runoff can occur. The normal range is 10–25 mm. A larger value will inhibit runoff after dry spells and reduce the total amount of runoff.

Catchment distribution (CD) — Sets the range of soil moisture values about MSM. Usual values are 25–60 mm. A larger value will initiate runoff earlier and more often.

Groundwater discharge (GWD) — Is the proportion of the groundwater store that discharges as baseflow to the stream. This is a simple linear function:

Baseflow = groundwater store x GWD

Usual values are small (0.001 to 0.0001).

Soil moisture discharge (SMD) — As soil moisture increases there is a rise in the baseflow that occurs due to the saturation of the soil storage. Values are usually small (0.0001).

Pan factor for soil (PF) — This factor is applied to the daily evaporation calculated from the monthly pan evaporation data. The usual range is 0.6–1.0. The higher the value, the less the runoff. The higher the value, the earlier runoff ceases after winter.

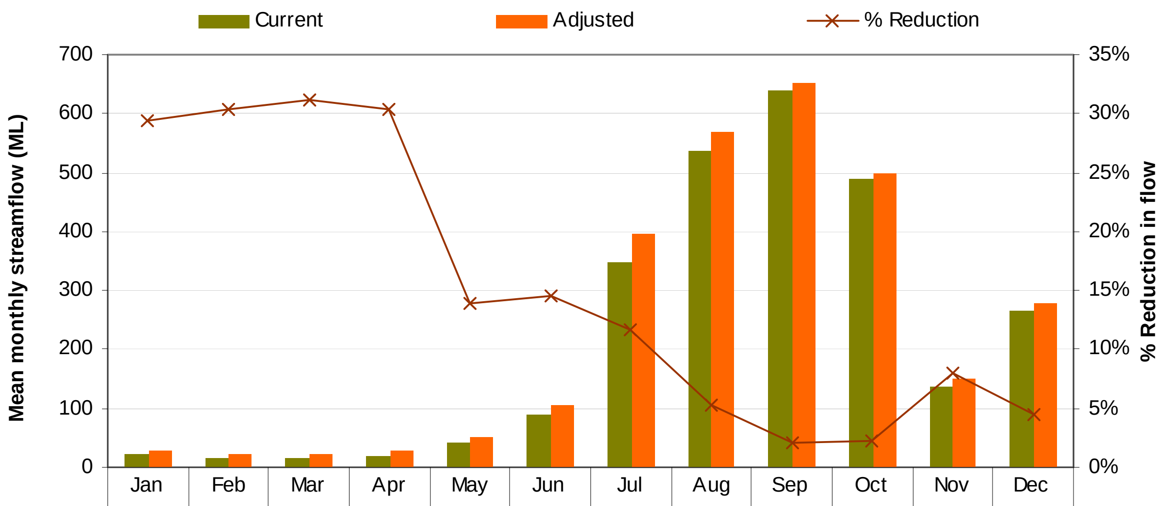
Proportion direct drainage (PDD) — This is the proportion of the catchment that can be considered relatively impervious. After an initial loss of 5 mm, rainfall on this area will be discharged as surface flow. Usual values for this are zero.

Store wetness multiplier (SWM) — This value determines the rate that water from the interception store moves to the soil store. The transfer rate is independent of season and ensures that the amount of water retained in the interception store follows a similar power recession curve of the Annual Precipitation Index (API). Usual values are ~0.9.

Groundwater recharge (GWR) — is the proportion of rainfall that recharges the groundwater store. Usual values are 0.05–0.3, indicating that 5–30% of the flow running off the catchment is entering the groundwater system.

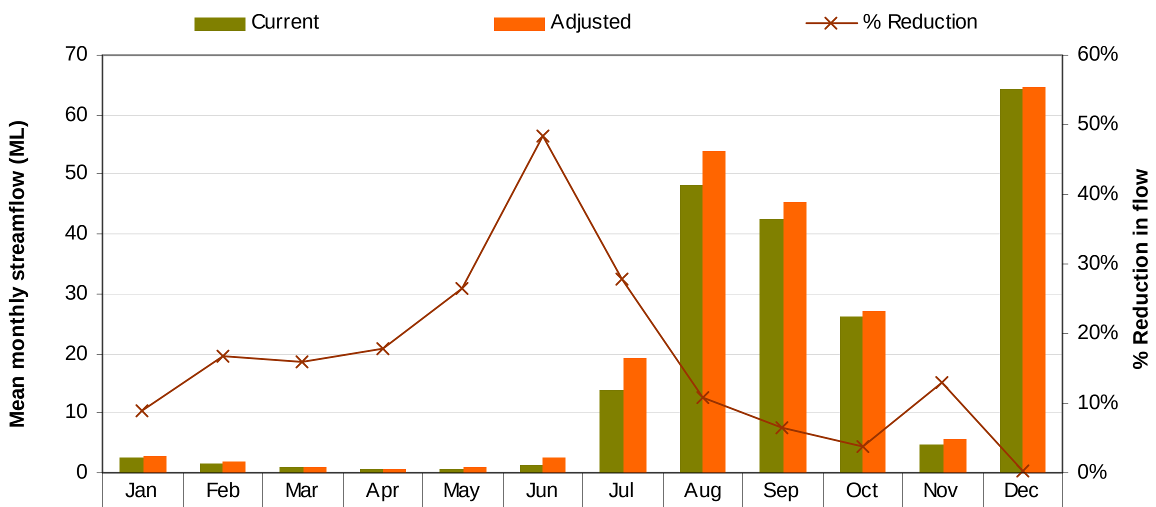
Creek loss (CL) — Is a reduction factor used to decrease runoff. It is generally set to zero.

D. MONTHLY RESULTS



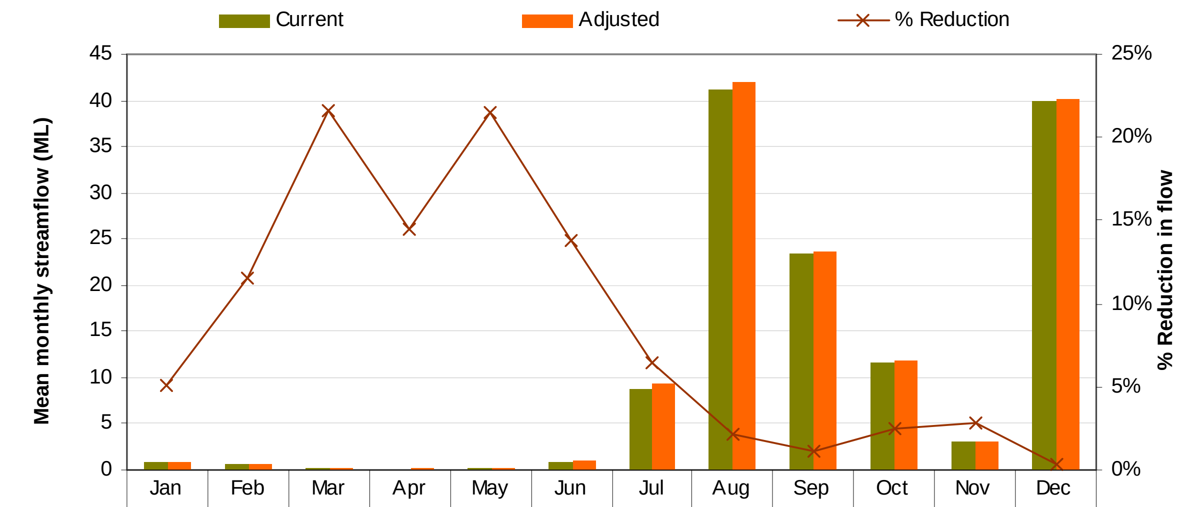
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	21.2	15.4	16.2	19.0	42.9	90.1	349.5	538.4	639.8	488.6	137.5	266.9
Adjusted	30.1	22.1	23.5	27.3	49.8	105.5	396.0	568.0	652.8	499.5	149.4	279.4
% Reduction	29%	30%	31%	30%	14%	15%	12%	5%	2%	2%	8%	4%

Figure D.1 Reduction in mean monthly streamflow, Lower Mount Barker Creek sub-catchment



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	2.5	1.5	0.9	0.5	0.7	1.3	13.9	48.2	42.6	26.1	4.8	64.5
Adjusted	2.7	1.7	1.0	0.6	0.9	2.4	19.2	54.0	45.5	27.1	5.5	64.6
% Reduction	9%	17%	16%	18%	27%	48%	28%	11%	6%	4%	13%	0%

Figure D.2 Reduction in mean monthly streamflow, Red Creek sub-catchment



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	0.7	0.5	0.2	0.1	0.2	0.8	8.7	41.0	23.3	11.6	3.0	39.9
Adjusted	0.8	0.6	0.3	0.1	0.2	1.0	9.3	42.0	23.6	11.9	3.1	40.1
% Reduction	5%	12%	22%	15%	21%	14%	6%	2%	1%	2%	3%	0%

Figure D.3 Reduction in mean monthly streamflow, Lower Bremer River sub-catchment

E. DAILY FLOW RESULTS – IMPACT OF FARM DAMS

The following figures indicate the daily flow exceedance for all modelled sub-catchments in the Bremer River Catchment, showing the effect of farm dams. As described in section 4, these data are generated by firstly constructing and calibrating the rainfall–runoff model, with farm dams included at the minor sub-catchment scale, and then running the model with those dams removed.

Due to the incorporation of a river loss function in the lower Bremer River Catchment (before the gauging station at Hartley), the derivation of daily flows for the receiving sub-catchments of Lower Mount Barker Creek and Lower Bremer River could be slightly skewed. Caution should therefore be exercised when interpreting the flow duration curves from the lower sub-catchments, most notably the Lower Bremer River sub-catchment. This will likely result in an overestimation of the impact of farms dams in that sub-catchment.

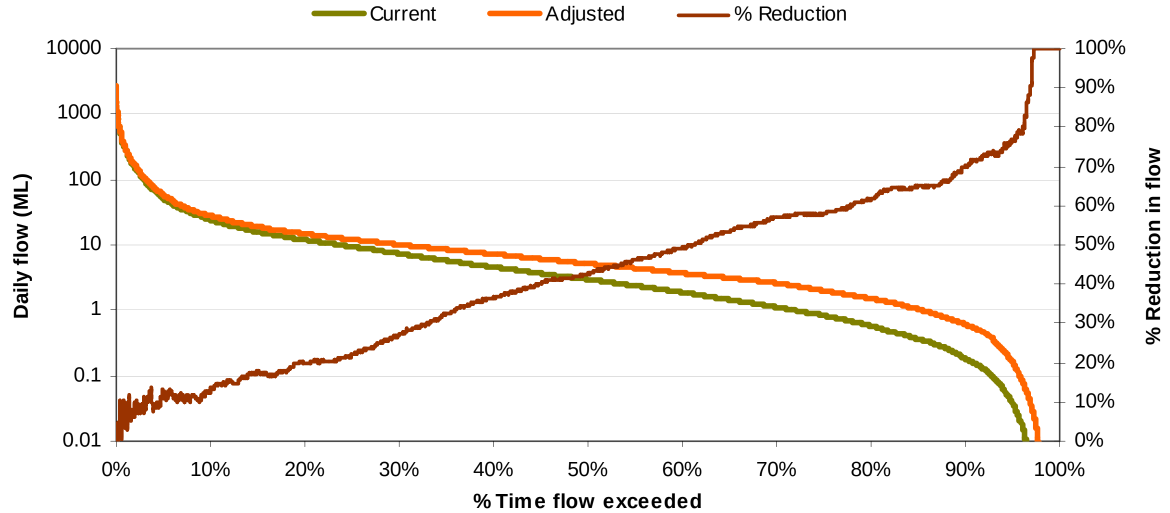


Figure E.1 Upper Mount Barker Creek sub-catchment daily flow duration – impact of farm dams

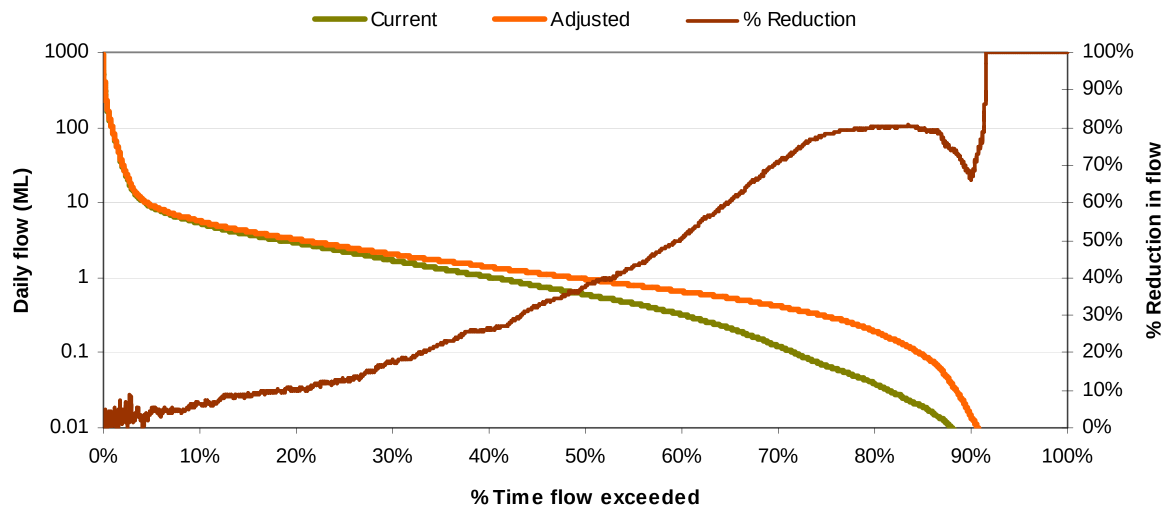


Figure E.2 Nairne Creek sub-catchment daily flow duration – impact of farm dams

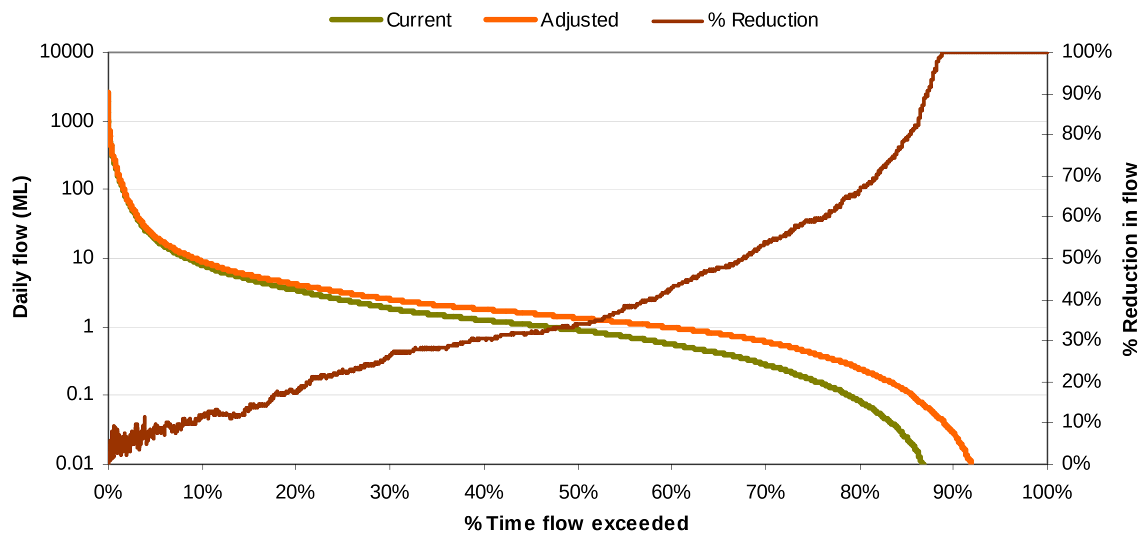


Figure E.3 Dawesley Creek sub-catchment daily flow duration – impact of farm dams

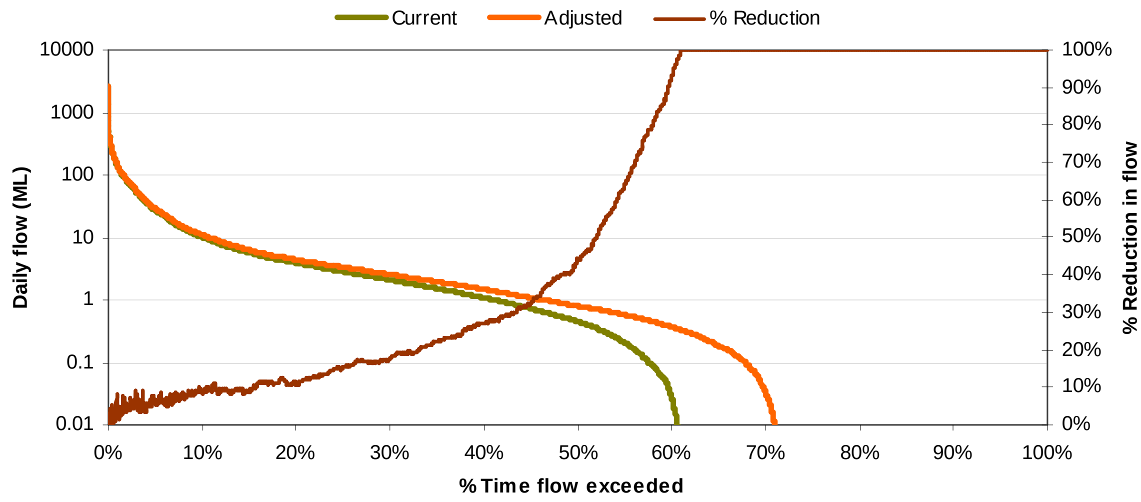


Figure E.4 Lower Mount Barker Creek sub-catchment daily flow duration – impact of farm dams

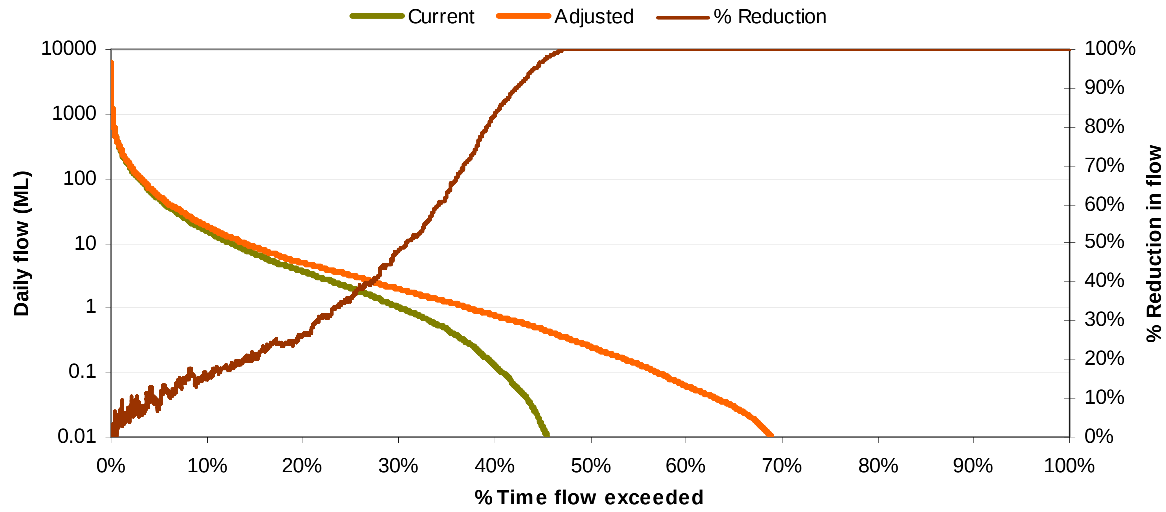


Figure E.5 Upper Bremer River sub-catchment daily flow duration – impact of farm dams

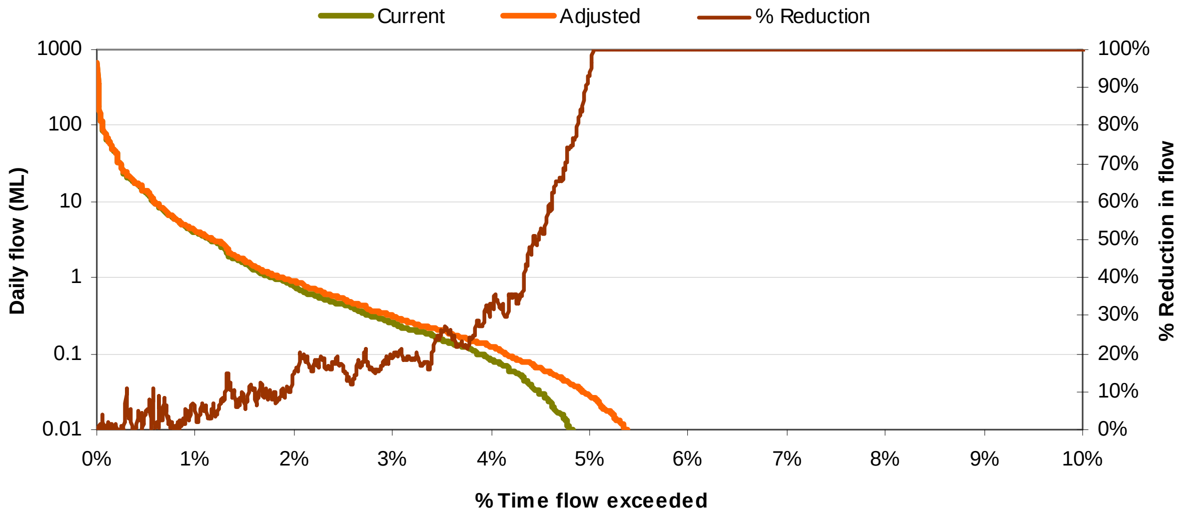


Figure E.6 Lower Bremer River sub-catchment daily flow duration – impact of farm dams

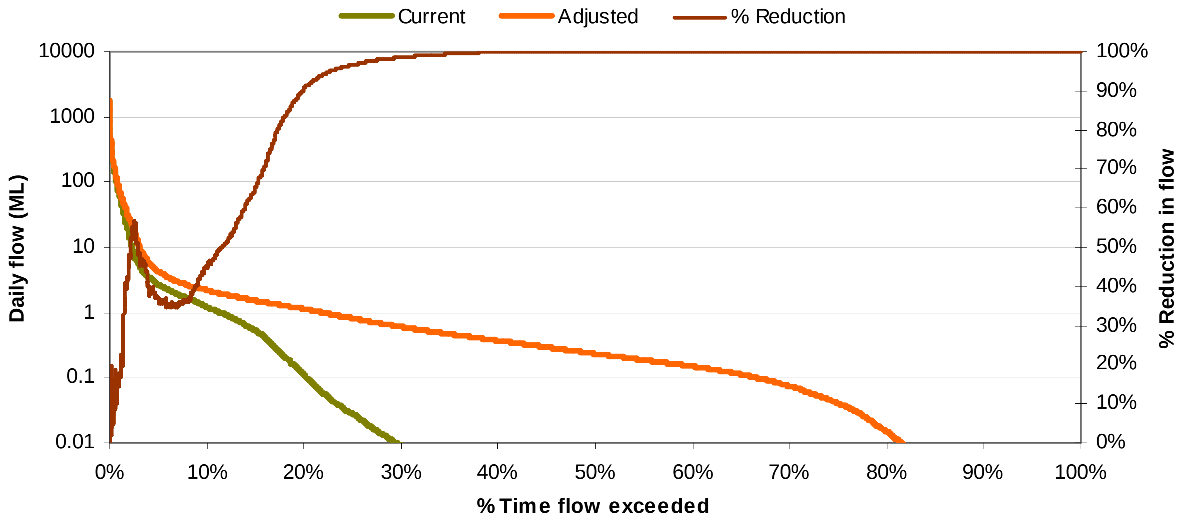


Figure E.7 Rodwell Creek sub-catchment daily flow duration – impact of farm dams

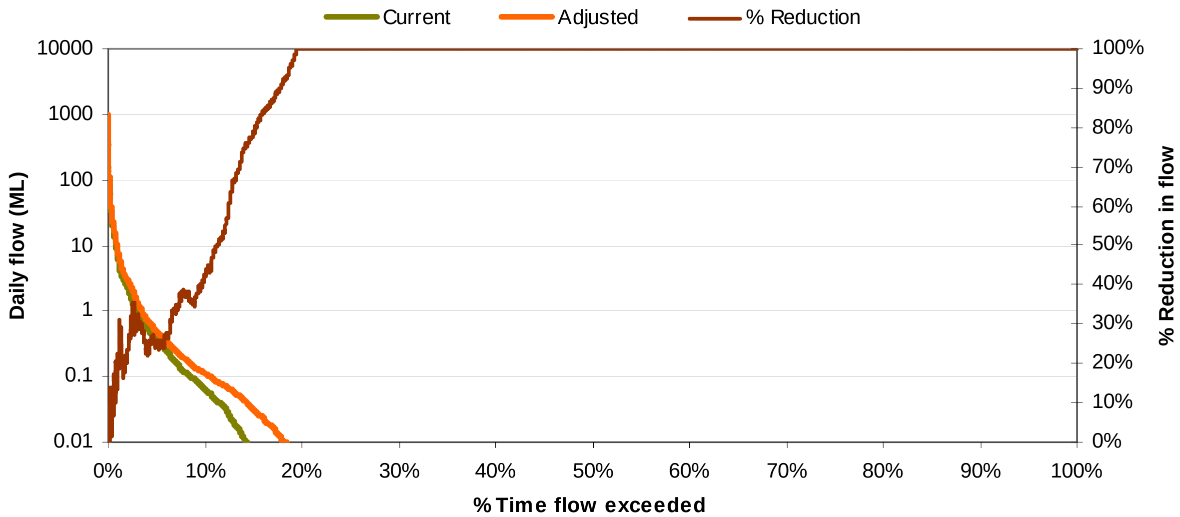


Figure E.8 Red Creek sub-catchment daily flow duration – impact of farm dams

F. BIRD-IN-HAND STEDS MONTHLY OUTFLOWS

Data sourced from SA Water.

Discharged Flows (ML) as measured by Mag-Flow Meter													
Year	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total**
2001–02				41.41	18.41	28.19	16.43	5.90	11.43	9.17	3.63	14.15	282.12
2002–03	35.22	23.56	17.89	22.50	16.74	9.70	1.73	12.12	10.38	2.20	20.77	18.09	190.90
2003–04	53.33	52.99	65.50	29.76	25.03	27.76	15.30	15.70	21.27	21.32	2.64	4.88	335.47
2004–05	34.16	44.08	13.15	11.15	13.06	13.26	10.56	17.11	14.12	14.55	2.42	20.67	208.30
2005–06	16.88	31.04	28.49	33.96	26.96	0.00*	1.17	0.00	0.00	0.00	46.98	22.17	207.63

*Flow not recorded due to flow meter being offline - flow likely to be around 40 ML

Discharged Flows (ML) as measured by V-notch Weir													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
1991	N/A	N/A	N/A	N/A	15	28.8	44.4	68.6	47.8	11.9	12	7.2	
1992	0	9.4	20.9	1.1	1.4	30.4	36	48.2	56.4	41.9	29.6	31.2	306.5

Plant inflow as calculated by pump run times (ML)													
Year	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total**
1996–97	36.8	43.2	35.0	32.6	22.7	21.4	20.0	18.3	20.3	19.6	20.6	27.6	318
1997–98	27.8	31.4	47.4	33.2	35.4	36.3	36.7	37.2	30.5	23.0	26.4	26.7	392
1998–99	33.0	33.8	29.9	29.1	24.4	23.4	21.9	21.0	24.7	24.1	28.3	29.9	323
1999–00	34.8	35.0	37.2	29.1	25.5	25.9	25.5	24.6	24.3	23.9	28.5	31.4	346
2000–01	39.8	42.3	45.6	35.8	28.1	26.8	24.3	22.0	24.8	23.5	28.7	36.9	379

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

~ approximately equal to

GLOSSARY

Act (the) — In this document, refers to the *Natural Resources Management Act* (SA) *2004*

Adaptive management — A management approach, often used in natural resource management, where there is little information and/or a lot of complexity, and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions, and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Ambient — The background level of an environmental parameter (e.g. a background water quality such as salinity)

Annual adjusted catchment yield — Annual catchment yield with the impact of dams removed

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through

Aquifer, confined — Aquifer in which the upper surface is impervious and the water is held at greater than atmospheric pressure. Water in a penetrating well will rise above the surface of the aquifer

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

AWBM — Australian Water Balance Model. A conceptual daily rainfall runoff model

Baseflow — The water in a stream that results from groundwater discharge to the stream (this discharge often maintains flows during seasonal dry periods and has important ecological functions)

Basin — The area drained by a major river and its tributaries

Biological diversity (biodiversity) — The variety of life forms: the different life forms including plants, animals and micro-organisms, the genes they contain and the *ecosystems (see below)* they form. It is usually considered at three levels — genetic diversity, species diversity and ecosystem diversity.

BoM — Australian Bureau of Meteorology

Bore — *See well*

Catchment — That area of land determined by topographic features within which rainfall will contribute to runoff at a particular point

Catchment water management plan — The plan prepared by a CWMB and adopted by the Minister in accordance with Part 7, Division 2 of the *Water Resources Act 1997*

Conjunctive use — The utilisation of more than one source of water to satisfy a single demand

CWMB — Catchment Water Management Board—A statutory body established under Part 6, Division 3, s. 53 of the Act whose prime function under Division 2, s. 61 is to implement a catchment water management plan for its area

Dams, off-stream dam — A dam, wall or other structure that is not constructed across a watercourse or drainage path and is designed to hold water diverted or pumped from a watercourse, a drainage path, an aquifer or from another source. Off-stream dams may capture a limited volume of surface water from the catchment above the dam

Dams, on-stream dam — A dam, wall or other structure placed or constructed on, in or across a watercourse or drainage path for the purpose of holding and storing the natural flow of that watercourse or the surface water

Dams, turkey nest dam — An off-stream dam that does not capture any surface water from the catchment above the dam

DEM — Digital Elevation Model

Domestic purpose — The taking of water for ordinary household purposes and includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectare

Domestic wastewater — Water used in the disposal of human waste, for personal washing, washing clothes or dishes, and swimming pools

DWLBC — Department of Water, Land and Biodiversity Conservation (Government of South Australia)

EC — Electrical conductivity, defined as: 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C. Commonly used to indicate the salinity of water.

Ecological processes — All biological, physical or chemical processes that maintain an ecosystem

Ecological values — The habitats, natural ecological processes and biodiversity of ecosystems

Ecology — The study of the relationships between living organisms and their environment

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

Effluent — Domestic and industrial wastewater

EMLR — Eastern Mount Lofty Ranges

Environmental values — The uses of the environment that are recognised as of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

Environmental water provisions — Those parts of environmental water requirements that can be met at any given time. This is what can be provided at that time with consideration of existing users' rights, and social and economic impacts.

Environmental water requirements — The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk

EPA — Environment Protection Authority (Department for Environment and Heritage, Government of South Australia)

Ephemeral streams or wetlands — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral

Erosion — Natural breakdown and movement of soil and rock by water, wind or ice. The process may be accelerated by human activities

ESD — Ecologically sustainable development

Evapotranspiration — The total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies

EWR — Environmental Water Requirement

Floodplain — Of a watercourse means: (a) the floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under Part 7 of the *Water Resources Act 1997*; or (b) where paragraph (a) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the *Development Act 1993*, or (c) where neither paragraph (a) nor paragraph (b) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse

Flow bands — Flows of different frequency, volume and duration

GA — Genetic algorithm

Geological features — Include geological monuments, landscape amenity and the substrate of land systems and ecosystems

GIS — Geographic information system. Computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

GL — Gigalitre, defined as: one thousand million litres (1 000 000 000)

Groundwater — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground

Habitat — The natural place or type of site in which an animal or plant, or communities of plants and animals, lives

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers.*(see hydrology)*

Hydrography — The discipline related to the measurement and recording of parameters associated with the hydrological cycle, both historic and real time

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere *(see hydrogeology)*

ILCL — Initial Loss – Continuing Loss

Indigenous species — A species that occurs naturally in a region

Infrastructure — Artificial lakes; dams or reservoirs; embankments, walls, channels or other works; buildings or structures; or pipes, machinery or other equipment

Integrated catchment management — Natural resources management that considers in an integrated manner the total long-term effect of land and water management practices on a catchment basis, from production and environmental viewpoints

Intensive farming — A method of keeping animals in the course of carrying on the business of primary production in which the animals are confined to a small space or area and are usually fed by hand or mechanical means

Irrigation — Watering land by any means for the purpose of growing plants

Irrigation season — The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May

Land — Whether under water or not, and includes an interest in land and any building or structure fixed to the land

Licence — A licence to take water in accordance with the *Water Resources Act 1997 (see water licence)*

Licensee — A person who holds a water licence

Local water management plan — A plan prepared by a council and adopted by the Minister in accordance with Part 7, Division 4 of the Act

Macro-invertebrates — Animals without backbones that are typically of a size that is visible to the naked eye. They are a major component of aquatic ecosystem biodiversity and fundamental in food webs.

Mag-Flow Meter — A device used to measure flow through pipes

MDBC — Murray–Darling Basin Commission

ML — Megalitre, defined as: one million litres (1 000 000)

MLR — Mount Lofty Ranges

Model — A conceptual or mathematical means of understanding elements of the real world which allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change

Mount Lofty Ranges Watershed — The area prescribed by Schedule 1 of the regulations

MREFTP — Marne River Environmental Flows Technical Panel

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc.) *(see recharge area, artificial recharge)*

Natural resources — Soil; water resources; geological features and landscapes; native vegetation, native animals and other native organisms; ecosystems

NHT — Natural Heritage Trust

NRM — Natural Resources Management**.** All activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

Occupier of land — A person who has, or is entitled to, possession or control of the land

Owner of land — In relation to land alienated from the Crown by grant in fee simple — the holder of the fee simple; in relation to dedicated land within the meaning of the *Crown Lands Act 1929* that has not been granted in fee simple but which is under the care, control and management of a Minister, body or other person — the Minister, body or other person; in relation to land held under Crown lease or licence — the lessee or licensee; in relation to land held under an agreement to purchase from the Crown — the person entitled to the benefit of the agreement; in relation to any other land — the Minister who is responsible for the care, control and management of the land or, if no Minister is responsible for the land, the Minister for Environment and Heritage.

Pasture — Grassland used for the production of grazing animals such as sheep and cattle

Percentile — A way of describing sets of data by ranking the dataset and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

Permeability — A measure of the ease with which water flows through an aquifer or aquitard; the unit is m^2/d

PIRSA — Department of Primary Industries and Resources, South Australia (Government of South Australia)

Precautionary principle — Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation

PPD — Patched Point Dataset

Prescribed area, surface water — Part of the state declared to be a surface water prescribed area under the *Water Resources Act 1997*

Prescribed lake — A lake declared to be a prescribed lake under the *Water Resources Act 1997*

Prescribed watercourse — A watercourse declared to be a prescribed watercourse under the *Water Resources Act 1997*

Prescribed water resource — A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system

Prescribed well — A well declared to be a prescribed well under the *Water Resources Act 1997*

Property right — A right of ownership or some other right to property, whether real property or personal property

Proponent — The person or persons (who may be a body corporate) seeking approval to take water from prescribed water

PWA — Prescribed Wells Area

PWCA — Prescribed Watercourse Area

PWRA — Prescribed Water Resources Area

Ramsar Convention — This is an international treaty on wetlands titled 'The Convention on Wetlands of International Importance Especially as Waterfowl Habitat'. It is administered by the International Union for Conservation of Nature and Natural Resources. It was signed in the town of Ramsar, Iran in 1971, hence its common name. The convention includes a list of wetlands of international importance and protocols regarding the management of these wetlands. Australia became a signatory in 1974.

Recharge area — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer *(see artificial recharge, natural recharge)*

Rehabilitation (of water bodies) — Actions that improve the ecological health of a water body by reinstating important elements of the environment that existed prior to European settlement

Remediation (of water bodies) — Actions that improve the ecological condition of a water body without necessarily reinstating elements of the environment that existed prior to European settlement

Restoration (of water bodies) — Actions that reinstate the pre-European condition of a water body

Reticulated water — Water supplied through a piped distribution system

Riffles — Shallow stream section with fast and turbulent flow

RMCWMB — River Murray Catchment Water Management Board

RMCWMP — River Murray Catchment Water Management Plan

SAMDB NRM — South Australian Murray–Darling Basin Natural Resources Management

Seasonal watercourses or wetlands — Those watercourses and wetlands that contain water on a seasonal basis, usually over the winter–spring period, although there may be some flow or standing water at other times

SILO — Rainfall database maintained by the Department of Natural Resources, Queensland

State water plan — The plan prepared by the Minister under Part 7, Division 1, s. 90 of the Act

STEDS — Sewage Treatment and Effluent Disposal System

Stock use — The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act)

Stormwater — Runoff in an urban area

Sub-catchment — The area of land determined by topographical features within which rainfall will contribute to run-off at a particular point

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

SIMHYD — A conceptual daily rainfall–runoff model

To take water — From a water resource includes (a) to take water by pumping or siphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir.

Transfer — A transfer of a licence (including its water allocation) to another person, or the whole or part of the water allocation of a licence to another licensee or the Minister under Part 5, Division 3, s. 38 of the Act. The transfer may be absolute or for a limited period

V-notch weir — A constructed weir across a river or creek with a triangular notch taken out of the middle. Used to provide sensitive measurement of water levels and flows

Volumetric allocation — An allocation of water expressed on a water licence as a volume (e.g. kilolitres) to be used over a specified period of time, usually per water use year (as distinct from any other sort of allocation)

WAP — Water allocation plan. A plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with Division 3 of Part 7 of the Act.

Water affecting activities — Activities referred to in Part 4, Division 1, s. 9 of the Act

Water allocation — (a) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (b) in respect of water taken pursuant to an authorisation under s. 11 means the maximum quantity of water that can be taken and used pursuant to the authorisation.

Water allocation, area based — An allocation of water that entitles the licensee to irrigate a specified area of land for a specified period of time usually per water–use year

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse.

WaterCRESS — Water Community Resource Evaluation and Simulation System

Water-dependent ecosystems — Those parts of the environment, the species composition and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground. The in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems.

Water licence — A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area. This grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water. A water licence confers a property right on the holder of the licence and this right is separate from land title.

Water plans — The State Water Plan, catchment water management plans, water allocation plans and local water management plans prepared under Part 7 of the Act

Water service provider — A person or corporate body that supplies water for domestic, industrial or irrigation purposes or manages wastewater

Water-use year — The period between 1 July in any given calendar year and 30 June the following calendar year. This is also called a licensing year

WC-1 — A conceptual daily rainfall–runoff model

Well — (a) an opening in the ground excavated for the purpose of obtaining access to underground water; (b) an opening in the ground excavated for some other purpose but that gives access to underground water; (c) a natural opening in the ground that gives access to underground water.

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.

WWTP — Waste Water Treatment Plant

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