DWLBC REPORT

Assessment of Surface Water Resources of Patawalonga Catchment and the Impact of Farm Dam Development

2007/09

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

Assessment of Surface Water Resources of Patawalonga Catchment and the Impact of Farm Dam Development

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Government of South Australia
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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 continues 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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EXECUTIVE SUMMARY

The Patawalonga Catchment Water Management Board (now part of the Adelaide and Mount Lofty Ranges Natural Resources Management Board) has asked the Department of Water, Land and Biodiversity (DWLBC) to establish a detailed daily rainfall to runoff model of its area of responsibility and to use the model to estimate the impact that farm dams are having on flows within the catchment, based on a number of modelling scenarios, namely:

- With farm dams at their current level of development.
- With all farm dams removed.
- With farm dams developed to a maximum level based on the 50% rule for rural catchments.
- At the above maximum level, but with the low flow bypass rule applied.

For each scenario, the level of annual dam water use was assumed to range from 30–100% of the dam capacity. 30% was assumed to be the current level of usage and was used in model flow calibration.

An assessment of the urban catchment flows at Morphettville Racecourse (Drain 3), Oaklands Park (Drain 4 and 6) and Parklands Creek at Victoria Park Racecourse has also been provided.

The Patawalonga catchment has a total area of 235 km^2 comprising about equal urban and rural parts. The catchment includes i) the main urban and rural catchments feeding to the Patawalonga basin outlets and ii) the Coastal urban catchments to the south of this basin, discharging to the sea between Glenelg and Seaford. The topography rises from sea level at the coast to 600 m at the highest elevation in the Adelaide Hills. The mean annual rainfall across the total area is about 657 mm with 70% of the rain occurring in the winter months.

At present, there are 229 irrigation, stock and domestic dams within the Patawalonga catchment, with a total capacity of 692 ML. Only 22 of these (those greater than 5 ML) are assumed to be for irrigation, but these comprise 61% of the total. About 565 ML or 82% of the total is located in the rural part of the Sturt River catchment.

The annual supply of surface water to irrigation from farm dams is estimated to be 415 ML of which 98% is supplied in the Sturt River catchment.

The WaterCress PC-based computer program (Cresswell, 2000) has been used as the platform for catchment modelling. For modelling purposes, the catchment has been separated into six major subcatchments, further subdivided into 91 minor subcatchments. The rainfall to runoff model contained within the WaterCress model has been calibrated against flow measured for 10 gauged catchments with areas ranging from 1.25 to 116 km^2. The bulk of the flow data has been recorded over the last 10 years, with the longest record spanning 25 years. A daily rainfall database has been established for calibration of the rainfall to runoff model and extension of the flow records. The database contains continuous daily rainfall records for 11 locations spread across the catchment with records extending back to 1900. Thus, once calibrated, the model could be used to estimate flows within the subcatchments over a continuous period of 102 years from 1900–2001.

KEY FINDINGS

Catchment flows. Flows for the six major subcatchments have been compared to previous estimates (Tonkin, 2000b). The DWLBC model, when calibrated to present day conditions, predicts the 102 year average flow to be 22.65 GL/a (median flow 21.2 GL/a). Of this, 2.51 GL/a is discharged through the Coastal catchments south of the Patawalonga estuary and 20.14 GL/a through the Patawalonga outlets. This total is 20% less than the Tonkin estimation, mainly because of a lower estimate of runoff from the urbanised parts of the catchments.

The lowest 3-year average flow was 11.7 GL/a (1912–14) and the highest was 35.4 GL/a (1922–24).

The surface water resource, defined by DWLBC as the median year catchment yield modelled with farm dams removed, was estimated as 21.32 GL/a. The urban and rural parts contribute about half each.

At the current development level, the long-term mean catchment yields for Morphettville Racecourse (Drain 3), Oaklands Park (Drains 4 and 6) and Parklands Creek at Victoria Park are estimated to be 348 ML/a, 1,148 ML/a and 955 ML/a respectively. In the extreme driest three year period (1912-914), the average annual yields are reduced to 241 ML/a, 646 ML/a and 697 ML/a.

Runoff coefficients. The overall runoff coefficient (ie runoff volume/rainfall volume) for the urban part of the Patawalonga catchment is 17% and the rural part 15%. For the urban part this is comparatively low, given that runoff coefficients for urban catchments are generally reported to be of the order of 20% or higher. At the major subcatchments level, the coefficients for the urban part of Brown Hill Creek, Keswick Creek and the Coastal catchments are 23% respectively. The overall coefficient is influenced by the low coefficients for the Sturt River, at 14%, and the Adelaide Airport Drain catchment, at 10%. The Adelaide Airport Drain has a substantial part of its catchment modelled as 'rural' catchment. The low values correspond to flow calibrations at gauging stations where the lower flows were recorded.

Farm dams and low flow bypasses. The current level of farm dam development has been shown to only have a very small impact on the flows (calculated as about 0.5% at the median flow level).

The numbers and sizes of farm dams could be greatly increased without exceeding current policy levels (by up to about 6 times the current volume, ie. increased to 3568 ML). If the full allocation of storage was taken up, modelling for the four rural catchments (Sturt River u/s Minno Creek, Minno Creek, Chambers Creek and Brown Hill Creek u/s Scotch College) shows that, without low flow bypasses incorporated into the farm dam structures, runoff in these catchments could be reduced by 17.5–45.2% in an average year, depending on the level of assumed water diversion from the dams to supply. This range corresponds to assumed annual diversions to supply being within the range 30–100% of the total capacity of the dams. In a dry year, downstream flows could be reduced to zero.

If low flow bypasses were instituted, the impact at maximum dam development would be significantly reduced, particularly in a dry year when the four rural catchments would still have more than 50% of the flows generated within the upstream catchment passing downstream.

The institution of low flow bypasses would not impact very much on the average level of annual supplies provided from farm dams (although the reliability of the supplies would reduce), however, they would have a very beneficial effect on downstream flow regimes. At maximum farm dam development, without bypasses, downstream flows would only occur, on average, over about 40% of the time. With bypasses, the downstream flows would be restored, on average, to about 80% of the time. This increase would restore flows for the protection of water-dependent ecosystems.

Information gaps. During model calibration evidence emerged on the likely existence of significant transmission losses in the Sturt River and Brown Hill creeks. Time was not available to investigate these losses which may also include such causes as raintanks, etc. Thus it is probable that total runoff generated within the catchments is greater than runoff measured by gauging stations situated at downstream locations. There are also information gaps which introduce uncertainties into flow estimates, such as the use of inaccurate rating curves, farm dam capacities and levels of usage from the dams.

CONCLUSIONS

Modelling confirms previous estimates of the total flow contributing to the Patawalonga basin. However, this study indicates that the contributions from the urban subcatchments are less and contributions from the rural subcatchments are greater than previously estimated. As a corollary, the flow contribution from the urbanised Coastal catchments south of Glenelg is estimated to be significantly less than previously estimated.

Current farm dam development is estimated to be not significantly impacting on catchment flows. However, there is considerable scope for further establishment of dams and under circumstances of high water use from dams and no flow bypasses, the impact could be significantly greater.

If low flow bypasses were instituted, they would not have a great impact on the present capability of farm dams to intercept catchment flows. They would, however, have a large beneficial effect on the daily flow regimes. Without low flow bypasses, at maximum farm dam development, downstream flows would only occur on average for 40% of the time. With low flow bypasses, the duration of downstream flows would be restored to 80% of the time. This would have a great impact on the water-dependent ecosystems.

Since runoff from urban areas is greatly in excess of pre-development levels, allocation and environmental protection policies for the two parts of the catchment may be very different. The model is a suitable tool for exploring the impacts of different policies.

The establishment of the model has revealed several information gaps and uncertainties. It is recommended that the model should continue to be upgraded so that flow estimates can be made with greater confidence.

RECOMMENDATIONS

1. The catchment flow estimates from this model are based on cohesive and wide-ranging information and assumptions. The flows have been given for a range of conditions. They are recommended for adoption as the present best estimates and are suitable for resource assessment and allocation planning.
2. Any future farm dam development should incorporate low flow bypasses in order to provide environmental flows for sustaining the downstream water dependent eco-systems.
3. A more proactive approach should be taken to checking and editing the flow data collected. This should include comparing flows from adjacent catchments and rainfall to runoff modelling. This would enable flow data anomalies to be identified and investigated without due delay. The recording of observations of catchment flow would assist in building up a history of flow behaviour suitable for addressing gaps and anomalies in recorded flows.
4. A number of information gaps have been identified during this study that need to be addressed to improve the catchment modelling, namely:
   - Transmission losses along the Upper Sturt River, Brown Hill Creek (downstream of Scotch College) and Keswick Creek should be investigated.
   - The accuracy of the rating curves for gauging stations where flows do not conform to expectation should be reviewed.
   - Runoff coefficients derived from catchments with recorded flows vary greatly from 9% to 41%. The reasons for the variation will include the intensity of urbanisation, however, the reasons for the variations should be investigated to enable improved predictions to be made.
   - Flow gauging should be undertaken on representative catchments within the Coastal catchment.
   - The accuracy of the flood warning stations maintained by the Bureau of Meteorology along Keswick Creek should be upgraded to enable them to be used for resource assessment.
   - The inflows and outflows of urban wetlands should be monitored to determine their water balance dynamics.
   - Empirical formulae are used to estimate farm dam volumes and the level of usage from farm dams for different purposes. Field data are needed to verify the formulae, or replace the need for the formulae. These data are vital for improving the accuracy of catchment and dam water balances and establishing efficient and equitable farm dam policies and regulations.

1. INTRODUCTION

1.1 PURPOSE

The Department of Water, Land and Biodiversity Conservation (DWLBC) and the Patawalonga Catchment Water Management Board (the Board) have jointly funded this study, which aimed to:

1. examine the rainfall and flow data in order to identify general or specific hydrologic processes occurring in the catchment
2. provide a calibrated daily time step catchment hydrological model for the Board which can be used at a later date for other runoff investigations
3. use the model to provide an assessment of the surface water resource of the Patawalonga catchment in its current state of development, but with farm dams removed
4. use the model to quantify the impact of farm dams on the surface water resource under different past and possible future development scenarios.

The WaterCress program is the platform used for the hydrological modelling.

1.2 BACKGROUND

Under the *Water Resources Act 1997,* the Board is required to manage the development and use of all water resources in the Patawalonga catchment and to ensure that available resources are used in a sustainable manner. This includes the requirement that water and riverine environments within the catchment can support a healthy ecosystem. DWLBC has a parallel interest through its responsibility for the State Water Plan (Department for Water Resources 2000).

DWLBC has previously studied the impacts of farm dams on catchment flows for several Mount Lofty ranges catchments using the WaterCress model. Although farm dams only occupy the upper, rural reaches of the Patawalonga catchment, DWLBC methods have been incorporated into this study.

1.3 APPROACH TO STUDY

The approach to the study used four essential steps:

1. sourcing, processing and validating available datasets including evaporation, rainfall, streamflow, farm dams and land use
2. constructing a daily time-step hydrological model and performing model calibration
3. using the model to investigate past, current and future farm dam development scenarios
4. interpreting and presenting the runoff simulation results.

In the absence of data, two levels of usage from farm dams have been assumed (at annual diversion rates equal to 30% and 100% of the dam storage capacity) to indicate the sensitivity to these assumptions.

The runoff simulation is performed using the historical rainfall record of 1900–2002. This allows catchment performance to be assessed over a wide range of climatic conditions, including the long-term averages and extremes of about 1-in-100 year recurrence.

2. CATCHMENT DESCRIPTION, DAMS AND WATER USE ESTIMATION

2.1 GENERAL DESCRIPTION

The Patawalonga catchment drains the western margin of the Mount Lofty Ranges and the Adelaide plains to the immediate south of Adelaide (Fig. 1) into Gulf St Vincent. All drains discharging through the Patawalonga estuary (including the Barcoo outlet) are part of the catchment, as is the coastal strip to the south of the estuary which discharges through many separate outlets between Glenelg and Seaford.

Land in the catchment lies within the boundaries of the Cities of Adelaide, Charles Sturt, Holdfast Bay, Burnside, West Torrens, Unley, Mitcham, Marion, Onkaparinga and the Adelaide Hills Council.

The Mount Lofty escarpment divides the catchment into upper and lower parts of about equal areas.

The upper part is hilly with elevations rising to 600 m at the eastern catchment boundary. Until recently, it was mainly rural except for the Blackwood and Belair residential areas. Urbanisation is rapidly expanding around Craigburn and along the Coromandel Valley, and soon about half of the upper Sturt River catchment above the escarpment will be fully urbanised.

The lower part is a coastal plain of low relief, rising to about 100 m at the foot of the escarpment. This area is largely urbanised.

The total catchment area of about 235 km^2 is divided into six major subcatchments (Fig. 2):

- Sturt River (120 km^2).
- Brown Hill Creek (36 km^2).
- Keswick Creek (includes Park Lands and Glen Osmond creeks; 30 km^2).
- Airport drain (18 km^2).
- Local Patawalonga catchment (4 km^2).
- Coastal catchment (26 km^2).

All except the last, discharge through the Patawalonga estuary.

Before urban development the only identified surface watercourses crossing the plains were Sturt River and Brown Hill Creek. Other creeks discharging from the escarpment were only traced a short distance across the plains. Sturt River and Brown Hill Creek discharged into an area of swampland in the vicinity of the present Adelaide airport, an area that also received discharges from the River Torrens. It was separated from the sea by a strip of coastal dunes and had outlets to both the north (at Port Adelaide) and the south (at the Patawalonga).

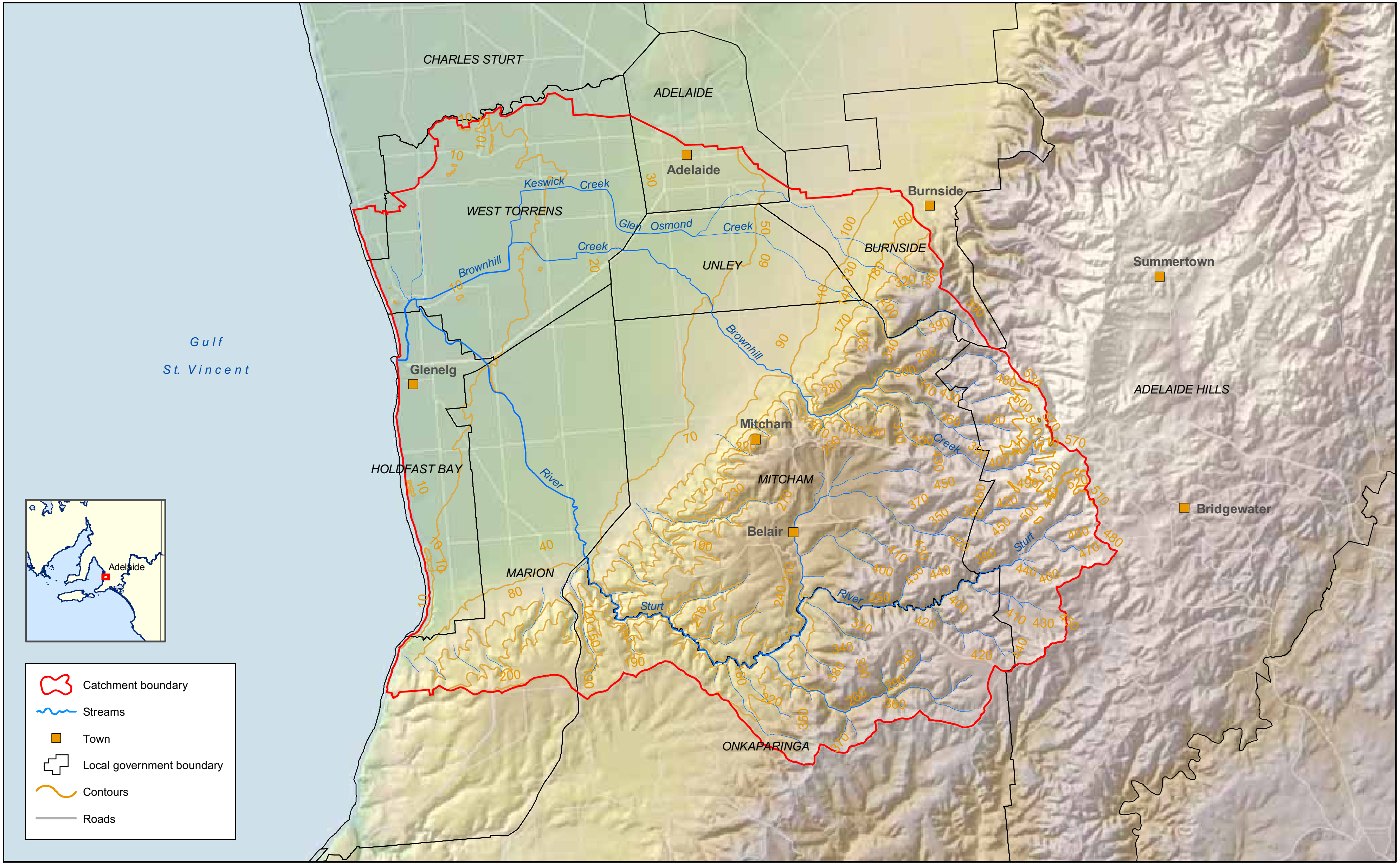

Figure 1: Patawalonga Catchment

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Department of Water, Land and Biodiversity Conservation
Projection: UTM Zone 54
Datum: Geocentric Datum of Australia 1994
Date: 1 June 2005

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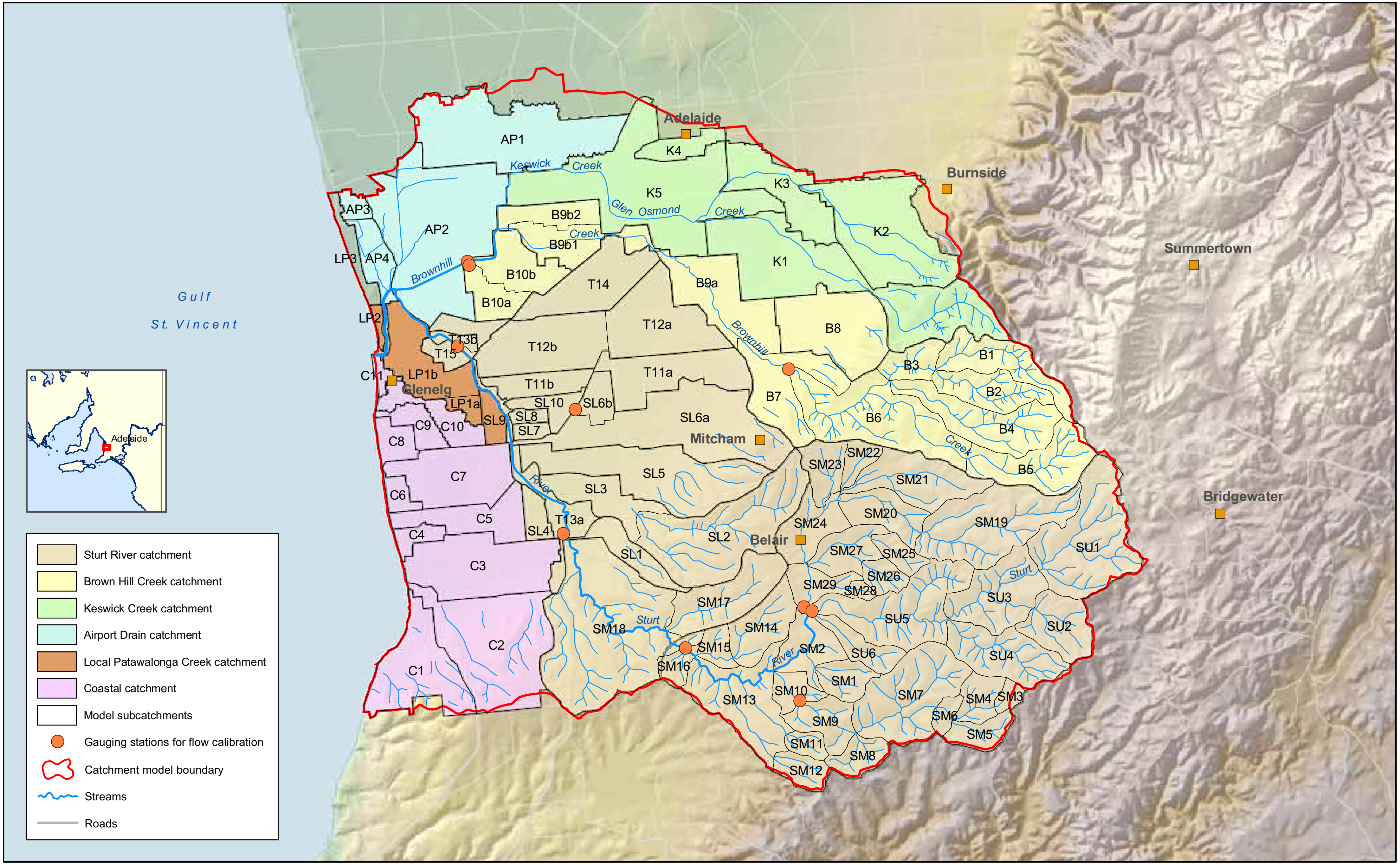

Figure 2: Model subcatchments

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With urbanisation, artificial drains were constructed to remove the additional flows produced by impervious areas. They generally followed the east–west road patterns; most were concrete-lined and many were laid underground. Only Sturt River, Brown Hill Creek and the Park Lands creek follow original paths over the plains, although somewhat straightened. The Sturt River has been concrete lined, leaving only the Brown Hill Creek and lower Park Lands Creek/Keswick Creek systems as mainly unlined.

DWLBC has produced an annual isohyet map on the basis of rainfall measured at a combination of rain gauges monitored by DWLBC and the Bureau of Meteorology (Fig. 6). Rainfall increases from the coast at Glenelg progressively eastwards to the highest point in the Sturt River catchment. The rainfall gradient mirrors the ground slope and is steepest over the Adelaide Hills face zone. The annual rainfall rises steadily from 470 mm near the coast to 710 mm at the Brown Hill Creek catchment boundary and 950 mm at the Upper Sturt River catchment boundary. The area weighted mean annual rainfall is 657 mm of which about 70% is received in the winter months of May to October.

The Heathfield Wastewater Treatment Plant (WWTP) is located just outside the Patawalonga catchment but discharges its treated effluent into the upper Sturt River catchment. The records indicate a mean discharge rate of 525 ML/a during 1991–2002, or about 23% of the annual flow volume recorded at the downstream gauging station just upstream of the junction of the Sturt River and Minno Creek.

A map of groundwater salinity has been prepared for the upper quaternary aquifers under the Adelaide plains (Pavelic 1992). This shows plumes of low salinity water following the direction of Sturt River and Brown Hill Creek as they emerge from the escarpment. This may be an indication of recharge taking place from losses in the surface flows in these reaches.

More than 20 gauging stations are listed for the Patawalonga catchment, though some are now closed. Most of them are located in the Sturt River, Brown Hill Creek and Keswick Creek catchments. The Bureau of Meteorology monitors eight for flood warning purposes, and the Board and DWLBC have monitored the others for stream flow and water quality. Only 10 of the gauging stations are considered to have sufficient length of good quality records for model calibration.

2.2 FARM DAMS AND WATER STORAGES

The farm dam and water storage data, which were supplied by the Department for Environment and Heritage, were digitised from 1999 air photography as part of a Country Fire Services (CFS) mapping project that aimed to provide mapped locations. Accuracy for estimation of areas and volumes may therefore not be necessarily very high.

Farm dams have been classified on the basis of their estimated volume as providing water for stock and domestic use (less than 5 ML) or for irrigation (greater than 5 ML). Usage from stock and domestic (S&D) dams is assumed to be at a constant rate throughout the year. Usage from irrigation dams is assumed to follow a seasonal pattern with the highest withdrawal rates being in the summer months. The water stored in the dams is assumed to have been captured from surface runoff from the upstream catchment.

Dam volumes have been estimated using a formula proposed by McMurray (2002) based on the mapped dam surface area:

For A <20 000 $V = 0.000215*A^{1.26}$

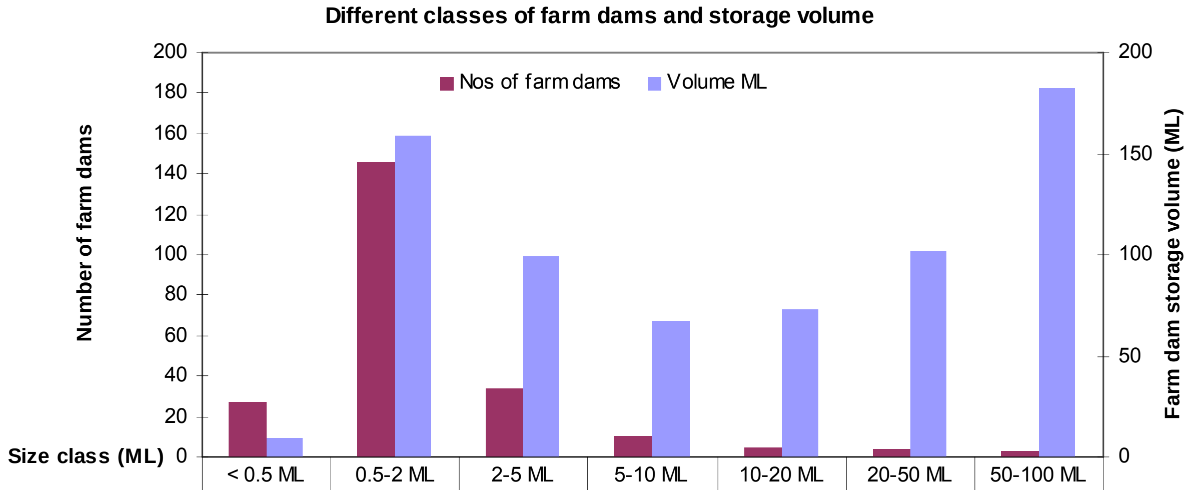
For A ≥ 20 000 $V = 0.0028*A$

where A = the dam surface area (m^2) obtained from the digitised data

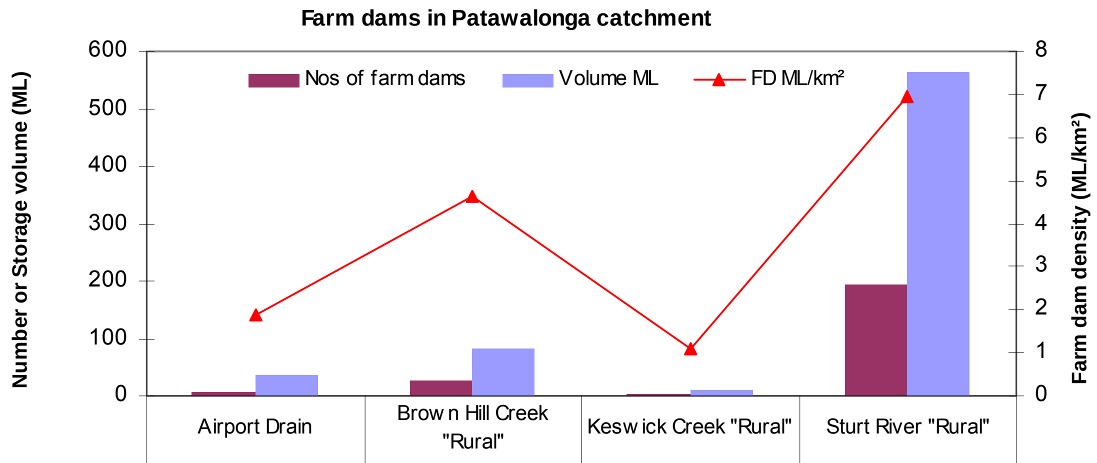
V = estimated volume (ML)

The database shows a total of 229 water storages within the total catchment. The formula produces an estimate of the aggregated storage capacity of 692 ML. This includes 156.2 ML of storages within the urban areas: Urrbrae Wetlands (48.6 ML), Airport Drain catchment (34.9 ML), Warriparinga Wetland (55.2 ML) and Flinders University Lake (17.5 ML). The formula does overestimate these urban storages but the values are retained for consistency.

The sizes, volumes and locations of water storages within each major subcatchment are shown in Figures 3–4. Aggregated dam volumes are shown in Table 1.



Size class (ML)	< 0.5 ML	0.5-2 ML	2-5 ML	5-10 ML	10-20 ML	20-50 ML	50-100 ML
Nos of farm dams	27	146	34	10	5	4	3
Volume ML	10	159	99	67	73	102	182



	Airport Drain	Brow n Hill Creek "Rural"	Kesw ick Creek "Rural"	Sturt River "Rural"
Nos of farm dams	8	25	4	192
Volume ML	35	82	10	565
FD ML/km²	1.9	4.6	1.1	7.0

Figure 3. Farm dam size and volume distribution

Figure 4: Spatial distribution of farm dams

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Projection: UTM Zone 54
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Table 1. Farm dam distribution

Catchment	Area* (ha)	No. of farm dams		Volume (ML)		Dam density (ML/ km^2)
		S&D	*Irrigation*	*S&D*	*Irrigation*	
Airport Drain	1 845	7	1	12	23	1.9
Brown Hill Creek	1 774	22	3	32	51	4.6
Keswick Creek	909	3	1	3	7	1.1
Sturt River	8 119	175	17	221	344	7.0
Total	**12 647**	**207**	**22**	**268**	**425**	**5.5**

Note: Areas are summed from minor subcatchments that contain farm dams

The aggregated dam volume of 692 ML is 21% higher than the 572 ML previously estimated (Tonkin Consulting et al. 2002). The discrepancy could be due to many reasons (e.g. an earlier formula used by DWLBC to estimate volumes would have given an estimate of 581 ML). More accurate volume estimates would require groundtruthing of the larger dams.

For this study, urban storages were treated in the same way as rural storages. Thus the seven dams of less than 5 ML within the Airport Drain catchment have been considered to have the same usage pattern as, for example, rural S&D farm dams.

Of the dams within the rural areas, only 22 have storage capacity greater than 5 ML but they constitute 425 ML or 61% of the total storage capacity. The spatial distribution shows that the rural part of the Sturt River catchment has the highest concentration of dams, comprising of 175 S&D dams (221 ML) and 17 irrigation dams (344 ML). This catchment contains 82% (565 ML) of the estimated total storage volume.

Intensity (or dam density) is calculated as the aggregated dam volume (ML) within a catchment divided by the catchment area (km^2). Within major subcatchments in which dams are present, the average density is 5.5 ML/km^2 (Table 1). For comparison, density in the Onkaparinga River catchment is 15.2 ML/km^2 (Teoh 2002).

2.3 LAND USE AND INFERRED IRRIGATION VOLUMES

Land use information was derived from the DWLBC LU98_ADL database, which combines data from the PIRSA Landuse99 database for the (mainly) rural area and the Planning SA 1998_Landuse database for the (mainly) metro area. DWLBC has also made some modifications and re-classifications based on the Australian and New Zealand Land Use Codes data system.

Land uses (other than residential gardens and other small open spaces) that take irrigation (supplied from any source but probably not mains water) for each of the six major subcatchments were obtained from these databases (Table 2).

Only about 10% (23.3 km^2) of the total catchment area supports land uses likely to be irrigated with non-mains water (Table 2). Of this area, 76% (17.6 km^2) is located in the rural part of the Sturt River catchment (Fig. 5). Figure 5 also shows areas classified as ‘protected’ which are not included in Table 2.

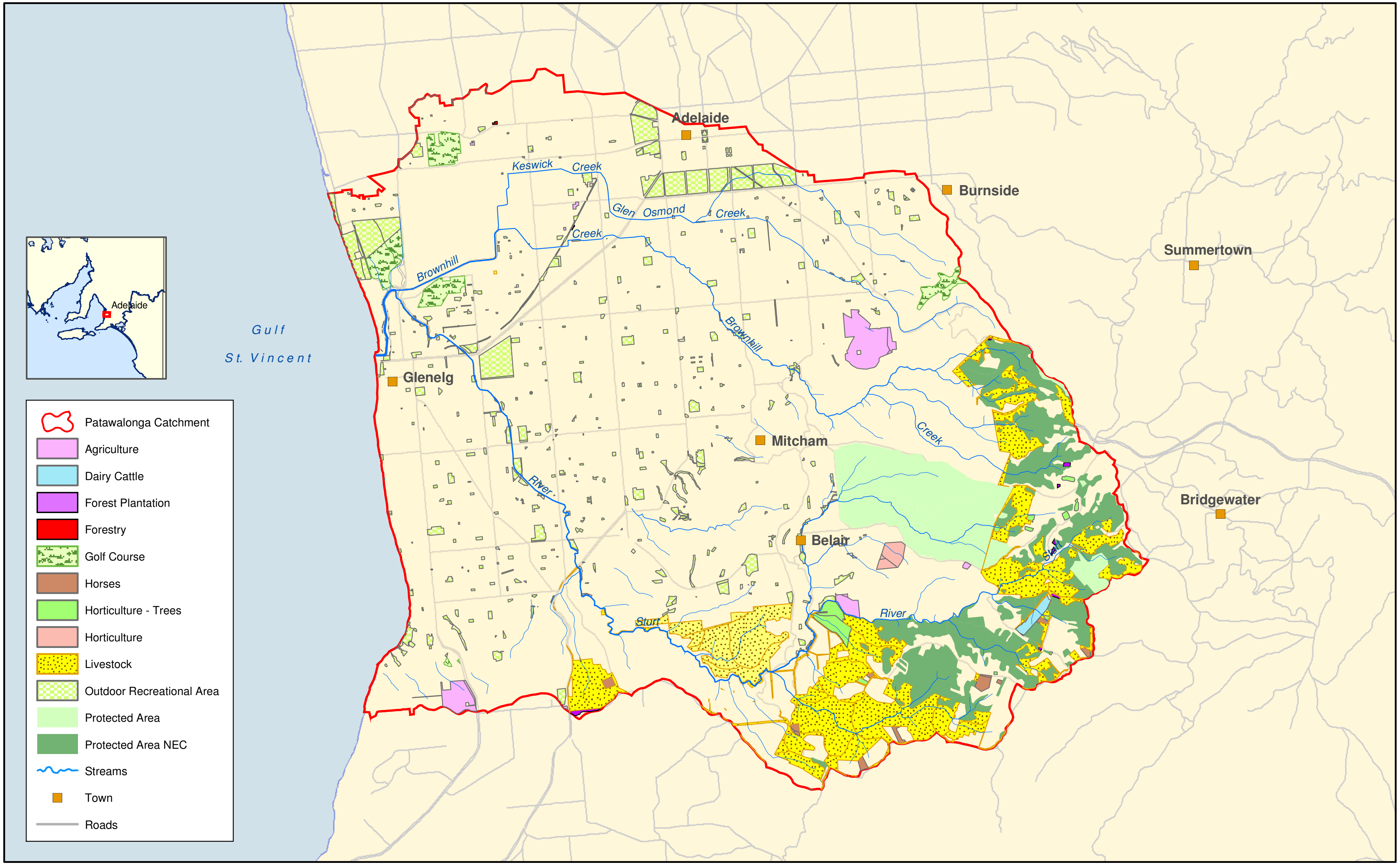

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Figure 5: Recreational and agricultural land use

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Datum: Geocentric Datum of Australia 1994
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Table 2. Land use associated with agriculture and primary produce

	Major subcatchment					
	Adelaide Airport	*Brown Hill*	*Coastal*	*Keswick*	*Sturt River*	*Total (ha)*
Agriculture	1	110	50	8	25	194
Dairy cattle					24	24
Livestock		172		3	1 548	1 723
Horses					41	41
Golf course	174		2	38		214
Forest plants		3			3	11
Forestry	1					1
Horticulture					34	34
Horticulture trees		3			64	67
Vine fruit					17	17
Vegetables nec					1	1
Total (ha)	**176**	**288**	**52**	**49**	**1 762**	**2 327**

Note: nec - not elsewhere classified

Table 3 shows an estimated average annual irrigation usage of 2956 ML/a, obtained using the 'global application method' developed by Teoh (2002; Table 10, p.47) with data for Onkaparinga catchment.

Table 3. Estimate of water use volume (ML)

	Proportion of irrigated area	**Application rate** (ML/ha)	Major subcatchment					
			Adelaide Airport	*Brown Hill*	*Coastal*	*Keswick*	*Sturt River*	*Total (ML)*
Agriculture	0.5	8.5	3.3	468.7	212.2	33.9	107.2	825.3
Dairy cattle	0.15	8.5	–	–	–	–	30.7	30.7
Livestock		0	–	–	–	–	–	
Horses	0.1	8.5	–	–	–	–	35.2	35.2
Golf course	1	8	1 390.3	0	18.9	307.0	0	1 716.2
Forest plants		0	0	–	0	0	–	
Forestry		0	–	–	0	0	0	
Horticulture	0.8	4	0	0	0	0	108.4	108.4
Horticulture trees	0.8	4	0	9.5	0	0	204.2	213.7
Vine fruit	0.75	2	0	0	0	0	25.1	25.1
Vegetables nec	0.3	6.5	0	0	0	0	1.2	1.2
Total (ML)			**1 393.5**	**478.2**	**231.2**	**340.9**	**512.0**	**2 955.8**

Note: nec - not elsewhere classified

Almost half of the estimated irrigation total is for irrigating the 174 ha golf course within the Adelaide Airport Drain subcatchment. Tonkin Consulting (2000, p15, Table 6.1) estimated a volume of the same order for the subcatchment. It has been assumed that all water supplied for irrigation within urban areas is derived from treated effluent, groundwater or mains water. Thus estimated irrigation usages for the golf courses and the urban ‘agricultural’ land have been deducted from the estimate for the total catchment area. This leaves only 415 ML of water used for irrigation within the rural catchments, 98% of which is in the Sturt rural catchment. This usage is equal to 80% of the aggregated farm dam volume (553 ML) located in this same catchment and falls within the range of usage of 30–100% of the aggregated farm dam volume assumed in the investigations.

Further detail on estimates of farm dam usage is given in Section 6, Farm Dam Scenario Modelling.

3. DATA DESCRIPTION AND ANALYSES

3.1 RAINFALL DATA

Over 50 locations were identified within the area of the Patawalonga catchment, and a 2 km extension beyond, where daily rainfall has been officially measured at some time. For the purposes of modelling, the study aimed to identify as large a set of rain gauge records as possible, relatively evenly distributed across the catchment and with at least 50 years of concurrent record. Only 11 met the criteria for length of concurrent record and spatial distribution (Table 4).

Table 4. Rainfall stations

No	Station name	BoM No	Period	Mean*	Median*
1	Adelaide West Terrace	M023000	1839–1979	520	511
2	Fulham Park	M023002	1898–1952	479	481
3	Glenelg Post Office	M023004	1891–1990	457	441
4	Adelaide (Glen Osmond)	M023005	1883–current	628	619
5	Mitcham Post Office	M023010	1883–1969	620	619
6	Belair (Kalyra)	M023703	1895–1996	697	693
7	Belair (State Flora Nursery)	M023704	1882–current	833	843
8	Cherry Gardens	M023709	1899–current	926	928
9	Coromandel Valley (Branden)	M023711	1890–1986	765	764
10	Happy Valley Reservoir E&WS	M023721	1864–current	670	657
11	Stirling	M023745	1883–1964	1 211	1 206

Note: Mean and median annual rainfalls obtained after data patched and in-filled annually for period 1900–2002

All records start before 1900 but several finish between 1952 and the present. These records were extended by reference to nearby stations using double mass correlations.

All data to 1998 had been processed by Sinclair Knight Merz (SKM) to fill gaps and distribute accumulated totals. The rainfall database has been extended to 2003 by using the same SKM technique on the post-1998 data (see Section 3.1.1).

In addition to daily rainfall records of point rainfall, an annual rainfall isohyet map (Fig. 6) has provided information on the spatial distribution of annual rainfall across the entire Patawalonga catchment. The map has been produced from a more recent and shorter period of records of about 30 years data (David Cresswell, Principal Hydrologist DWLBC pers. comm.) but has allowed the relationship between rainfall measured at the 11 point rainfall stations and that over the spatially distributed subcatchment areas, to be identified.

3.1.1 PROCESSING RAINFALL DATA

SKM previously used a method for distributing rainfall totals accumulated over periods when the observer was absent (often over weekends and public holidays) or for filling gaps in the record. The method uses correlations between several nearby gauges with weighting in inverse proportion to the distance between the gauges. It was applied to most daily-read records up to 1998 (Sinclair Knight Merz 2000 and App. A).

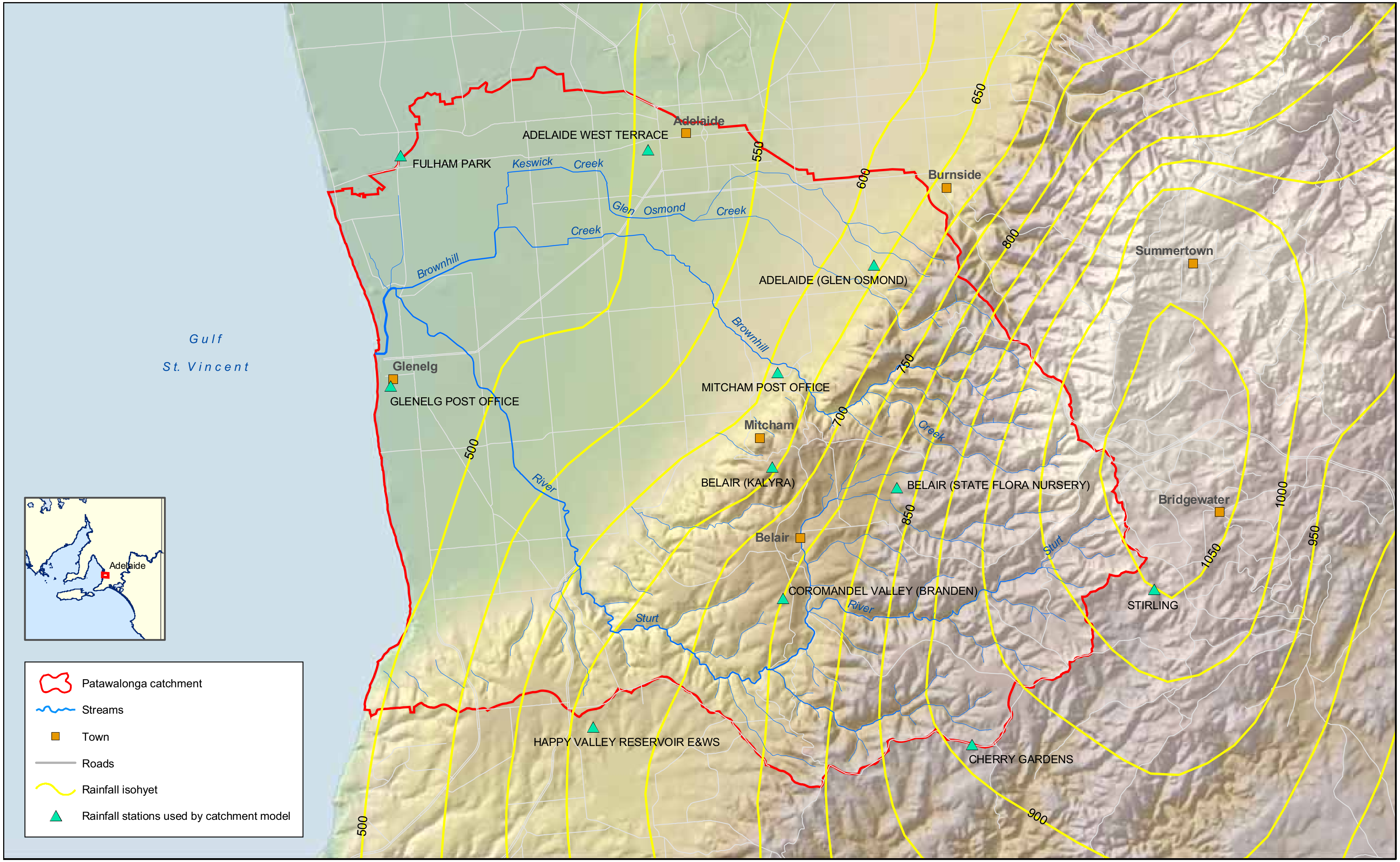

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Figure 6: Rainfall stations and isohyets used by model

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Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation
Projection: UTM Zone 54
Datum: Geocentric Datum of Australia 1994
Date: 1 June 2005

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This same method was used to extend and update the records for the now-closed representative rainfall stations (Table 4) and disaggregate and fill gaps in the more recent data. Thus a continuous data set for each of the 11 selected daily rainfall sites was obtained over the total period 1900–2002.

The homogeneity of the rainfall data for each station was also checked by plotting its double mass curve against that of the other 10 gauges (a standard hydrological correction mechanism). In order to avoid excessive manipulation, adjustments were only made where the slope of the double mass curve deviated by more than 6%. Only four rainfall stations – Belair Kalyra (M023703), Belair State Floral Nursery (M023704), Coromandel Valley (M023711) and Happy Valley Reservoir (M023721) – required adjustment.

3.1.2 RAINFALL DATA ANALYSIS – TEMPORAL VARIATION AND TRENDS

3.1.2.1 Ten year and three year trends

Figure 7 plots the average rainfall for the 11 listed gauges (including their fitted extensions) for each 10 year period from 1900.

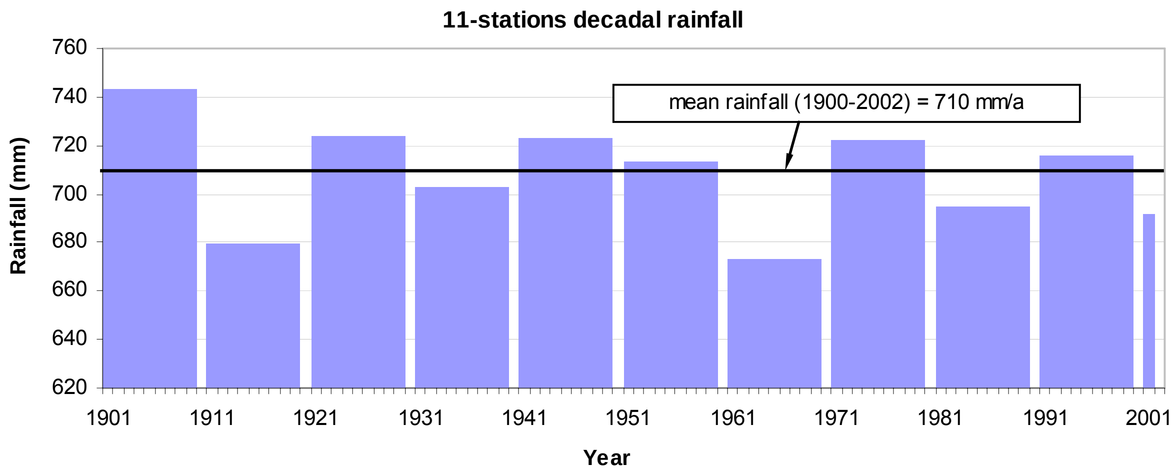


Figure 7. 11-Stations decadal mean rainfall

The long-term average annual rainfall (1900–2002) is 710 mm. The minimum 10 year average occurred in the 1960s (674 mm/a) and the maximum in the 1900s (743 mm/a).

The trendline fitted by least squares to the 10 year averages shows a downward trend with the average being 6 mm/a above the long term average for the first half century and 7 mm/a lower for the second half century.

This observation is confirmed by the 3 year moving average residual mass curve shown in Figure 8 (showing the cumulative deviation of the 3 year mean annual rainfall from the mean value over the total period). A slope trending upward indicates a higher than average rainfall for that period. A slope trending downward indicates the reverse. The period 1912–14 was the driest 3 year period (514 mm/a) and 1922–24 the wettest 3 year period (880 mm/a); 1958 is a trend reversal point when considering the total period as two 'halves'.

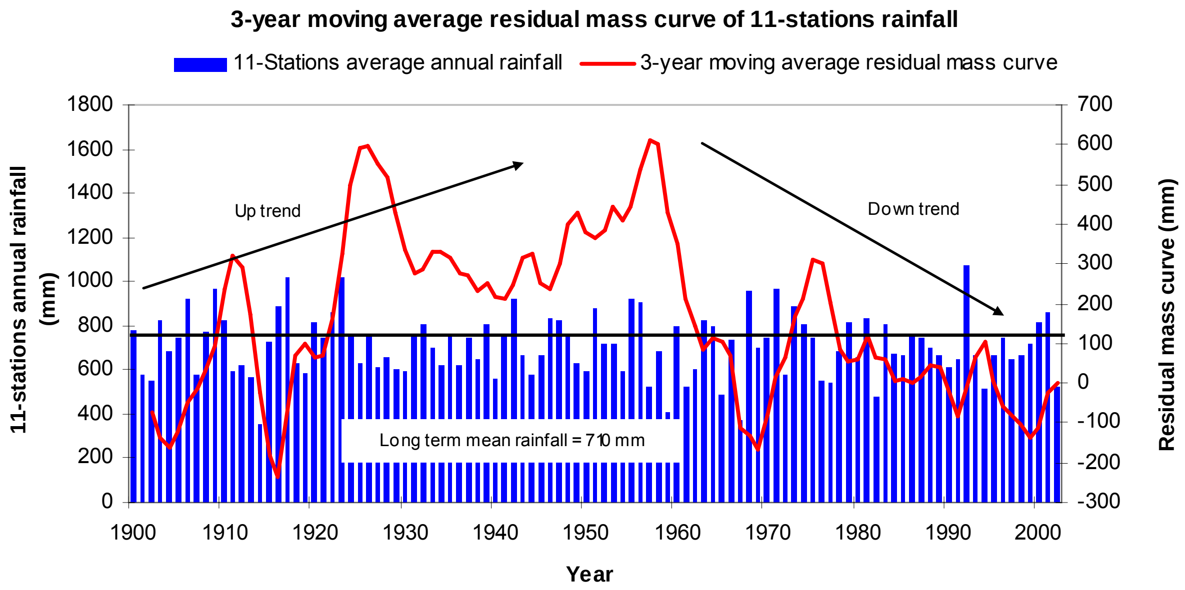


Figure 8. Residual mass curve of 3-year moving average

3.1.2.2 Annual and monthly rainfall trends

The moving average residual mass curve method was applied to the annual rainfalls and also to each monthly rainfalls taken separately (i.e. all January records (only) 1900–2000, all February records, etc.). Annual curves were similar to the three year curves. Of the monthly rainfall analyses, only curves for June and July showed any marked trends. These are two of the wettest months, with 70% of the total annual rain falling between May and October.

Figure 9 shows that the curve for June generally follows the annual trendline. However, the curve for July, although less marked, is almost reversed in shape – for the second half of the century, rainfall in June has been generally reducing as July is receiving more. These trends are consistent with both a delay in the start of winter rainfall and a shortening of the wet season.

They are also compatible with a shift to a later runoff season, an effect that has been noted in many catchments in the Mount Lofty Ranges. A consequence may also be for flooding to be concentrated in later winter, when catchment wetness has built up. Further investigation is recommended into this phenomenon.

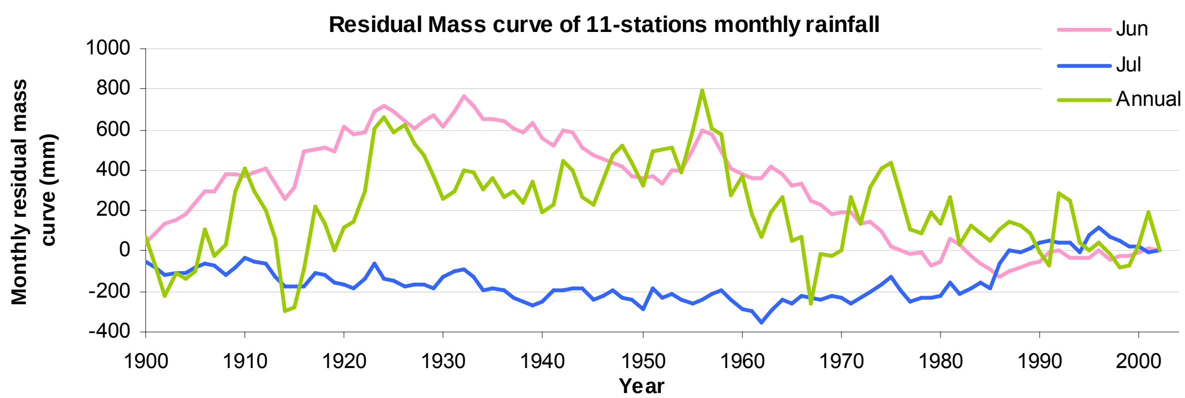


Figure 9. Residual mass curve for June and July

3.2 EVAPORATION DATA

As no other data are readily available, evaporation data from the Bureau of Meteorology station at Adelaide have been applied to all minor subcatchments in the model. The model uses only a single annual set of mean monthly evaporation depths, which is reapplied each year for runoff simulation.

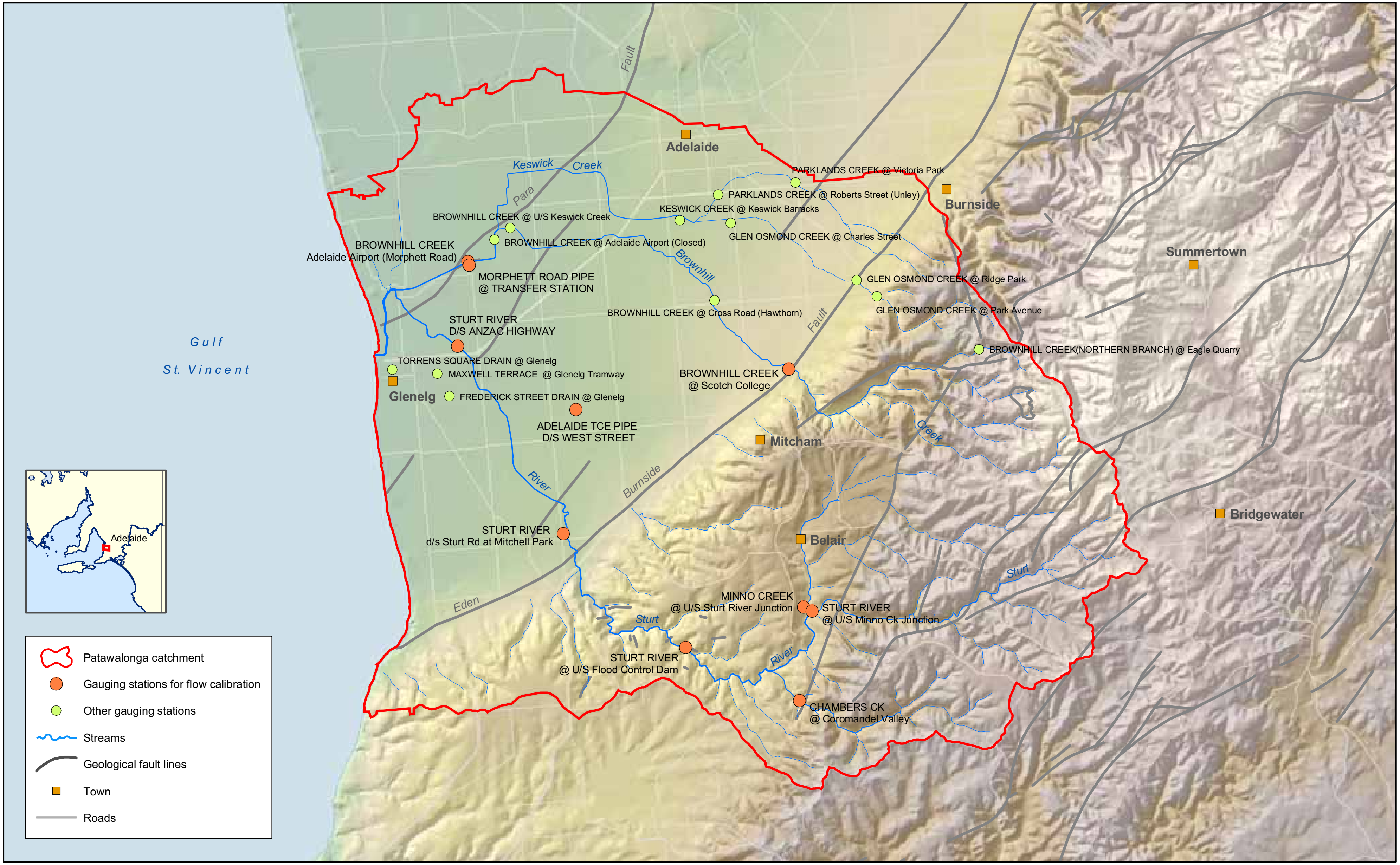
3.3 STREAMFLOW DATA

Table 5 lists information about the flow gauging data that have been used in the study. Figure 10 shows the location of the gauges. All data have been extracted from the Hydstra database maintained by DWLBC. The gauges have been operated by different agencies for different purposes.

Table 5. Gauging stations with flow data in the DWLBC Hydstra database

Station	Name	Catchment area	Start	End	Control	Remarks
Sturt River catchment						
AW504518	STURT RIVER @ u/s Minno Creek Junction	19.3	7.10.76	Current	Low profile concrete V crump weir	Closed from 1983, reopened 2001
AW504519	MINNO CREEK @ u/s Sturt River Junction	18.3	8.12.77	Current	Low profile V crump weir	
AW504521	CHAMBERS CK @ Coromandel Valley	10.0	3.11.76	26.06.89	Standard concrete V crump weir	Closed since June 1989
AW504530	STURT RIVER at u/s flood control dam	60.2	24.07.79	27.06.89	Concrete V notch crump weir	Closed since June 1989
AW504576	STURT RIVER @ d/s Sturt Rd Mitchell Park	73.3	01.09.94	Current	Open channel	
AW504582	ADELAIDE TCE PIPE @ d/s West Street	0.9	7.07.96	Current		
AW504549	STURT RIVER @ d/s Anzac Highway	115.0	24.07.90	Current	Concrete trapezoidal channel	
Brown Hill Creek and Keswick Creek catchments						
AW504901	BROWN HILL CREEK @ Scotch College	17.5	16.02.90	Current	Low profile flat V weir	
AW504580	BROWN HILL CREEK @ u/s Keswick Creek	31.5	12.05.96	Current		
AW504581	MORPHETT ROAD PIPE @ transfer station	1.25	13.06.96	current		
AW504575	BROWN HILL CREEK @ Adelaide Airport (closed)	62.4	31.08.94	10.01.97	Open channel	Closed since January 1997
AW504583	BROWN HILL CREEK @ Adelaide Airport (Morphett Road)	65.8	29.11.93	current	Broad crested rectangular drop weir	
Local Patawalonga catchment						
AW504561	FREDERICK STREET DRAIN @ Glenelg	0.42	30.06.92	24.05.04	Free flowing reinforced concrete pipe	Closed since 2004

Note: d/s - downstream; u/s - upstream



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N

0 2.5 5 km

Figure 10: Location of gauging stations

Produced By: Major Investigation and Field Services
Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation
Projection: UTM Zone 54
Datum: Geocentric Datum of Australia 1994
Date: 1 June 2005

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A recent update of the database has included a further six gauges on Keswick Creek and two on Brown Hill Creek. Some of these have up to 10 years of continuous water level records but the rating curves, which are required to translate the water level recordings into flow estimates, are either missing or have been classified of a lower/uncertain quality (Quality Code 150). These data were not used in the study.

In general, the accuracy of the flow measurements is believed to be satisfactory at low flow but less certain at high flow. Comments by the data collectors on the perceived accuracy of the urban records used in the study are given in Appendix B.

3.3.1 FLOW ANALYSIS

3.3.1.1 Annual flow

Table 6 shows mean and median annual flows for the gauging stations. The runoff coefficient is the ratio of runoff to rainfall volume over the period of flow records expressed as a percentage. It is used to estimate runoff flows from rainfall data in a given area. More accurate longer term estimates are given by the model process.

Table 6. Annual streamflow measured at gauging stations

Station	Name	Catchment area (km^2)	Period	Mean annual flow (ML)	Median annual flow (ML)	Mean RO (mm)	Median RO (mm)	Gridded rainfall (mm)	Mean runoff coeff
Sturt River catchment									
AW504518	STURT RIVER @ u/s Minno Creek Junction	19	1978–2003	2632	2520	139	133	949	15%
AW504519	MINNO CREEK @ u/s Sturt River Junction	18	1979–82 & 2002	2230	1544	124	86	837	15%
AW504521	CHAMBERS CK @ Coromandel Valley	9.8	1979–88	1611	1469	164	150	873	19%
AW504530	STURT RIVER at u/s flood control dam	60	1984 & 1988	5912	5912	99	99	862	11%
AW504576	STURT RIVER @ d/s Sturt Rd Mitchell Park	73	1995–2002	7946	5544	109	76	821	13%
AW504582	ADELAIDE TCE PIPE @ d/s West Street	0.87	1997–2001	191	194	220	223	530	41%
AW504549	STURT RIVER @ d/s Anzac Highway	116	1992, 1994–2003	11 64 5	10 63 2	100	92	734	14%
Brown Hill Creek and Keswick Creek catchments									
AW504901	BROWN HILL CREEK @ Scotch College	17.65	1991–2002	2530	2249	143	127	865	17%
AW504580	BROWN HILL CREEK @ u/s Keswick Creek	32	1997–2002	2252	1923	70	60	742	9%
AW504581	MORPHETT ROAD PIPE @ transfer station	1.25	1997–2002	238	225	190	180	478	40%

Station	Name	Catchment area (km²)	Period	Mean annual flow (ML)	Median annual flow (ML)	Mean RO (mm)	Median RO (mm)	Gridded rainfall (mm)	Mean runoff coeff
AW504575	BROWN HILL CREEK @ Adelaide Airport (closed)	62.4	1995	5257	5257	83	83	662	13%
AW504583	BROWN HILL CREEK @ Adelaide Airport (Morphett Rd)	64.2	1994–2002	7759	7237	121	113	653	19%

Note: d/s - downstream; u/s - upstream

The coefficients for urban catchments vary from 9% for the gauging station of Brown Hill Creek upstream of its junction with Keswick Creek (AW6504580) to 41% for the gauging station of Adelaide Terrace downstream of West Street (AS504582) (Table 6). The coefficients are expected to be highly dependent on the ratio of impervious to pervious areas within the catchments and to be only slightly higher for higher rainfall areas. The fact that the flows decrease in the reach of Brown Hill Creek downstream of Scotch College (Table 6) shows that in-stream losses may be large and may influence the calculations. Other than these 'rational' explanations, variations may indicate data error, particularly from the uncertain nature of some of the rating curves used in the estimation of flow.

(The possible existence of data error and/or the dangers of relying on short records are demonstrated by the large difference in runoff coefficients between the two gauges on Brown Hill Creek adjacent to the Airport, and the difference between the runoff coefficients on Sturt River at the flood control dam and those on the subcatchments just upstream).

Coefficients for residential urban catchments are generally of the order of 20–25%, with higher figures for industrial and commercial areas. Small, fully impervious areas such as car parks may have coefficients as high as 80–90%. Thus most of the larger urban catchments in the lower reaches of Sturt River and Brown Hill Creek appear to have lower than expected coefficients. These were re-examined after the proportions of impervious area were investigated and the records extended by modelling.

Trend in Upper Sturt flow

Figure 11 shows annual flows for Sturt River upstream of the Minno Creek junction (AW504518). The least squares linear trend over the period from 1977 is downward which agrees with the rainfall trend (Fig. 8) over the same period. The catchment has not undergone any significant development over this time.

3.3.1.2 Monthly flow

Figure 12 shows the distribution of mean monthly flows for the gauging station on Sturt River upstream of Minno Creek junction (AW504518). This pattern is typical for the gauged rural catchments which generally have 80–90% of their annual flow in the winter months (May–October).

The ratio of summer to winter flows was also investigated for the urban catchments gauged. As the ratio of impervious to pervious area rises (e.g. for the small urban catchments), the proportion of the total annual flow generated from summer rainfalls rises and the winter proportion therefore falls. Winter flow is 73% (AW504581, Morphett Road at the transfer station) and 77% (AW504582, Adelaide Terrace downstream of West Street) of the annual flows at the small urban catchments.

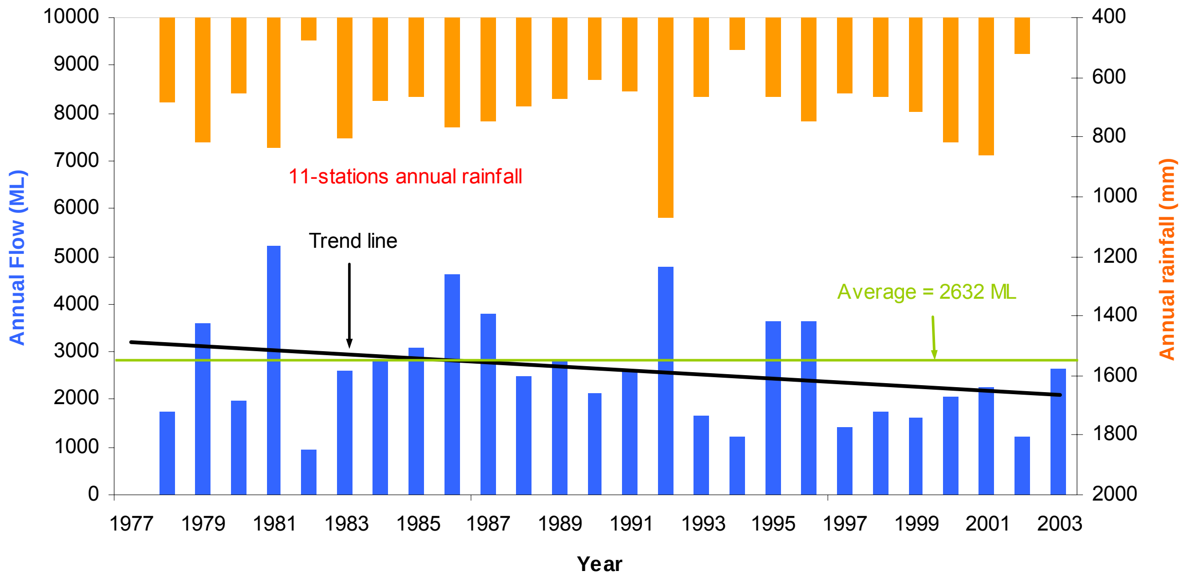


Figure 11. Annual flow of Sturt River upstream of Minno Creek junction (AW504518)

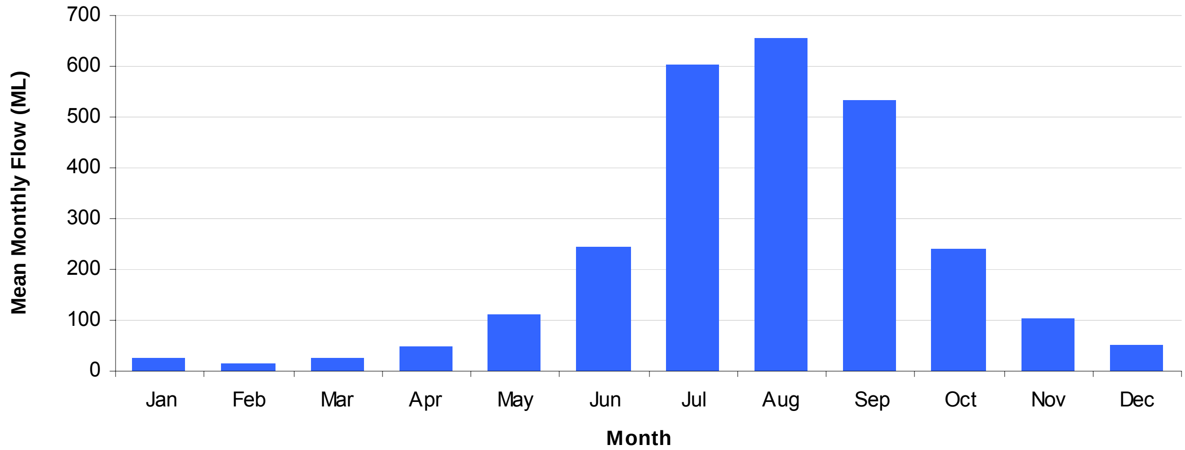


Figure 12. Monthly flow of Sturt River upstream of Minno Creek junction

3.3.2 HEATHFIELD WWTP DISCHARGE

Heathfield WWTP is located just outside the Patawalonga catchment but discharges its wastewater into an upper reach of the Sturt River. It was commissioned in 1981 to serve a population of 6000 with an estimated wastewater discharge of 1.05 ML/day. Discharged flow is measured at gauging station AW504931 immediately downstream of the discharge point.

Records of wastewater discharge were only available from January 1991 onwards, at first in monthly time-steps but in daily time steps from March 1997 onwards. A repeat of the discharges of 1991–95 has been used to synthesise the missing data from 1981–90. Daily flows have been obtained from monthly flow data by dividing the monthly flows by the number of days of that month.

Table 7 shows that the mean annual discharge between 1991–2002 has been gradually rising with a mean of 526 ML/a. This flow is about 23% of the annual flow volume recorded at the gauging station (AW504518) situated just upstream of the junction of Sturt River with Minno Creek.

Table 7. Annual wastewater disposal from Heathfield WWTP

Year	**Heathfield** (ML/a) **AW504931**	**AW504518** (ML/a)
1991	424	2 610
1992	489	4 770
1993	399	1 668
1994	387	1 206
1995	487	3 635
1996	533	3 648
1997	480	1 439
1998	587	1 757
1999	589	1 616
2000	653	2 067
2001	686	2 264
2002	599	1 215
Average	**526**	**2 325**

Discharges from the plant have been measured in various ways, some giving conflicting values. In general, only monthly discharges are available before March 1997 but with some gaps. Daily flow records are available from March 1997 to November 1998 and from July 1999 to June 2003, again with some long and many short gaps. Some of the daily flow records appear to have included significant proportions of stormwater discharge. Comparisons are not possible for all the records, so uncertainty remains on much of it.

A ‘best’ reconstruction of the discharge from the plant was undertaken by infilling gaps with best guesses based on flows before and after the gaps and by correlating the flows with downstream gauges.

3.3.3 TRANSMISSION LOSSES

The correlation between flows measured at the WWTP discharge site (AW504931) and downstream, just above the junction with Minno Creek (AW504518) indicates transmission losses of the order of at least 1.5 ML/d in the intervening channel.

Estimation of the transmission loss in winter, in rural catchments, is difficult due to the high and variable flows; in summer when the flows are more stable, estimation is more likely to be accurate. By comparing summer baseflows at AW504518 before and after the commissioning of the WWTP it appears that about 85% of discharged flows may be lost (either by infiltration or diversion to irrigation).

Using the same investigation technique on flows measured on Brown Hill Creek at Scotch College and downstream, just above the junction with Keswick Creek, it appears that losses of up to 5 ML/d may be taking place. This would account for the very low runoff coefficient calculated for the lower site.

It is expected that losses will also be taking place on Sturt River where it emerges from the escarpment.

The areas where the Park Lands and Glen Osmond creeks emerge from the escarpment do not seem to align with a groundwater plume with such low total dissolved solids values as those mapped for Sturt River and Brown Hill Creek. Thus large losses (if any) may be concentrated in certain locations only.

4. MODELLING METHODOLOGY, NODES AND INPUTS

4.1 OVERVIEW

Catchment models are an assembly of mathematical formulae and logic statements, contained within a software package, designed to conceptualise and simulate the major surface hydrologic processes taking place within a catchment. The model operates within a boundary defined by the catchment surface area. Rainfall is the main input and flow, evapotranspiration and losses to groundwater are the main outputs. The models are operated to provide a temporal sequence of flow resulting from the temporal sequence of rainfall records.

The WaterCress Program has been used as the modelling platform to represent the Patawalonga catchment. WaterCress is a PC based catchment water-balance model developed by Clark and Cresswell (Cresswell 2000).

The catchment model is represented by multiple interlinked 'nodes', each of which may represent a different water related process (such as a rural or urban subcatchment, a water storage, a diversion, water demand). Water is carried between nodes by links which are analogous to drainage paths or pipes. Daily water balances are calculated for each node and for the total model.

The model is used to identify the predicted effects of changes to any of the inputs to the model on processes within the model or its outputs.

Water is moved through the model from upstream to downstream. Urban and rural nodes calculate the amount of flow generated within the catchments by application of rainfall to runoff submodels.

The rural catchment node is used to model the relatively complex processes occurring within pervious sub-areas of the catchment. The urban catchment node is used to model the less complex processes involved in impervious areas such as roofs, roads, car parks. These are less affected by soil drainage and evaporation and generally have a higher efficiency in converting input rainfall to output flow than that of the rural catchment process.

The steps for catchment modelling are:

- processing and validating data to be used in the model
- constructing a conceptual catchment model as an assembly of interlinked nodes performing all major water transactions within the catchment
- calibrating key transactions calculated by the model against actual observed data (usually streamflow measured at gauging stations)
- running the model to simulate catchment processes for various scenarios
- interpreting the modelling results.

4.2 MODEL CONSTRUCTION

Before the model is constructed, catchment data are collected and processed to a format that can be used for constructing the model. The basic input data needed to construct the Patawalonga catchment model are:

- rainfall and evaporation data
- catchment areas of all rural and urban subcatchments
- surface areas and volumes of individual farm dams.

Details of the data used as input for constructing individual nodes can be found in Appendix C (Tables 19 and 20) which also provides a brief description of how the catchment model is constructed and operated.

Figure 13 shows a schematic diagram of the Patawalonga catchment model and Figure 14 shows the model in WaterCress format. The Patawalonga catchment model contains about 240 nodes, consisting mainly of catchment, storage and transfer components.

4.2.1 RAINFALL AND EVAPORATION DATA

All catchment and (uncovered) storage nodes require the input of rainfall and evaporation data. Daily rainfall data is read sequentially from a text file (filename.rai) with all gaps filled. Monthly mean evaporation is read from a text file (filename.evp) containing pan evaporation depths from January to December. The daily evaporation is obtained by dividing the monthly evaporation value by the number of days in that month. The same calculated value is used for all days in that month in all years over the whole period of simulation.

Table 8 provides the filenames of the 11 rainfall stations used by the Patawalonga catchment model (listed previously in Table 4).

Table 8. Point rainfall stations used for the catchment model

Station no.	Filename	Location
M023000	WestTce.rai	ADELAIDE WEST TERRACE BoM Met Station
M023002	FulhamPK.rai	FULHAM PARK BoM Met Station
M023004	GlenPO.rai	GLENELG POST OFFICE BoM Met Station
M023005	AdelGlenOsm.rai	ADELAIDE (GLEN OSMOND) BoM Met Station
M023010	MitchamPO.rai	MITCHAM POST OFFICE BoM Met Station
M023703	BlrKa.rai	BELAIR (KALYRA) BoM Met Station
M023704	BlrSta.rai	BELAIR (STATE FLORA NURSERY) BoM Met Station
M023709	CherryG.rai	CHERRY GARDENS BoM Met Station
M023711	CorVal.rai	COROMANDEL VALLEY (BRANDEN) BoM Met Station
M023721	HVR.rai	HAPPY VALLEY RESERVOIR E&WS BoM Met Station
M023745	Stirling.rai	STIRLING BoM Met Station

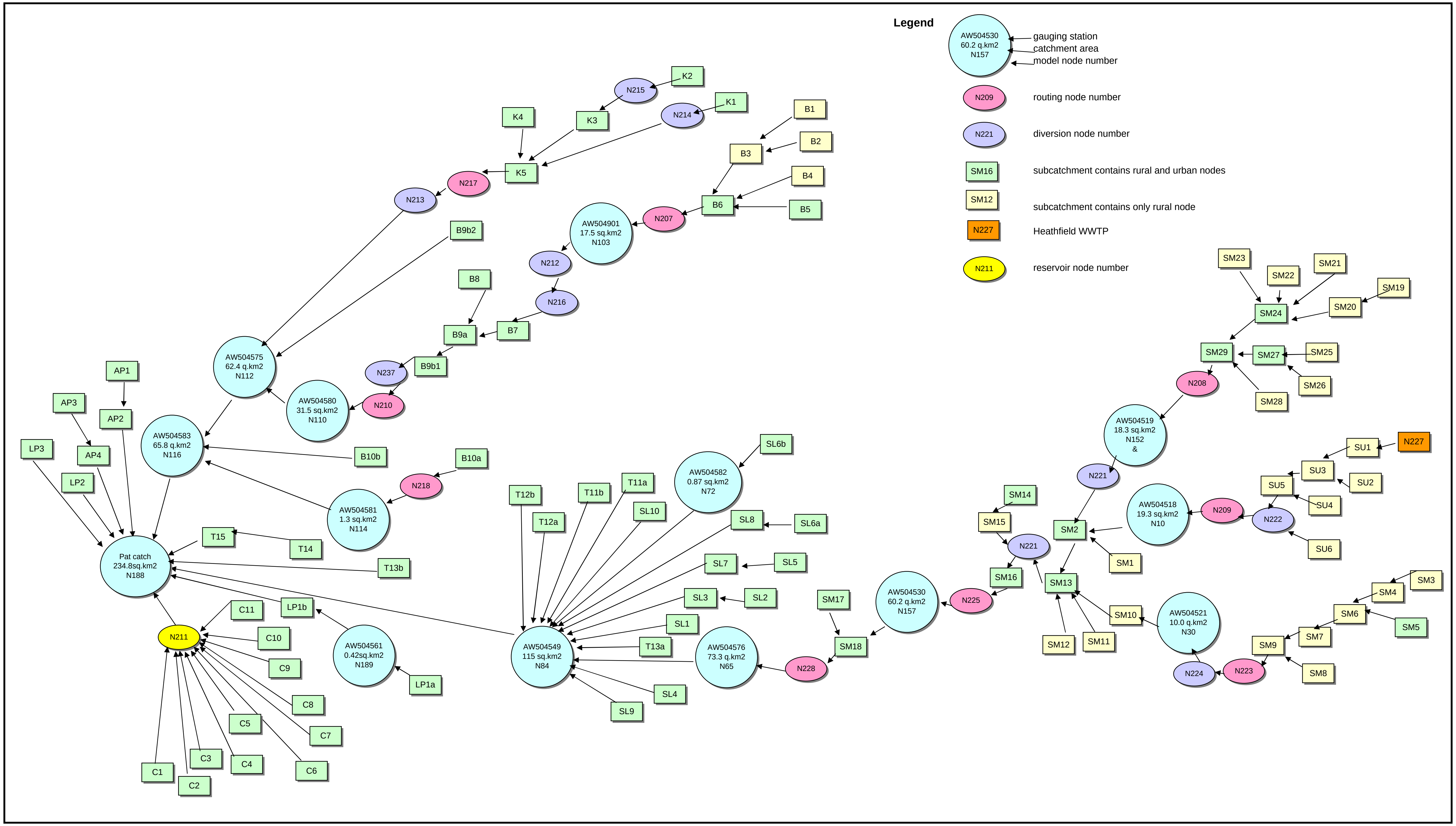


Figure 13. Schematic diagram of Patawalonga catchment model

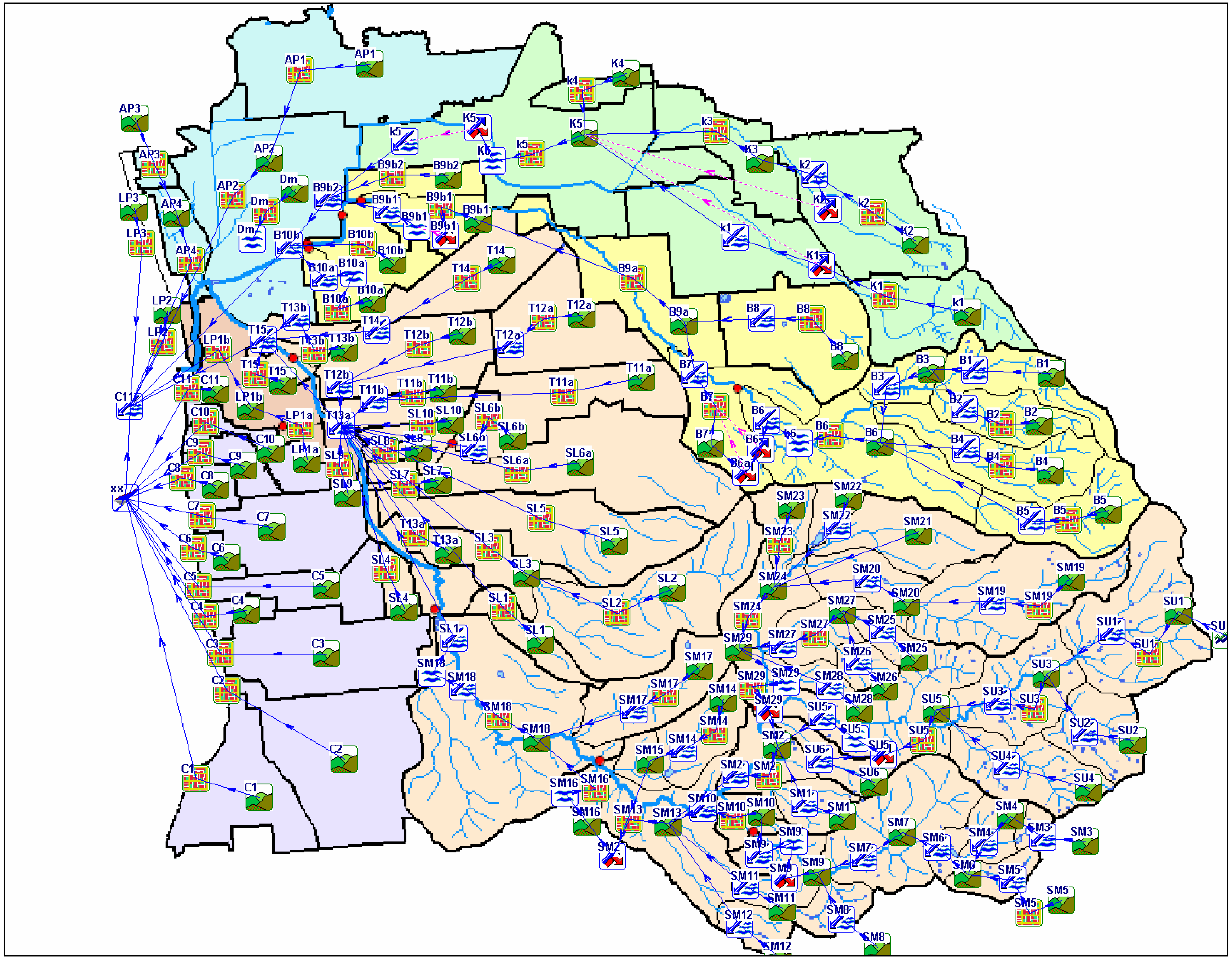


Figure 14. Patawalonga catchment model, WaterCress nodes and flowpaths

The mean annual rainfall at the centroid of each the modelled drainage subcatchments was identified from the isohyet map. The nearest of the rain gauges (Fig. 6) to that same location was chosen from those listed in Table 4. A rainfall factor was calculated as the ratio of the mean annual rainfall at the subcatchment centroid as interpolated from the map (X) to the mean annual rainfall calculated for the selected nearest rain gauge (Y). The daily rainfall for the subcatchment was then taken to be the daily rainfall given by the selected rain gauge times the rainfall factor X/Y. The rainfall adjustment factors applied for each of the subcatchments are listed in Appendix C.

4.2.2 FLOW DATA USED FOR CALIBRATION

The gauging stations located in the Sturt River, Brown Hill Creek and Keswick Creek catchments used for flow calibration are:

- AW504518 Sturt River @ u/s Minno Creek Junction (19.3 km^2)
- AW504519 Minno Creek @ u/s Sturt River Junction (18.3 km^2)
- AW504521 Chambers Creek @ Coromandel Valley (10 km^2)
- AW504530 Sturt River @ u/s flood control dam (60.2 km^2)
- AW504576 Sturt River @ u/s Sturt Rd Mitchell Park (73.3 km^2)
- AW504582 Adelaide Tce Pipe @ d/s West Street (0.9 km^2)
- AW504549 Sturt River @ d/s Anzac Highway (115 km^2)
- AW504901 Brown Hill Creek @ Scotch College (17.5 km^2)
- AW504581 Morphett Road Pipe @ transfer station (1.25 km^2)
- AW504583 Brown Hill Creek @ Adel Airport/Morphett Rd (65.8 km^2)

Other gauging stations with reasonable length of flow records were not used for flow calibrations, mainly because of the lack of a rating relationship.

4.2.3 IDENTIFICATION OF MINOR SUBCATCHMENTS

4.2.3.1 Urban catchments

The mainly urbanised catchments of the Adelaide Plains are defined by the layout of the stormwater drains and the land parcels connected to them. Most of the drains were located beneath roads and thus the minor subcatchments mostly follow geometric shapes based on stormwater drainage systems as defined by the road and land division boundaries. In their lower reaches the drains discharge to the few creek drainage systems which pre-dated the urban development and follow irregular paths. The minor subcatchment boundaries adopted were based mainly on the areas contributing to the existing gauging sites.

Each urban minor subcatchment has been assigned an urban and rural catchment node to represent the runoff processes from the impervious and pervious surfaces within it. Occasional large waterbodies within the urban areas were modelled by a dam node.

4.2.3.2 Rural catchments

The boundaries of the mainly rural catchments in the Adelaide Hills were dictated by topography and natural stream patterns. The minor subcatchments selected for modelling have been based on these patterns but were influenced by the locations, numbers and sizes of farm dams. A minor subcatchment, as determined for modelling, may be identified at its downstream point by a location where a farm dam node could be sited. The node represents the amalgamation of the farm dams within the upstream subcatchment and the processes associated with them.

Several rural subcatchments also contain significant areas of urbanisation. The impervious areas within them have been estimated and their runoff was modelled by an urban node. Their pervious areas may be modelled separately or may be amalgamated with an area of surrounding rural land.

The area for each rural catchment is entered in a rural node, as shown for subcatchment cat_B9b1 in Figure 23, Appendix C. (Note: The term ‘rural’ catchment is also applied to the aggregation of pervious areas within the urban catchment.)

4.2.4 ESTIMATION OF IMPERVIOUS AREAS AND SELECTION OF MODELS

Most runoff from urban catchments is generated by the impervious areas of roofs and paved surfaces. Within the model, the total impervious area is accounted for by multiplying a notional number of houses by notional areas of roof, pavement and road per house. Each of these three types of impervious area may be provided with a different selection of initial loss; ongoing fraction and connection (Fig. 24, App. C). The initial loss and continuing loss represent the losses to depression storage, infiltration and evaporation.

The basic formula used is:

Runoff = Area*Connection*(rainfall depth–IL)*Ongoing fraction (for rainfall depth > IL)

Or runoff = 0 for rainfall depth < IL

where IL is initial loss, Connection the fraction of the impervious area deemed to be connected to the drainage system and Ongoing fraction determines the proportion of runoff thus calculated from the formula enters the drainage system. The fraction of runoff calculated by the formula with the factor (1 minus Ongoing fraction) is deemed retained and lost by evaporation, infiltration or permanent retention (e.g. in rainwater tanks).

Each urban node allows the delineation of three area types (roof, house pavement and road pavement) having different values of initial loss, connection and ongoing fraction. These together form an urban catchment characteristic set.

Connection relates to the connectivity of the area to the drainage path. For example, 0.85 for roof means 15% of the runoff from the roof area is assumed lost. The connection for the road pavement is fixed at 100%.

In the absence of data, it is usual to choose a ‘standard’ allocation of these impervious areas per house and then adjust the number of houses so that the total impervious area for the catchment equals that estimated.

Kemp (App. D) has estimated the percentage of impervious areas for many ‘typical’ medium sized urban catchments. His results vary from 70% to 11%, with an overall average of 28.2%. Industrialised/CBD type subcatchments have high percentages (up to 100% for small totally paved subcatchments); subcatchments with high proportions of parklands, golf courses, etc, will have lower values.

In preparing an initial model (before calibration), all large pervious areas within each subcatchment were separately identified, summed and subtracted from the subcatchment area. The percentage of actual impervious area within the remaining (urbanised) area was then set at 40% for the majority of typical residential areas but was increased in steps to 50%, 65% and 70% with the last step being for highly industrialised catchments, such as those in Mile End. The assumed pervious parts of the urbanised area were then also calculated and added back to the initial summation of the large pervious areas. The separation of the total catchment area into its pervious (rural) and impervious (urban) parts is given in Table 19 (App. C).

Areas with a high runoff would be expected to have both a higher connectivity and a lower continuing loss. Thus a different set of parameters was initially selected for each of the urban model nodes, depending on their level of assumed impervious proportion. These sets were later reduced to only three (Table 12). Each model has the same notional roof, road and pavement area per notional house, and the same allocation of initial losses to these areas. Model 19 gives a higher prediction of runoff because it assumes higher levels of connection and lower levels of continuing loss (higher ongoing fraction).

The simplest and most direct means for initial calibration between predicted and observed flows is to alter the assumed numbers of houses to adjust the overall volumetric fit and to substitute one model for another to adjust the fit between the observed and predicted slopes of the rainfall to runoff plots.

The urban model parameter set selected for each of the urban nodes is shown in Figure 24 and Table 19 (App. C). In summary, the six major subcatchments have been subdivided into 91 minor subcatchments (Fig. 14). Appendix C summarises the criteria used to select them. The runoff processes within each of the 91 subcatchments are modelled by a ‘train’ of nodes. This train may include only a single rural node (for an undeveloped rural catchment) or up to three nodes (consisting of a rural, urban and farm dam node) for a partly urban/rural catchment containing dams. In many cases this train is augmented by nodes inserted to represent losses and/or other localised processes. Transmission losses have been identified in several locations (mainly within the urban areas) and these are represented by a diversion node. Routing nodes are inserted where modelled flows need to be redistributed to improve calibration of the model.

The only external input to the model, other than rainfall, is the discharge of treated wastewater into the Upper Sturt catchment from Heathfield WWTP. Daily inflows are read from a pre-prepared text file node.

Outflow points from the model are the main outflow from the Patawalonga plus the 11 separate coastal discharges.

4.2.5 SELECTION OF RURAL RUNOFF MODELS AND PARAMETERS

The WaterCress model platform provides a choice of standard rainfall to runoff models for predicting runoff from pervious catchments, such as the WC-1, AWBM and SDI models. For this study the WC-1 model was chosen as it has been widely applied to other catchments in the Mount Lofty Ranges.

The model requires the input of 10 parameters (Fig. 26, App. C).

The WC-1 model calculates runoff as the result of water movement through three layers of conceptual storages. The upper (interception) store receives the daily precipitation depth, infiltrates part, stores part and identifies the remainder (if any) as surplus (effective rainfall). The surplus is partitioned into runoff, additional soil infiltration or groundwater infiltration according to prediction formulae. Soil storage is the middle store and groundwater store is the lower store. Part of the water within the middle (soil) storage is lost by evaporation, part is discharged as interflow runoff and part is drained to the lower storage. Water within the lower (groundwater) storage is partitioned to groundwater flow or is lost from the model as permanent loss (to conceptual deeper aquifers).

The influence of the 10 parameters on the runoff processes is also given in Appendix C.

The input parameters selected for the rural nodes used in the Patawalonga model are shown in Table 19 (App. C).

4.2.6 DAM NODES

The majority of the dam nodes are included to represent the processes and influence of farm dams within the rural catchments but they have also been used in the same way for the larger open waterbodies in urban areas at Urrbrae and Warriparinga (only). In the absence of more detailed data, these have been modelled with the same assumptions used for rural farm dams. (A water storage indicated in the Airport Drain catchment has not been included in the model as the data appear dubious).

An off-stream dam node has been selected for use in the model to simulate the effects of farm dams; this may also represent an on-stream dam situation and is thus more flexible in its application.

Storage volumes and surface areas for all farm dams within each minor subcatchment have been aggregated and then used to define the area–volume relationship for a single node to represent them.

Different parts of aggregated upstream catchments will have different ratios of land area contributing runoff to dam volumes. Some sub-areas may even have no dams and are thus ‘free to flow’ at all times. To account for these differences, an allowance can be made for the single aggregated dam to pass a proportion of its inflow downstream, even though the dam may not be full. Thus the inflow to the dam is calculated as:

Inflow to dam = (generated flow – baseflow to pass)*diversion fraction.

The daily inflow is also limited to a maximum value. Mapped information is used, where possible to estimate the values of the diversion fraction and maximum inflow. In the absence of other information, and for consistency, it was assumed throughout that unless specifically identified:

baseflow to pass = 0.0

diversion fraction = 1.0

maximum inflow rate = maximum (aggregated) dam volume.

This set of assumptions therefore implies that all dams are on-stream and that no proportion of the catchment is 'free to flow'. This may result in a slight overestimate of the amount of water being lost and diverted by the farm dams.

The amount of water diverted from the dams to supply is also largely unknown, although smaller farm dams are deemed to be used only for stock watering and thus are usually also assumed to have small off-takes. Where dams are larger, and photographic or mapped information indicates irrigation taking place, a larger off-take rate may be assumed. However, in the absence of such information, the annual rate of usage (distributed according to a seasonal pattern) has been assumed to be equal to 30% of the maximum aggregated dam volume, for all dams and subcatchments. This is the level of usage adopted by many catchment studies in South Australia, and is backed up by DWLBC study (McMurray 2003). In this study, a usage rate of 100% of the dam capacity has also been used in order to study the sensitivity of usage rate on yield.

The daily usage rate is calculated by proportioning the annual usage volume according to a seasonal pattern, and most usage to the summer months. A type 3 pattern has been assumed (Fig. 15).

4.2.7 DIVERSION WEIR (LOSS) AND ROUTING NODES

Diversion weir and routing nodes have been included to assist in model calibration.

The diversion node is added to simulate water losses by infiltration in a reach of a stream. These losses appear unrelated to the evaporation pattern and thus should not be modelled by the 'creek loss' parameter in the rural catchment node. The losses being modelled are mainly indicated by a downstream flow gauge showing dry weather flows significantly and repeatedly less than flows measured by an upstream gauge. The likelihood of such losses is high where these reaches are associated with fault lines or gravel outwash fans.

The diversion node diverts flow to 'loss' by a simple initial and continuing loss formula:

Daily downstream flow = (daily upstream flow – loss)*loss fraction

The routing node has been similarly used to improve the daily time-step flow calibrations. The node retains the inflow in a temporary storage. Outflow is governed by two variables RF1 and RF2. The effect of the node is to increase the size and duration of low flows and reduce the sizes of the largest flows.

The data required for operation of a diversion node and of a routing node are shown in Appendix C.

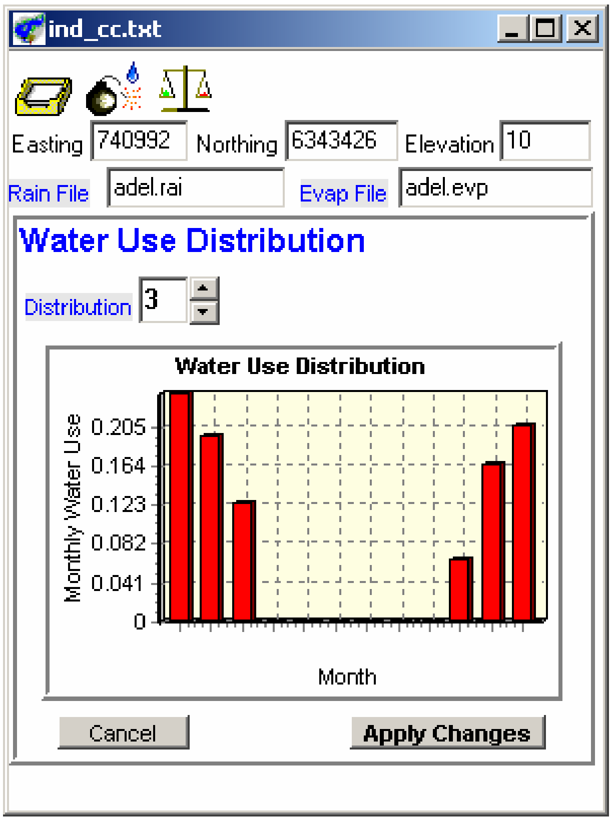


Figure 15. Monthly water use distribution

5. FLOW CALIBRATION AND INITIAL RESULTS

5.1 METHODOLOGY

Flow calibration is an iterative process that aims produce a consistent and reasonable set of inputs to the model (e.g. parameters for the rainfall to runoff models, pervious and impervious areas, water storages and diversions), and provide predictions of flow that accord with daily, monthly and yearly streamflow records.

Each daily flow record is assigned a quality code (QC) based on criteria adopted by the DWLBC Hydstra database system. Data assigned QC 150 and below are considered accurate and suitable for flow calibration. Many higher flows estimates, above the limit of the rating curve and assigned a QC > 150, are generally also included but treated with caution.

Steps in flow calibration may include:

- adjusting the proportion of rural (pervious) to urban (impervious) catchment areas in subcatchments (an upward adjustment in urban area proportion will tend to increase runoff volume but decrease the duration of flows)
- selecting different urban or rural runoff models or (only if necessary) adjusting the actual parameters within a model (which will create a different and additional model set)
- incorporating assumed diversions or infiltration losses into flow reaches (using the diversion weir node), where evidence may support such assumptions
- incorporating flow routing in order to obtain a better distribution between high and low flows (i.e. a better fit for flow duration calibration).

The adequacy of flow calibration is measured by a combination of statistical indicators such as the R-square, coefficient of variation, percentage volume difference, and the visual fit of flow duration curves.

5.2 ASSUMPTIONS

Flow calibration has been based on the current level of urban and farm dam development. It has been assumed that this level is not significantly different to conditions existing over the period of flow measurement, with some flow data dating back to the late 1970s when records were first obtained. The level of farm dam development was obtained from the 1999 CFS survey of farm dams and the current land use conditions. The development has been identified as the 'current development scenario' and is assumed to have been 'frozen' in time for the duration of flow calibration.

Under this scenario there is no distinction made between irrigation and S&D dams. All dam surface areas and volumes within a subcatchment are aggregated and treated as one dam. Usage from the dams is assumed to be 30% of the aggregated dam volume, taken according to a seasonal pattern (see Dam information in Table 9).

Table 9. The statistics of the calibration for the gauged catchments (a)

(1) Catchment parameter	**SR u/s of Minno Creek**	**BH Creek @ Scotch College**	**Minno Creek**	***BH Creek @ u/s Keswick Creek**	***BH Ck @ Adel Airport**	**Morphett Rd Transfer Stn**	**BH Adel Airport Morphett Rd**	**SR Chambers Creek**	**SR Flood Control Dam**	**SR Mitchell Pk**	**SR Anz HW**	**Adel Tce Pipe West St**
Gauging station	AW504518	AW504901	AW504519	AW504580	AW504575	AW504581	AW504583	AW504521	AW504530	AW504576	AW504549	AW504582
Revision No.	R41	R40a	R23	R20	R16	R17	R18	R10	R9	R6	R9	R1
Start Year	1976	1988	1977	1994	1992	1994	1991	1977	1977	1993	1988	1994
Over (Year)	21	16	27	10	5	10	13	14	14	12	16	11
Daily	1978	1988	1977	1996	1994	1996	1993	1979	1979	1994	1990	
Over (Year)	19	16	27	8	4	8	11	12	12	11	15	
Node No.	N10	N103	N221	N110	N112	N114	N116	N30	N157	N65	N84	N72
Routing node	N209	N207	N208	N210	N217	N1218	N238	N223	N225	N228	None	None
Catchment characteristic set	1	2	3	*4	*5	6	7	8	9	10	Mixed	6
Model type	WC1	WC1	WC1	WC1	WC1	WC1	WC1	WC1	WC1	WC1	WC1	WC1
Parameters required:	10	10	10	10	10	10	10	10	10	10	10	10
Median soil moisture MSM	180	155	160	160	180	160	140	140	180	140		160
Interception store IS	22	13	17.5	20	15	14	14	13	22	13		14
Catchment distribution CD	40	27	30	27	27	27	25	24	40	15		27
Groundwater discharge GWD	0.02	0.007	0.013	0.01	0.01	0.003	0.003	0.008	0.001	0.03		0.003
Soil moisture discharge SMD	0	0	0	0	0	0	0	0	0	0		0
Pan factor soil PF	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75		0.75
Fraction groundwater loss FGL	0.3	0.35	0.45	0.5	0.5	0.003	0.003	0.35	0.3	0.01		0.003
Store wetness multiplier SWM	0.85	0.85	0.85	0.9	0.85	0.85	0.85	0.85	0.85	0.85		0.85
Goundwater recharge fraction GW	0.5	0.4	0.4	0.5	0.5	0.1	0.2	0.3	0.5	0.2		0.1
Creekloss CL	0.01	0	0.02	0.3	0.5	0	0.08	0	0.3	0		0
(2) Dam information												
Input annual as fraction of storage	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Input distribution	3	3	3	3	3	3	3	3	3	3	3	3

Note: Calibration for the gauging station was subsequently abandoned

5.3 CALIBRATION

The adequacy of the calibration is indicated by the information given in Table 10. The R-square value is the most commonly used measure of goodness of fit between recorded and modelled estimates of flow. A value of 1.0 indicates a perfect fit (which would not be expected). Values greater than 0.9–0.95 is generally regarded as adequate for rainfall to runoff modelling. The values for the 10 sites (Table 11), calculated at the monthly and annual time periods, range from 0.89 (Brown Hill Creek at Scotch College) to 0.98 (Adelaide Terrace at West Street), indicating a generally good fit between recorded and modelled flows.

Table 10. Statistics of the calibrations for the gauged catchments (b)

(3) Statistics		No. of samples	R-square	Coeff of efficiency	Variation of CV	Std error of estimate	% difference in volume
SR u/s of Minno Creek	Daily	6954	0.81	0.6	0.06	0.15	-0.44
AW504518	Monthly	252	0.94	0.89	-0.08	7.7	-0.46
	Annual	21	0.95	0.89	0.06	105	-0.46
BH Creek @ Scotch College	Daily	5856	0.78	0.5	0.11	0.13	-1.6
AW504901	Monthly	183	0.91	0.83	-0.12	9.2	-1
	Annual	15	0.89	0.79	-0.09	187	-1.07
Minno Creek	Daily	9882	0.82	0.67	-0.1	0.06	-0.21
AW504519	Monthly	315	0.94	0.88	-0.12	3.7	-0.55
	Annual	26	0.97	0.95	0	51.1	-0.9
*BH Creek @ u/s Keswick	Daily	2928	0.88	0.78	-0.08	0.16	-0.16
Creek	Monthly	111	0.94	0.87	-0.12	8.9	0.22
AW504580	Annual	9	0.95	0.9	-0.14	156.3	0.5
*BH Creek @ Adel Airport	Daily	1464	0.76	0.54	-0.07	0.5	1.26
AW504575	Monthly	60	0.92	0.85	-0.05	18.6	1.26
	Annual	5	0.94	0.88	0	379.6	1.2
Morphett Rd transfer stn	Daily	2928	0.93	0.82	0.18	0	-5.4
AW504581	Monthly	111	0.94	0.86	0.09	0.51	0.06
	Annual	9	0.95	0.9	0	11.8	1.1
BH Adel Airport Morphett Rd	Daily	4026	0.91	0.83	-0.05	0.3	-0.049
AW504583	Monthly	147	0.95	0.91	-0.08	15.1	-0.61
	Annual	12	0.97	0.93	-0.08	313.5	-0.98
SR Chambers Creek	Daily	4392	0.86	0.71	0.05	0.09	-3
AW504521	Monthly	149	0.96	0.92	-0.05	5	-1.3
	Annual	12	0.96	0.92	0.02	65.5	-1.17
SR flood control dam	Daily	4392	0.73	0.37	0.04	0.37	8.4
AW504530	Monthly	149	0.91	0.76	0.16	25.2	2.1
	Annual	12	0.94	0.79	0.2	361.5	2.1
SR Mitchell Pk	Daily	4026	0.85	0.71	-0.2	0.53	-6.4
AW504576	Monthly	123	0.93	0.86	-0.11	30.7	-2.4
	Annual	10	0.92	0.82	-0.2	652.3	-2.5
SR Anz HW	Daily	5490	0.91	0.83	-0.15	0.45	0.12
AW504549	Monthly	183	0.93	0.87	-0.12	30.7	-1.4
	Annual	15	0.93	0.87	-0.05	560.3	-1.4
Adel Tce Pipe West St	Daily	3660	0.91	0.83	-0.15	0	10.4
AW504582	Monthly	111	0.95	0.9	-0.06	0.4	-0.65
	Annual	9	0.98	0.96	0.04	5.2	-0.14

* Note: Flow calibration at the gauging station was abandoned subsequently

Table 11. Urban catchment characteristic set

Urban characteristic set	16			17			19		
Impervious surface	R	HP	RP	R	HP	RP	R	HP	RP
Area (m^2)	55	25	20	55	25	20	55	25	20
Connection	0.5	0.5		0.65	0.85		0.85	0.85	
Initial loss	1	2	2	1	2	2	1	2	2
Ongoing fraction	0.7	0.6	0.9	0.9	0.8	0.9	0.9	0.8	0.9
Effective area	0.35	0.3	0.9	0.585	0.68	0.9	0.765	0.68	0.9

Note: R - roof; HP - house pavement; RP - road pavement

In general, R-square values at the daily time period are lower than those at the monthly and annual time periods because of timing errors and delays between the rainfall and flow recordings (i.e. rainfalls are often recorded on the wrong day). In general, higher R-square values are also achieved for urban than rural catchments because of the more direct and simpler relation between rainfall and runoff in urban areas.

A good fit between the recorded and modelled flow duration curves at the monthly and daily time steps are shown in Figures 16 and 17 for the Sturt River upstream of Minno Creek.

The model parameters used in the WC-1 model for estimating runoff from the pervious portions of the catchments are given in Table 9. Ten different parameter sets were used. The values of the parameters fell within the range previously used for modelling catchments within the Mount Lofty Ranges.

The model parameters used for the estimation of runoff from the impervious parts of the catchments are given in Table 11. Only three models were used, with parameters selected to cover low runoff efficiency (Set 16 for those catchments where high losses were expected or indicated) to high runoff efficiency (Set 19 for those catchments where low losses were expected or indicated).

For the same rainfall in the range 450–600 mm/a, the impervious area models give much higher runoff than the pervious area models. Thus runoff efficiency from urban catchments depends on both the:

- assumed proportion of pervious to impervious areas contained within the catchment
- selected impervious area model (i.e. Set 16 to 19).

While GIS has been used to identify the sum of the larger pervious areas within the urban catchments, the summation of the many smaller areas (mostly contained within small parks, undeveloped blocks, private gardens, etc) can only be guestimated.

Kemp (Table 21, App. D) has estimated the split between pervious and impervious areas for 24 small ‘sample’ subcatchments in Adelaide. For industrial/commercial areas he found 50–70% to be impervious (rising to 100% for smaller or more intensely developed areas such as car parks or CBD areas). For repeating patterns of residential areas (i.e. without significant open spaces) he found 20–25% to be typically impervious for houses established in the 1930s–1960s, with higher values where gardens are smaller. The average value of impervious area was 28% across all samples.

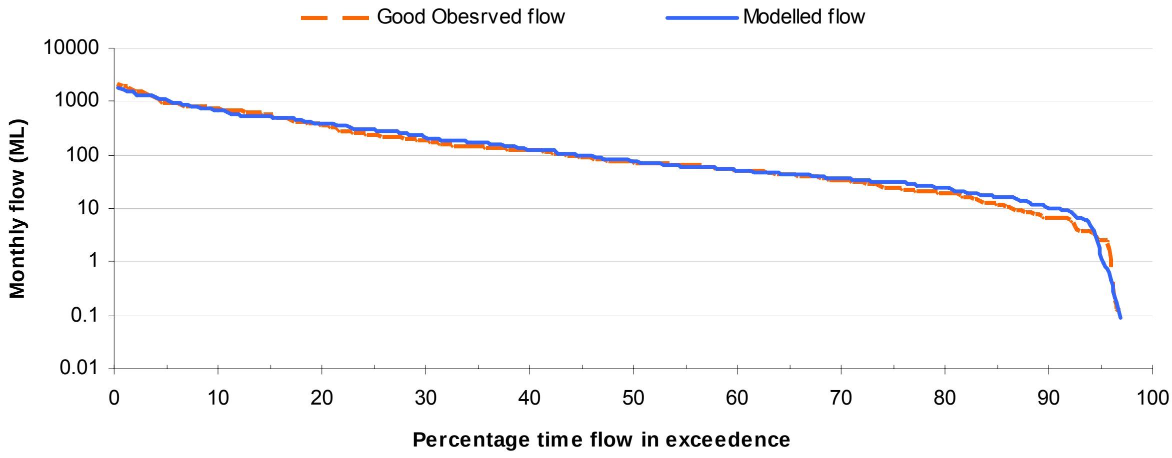


Figure 16. Monthly flow duration curves (78–96) Sturt River upstream Minno Creek (AW504518)

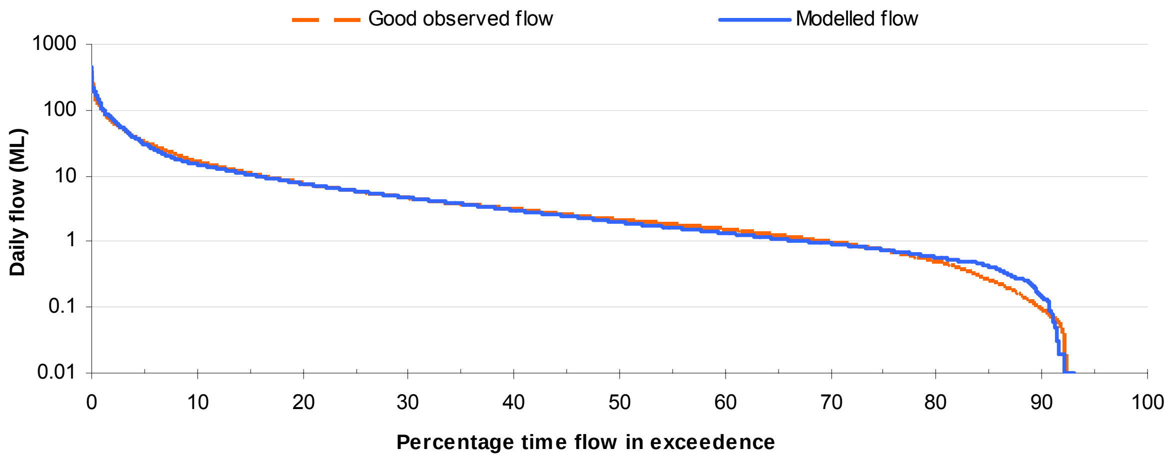


Figure 17. Daily flow duration curves (78–96) Sturt River upstream Minno Creek (AW504518)

The percentages of impervious area within the urban subcatchments are given in Table 20 (App. C).

Kemp's values were used to estimate the impervious area but, in general, the calibration also appeared to suggest that runoff efficiency was also related to the proportion of impervious area. It was very difficult to find a consistent method for estimating the proportion of the impervious area within each urban subcatchment and then assigning an efficiency of runoff from this area (i.e. selecting the impervious model set number to be used).

The difficulty was compounded in the gauged records for Brown Hill Creek where the recorded flows indicated losses of up to 5 ML/day on the downstream run between the gauge at Scotch College and the gauge just upstream of the junction with Keswick Creek. The calibration in Table 10 for the downstream gauge (AW504580) was fitted using an impervious area model with a very low efficiency. This calibration was subsequently abandoned (and the gauged records ignored); a higher efficiency model was inserted and only gauged records further downstream, adjacent to the Adelaide Airport (AW504583), were calibrated.

Differences between recorded flows at upstream and downstream locations may indicate flow processes (e.g. infiltration losses and/or gains) or systematic errors in flow measurement. This study has established an initial model but it is recommended that the data (including data from stations not analysed here) are further analysed to help identify those processes, particularly flow losses to underlying aquifers.

5.4 RESULTS

5.4.1 CATCHMENT YIELD – CURRENT DEVELOPMENT SCENARIO

Initial results show that under current levels of urban and farm dam development, with the assumptions identified above, the calibrated model gives a mean annual catchment runoff of 22 650 ML/a, simulated for the period 1900–2002 (median flow 21 200 ML/a).

Table 12 gives the breakdown of mean annual runoff for the main subcatchments modelled by this study and estimated by Tonkin Consulting (2000):

- The model provides a significantly lower total catchment estimate (22 650 ML/a) than that of Tonkin Consulting (27 330 ML/a), mainly as a result of a much smaller estimate of runoff from the Coastal catchment.

Table 12. Mean annual runoff simulated by model for the period 1900–2002

Major subcatchment	Area (ha)			Tonkin Consulting 2000 (ML)			DWLBC Model (ML)		
	Total	*Urban*	*Rural*	*Total*	*Rural*	*Urban*	*Total*	*Rural*	*Urban*
Coastal	2 649	1 568	1 080	6 100	?	6 100	2 510 (2 470)	700 (680)	1 810
Sturt River	11 993	3 874	8 119	11 500	5 250	6 250	10 840 (10 000)	7 770 (7 150)	3 070
Brown Hill @ u/s of the gauging station	3 621	1 615	2 006	7 900	2 650	5 250	4 620 (4 460)	2 430 (2 290)	2 190
Keswick @ u/s of the gauging station	2 956	2 615	341	1 400	650	750	3 430 (3 320)	30 (30)	3 400
Airport	1 845	1 845		430		430	860 (850)		860
Pat local	420	420		?	?	?	390 (380)		390
Total	**23 484**	**11 938**	**11 546**	**27 330**	**8 550**	**18 780**	**22 650** (21 200)	**10 930** (9 960)	**11 720**

Note: DWLBC model based on current farm dam development and 30% usage
Figures shown in brackets are median flow
DWLBC and Tonkin Consulting major subcatchment areas may be different

- Except for Keswick Creek, the model generally gives a much lower estimate of runoff from urban areas than has been given by Tonkin Consulting (less than a half).
- Total estimates for the Sturt River catchment are similar, but again, the model gives a higher estimate for the rural sub-area and a lower estimate for the urban sub-area.
- Total estimates for Brown Hill and Keswick creeks are similar, but the model predicts a much larger proportion provided by Keswick Creek (and a lower proportion provided by Brown Hill Creek) than estimated by Tonkin Consulting.

- The model predicts a larger runoff contribution from the Airport and local Patawalonga catchments. (The fact that Tonkin Consulting omits the latter may indicate different assumptions being made on reporting boundaries).

5.4.2 MORPHETTVILLE RACECOURSE, OAKLANDS PARK, PARK LANDS CREEK

Catchment yield for Morphettville Racecourse (Drain 3), Oaklands Park (Drains 4 and 6) and the Park Lands creek at Victoria Park (Table 13) shows that their long-term mean (1900–2002) annual catchment yields of 348 ML, 1148 ML and 955 ML respectively reduced to 241 ML, 646 ML and 697 ML in the extremely dry years (1912–24).

Table 13. Morphettville Racecourse, Oaklands Park and Park Lands creek water resources

Current FDD	**Drain 3** (Morphettville Racecourse)	**Drain 4** (Oaklands Park)	**Drain 6** (Oaklands Park)	**Park Lands creek at Vic Park**
Catch area (ha)	477	791	589	618
Mean (1900–2002)	348	713	435	955
Median (1900–2002)	333	700	425	927
Dry year (1912–14)	241	401	245	697
Wet year (1922–24)	497	1 061	644	1 356
Gridded rainfall	539	575	593	640
Runoff coefficient	14%	16%	12%	24%

5.4.3 RUNOFF COEFFICIENT

Catchment yield expressed as a percentage of the mean annual rainfall is termed the runoff coefficient.

Although the runoff coefficient was expected to be of the order of 20% and above for the catchment, it was 17% for the urban part of the Patawalonga catchment and 15% for the rural part.

The low runoff coefficient is a reflection of the flows recorded for the gauging stations located in the urban area and in part, is caused by the existence of large open areas, such as the airport and parklands.

On the major subcatchments level, modelled runoff coefficients for the urban parts of Brown Hill Creek, Keswick Creek and Coastal catchments were all 23% (Table 14); for Sturt River it was 14% and for Adelaide Airport Drain catchment 10%. The Adelaide Airport Drain is modelled with a substantial part of the catchment area as rural catchment.

5.4.4 MODEL CATCHMENT BOUNDARY

There is a slight difference between the modelled catchment boundary and the Patawalonga catchment hydrological (natural drainage) boundary.

Table 14. Modelled runoff coefficients for rural and urban catchments

Major subcatchment	Urban and rural areas combined			Rural area			Urban area		
	Area (ha)	*Gridded RF (mm)*	*RO coeff (%)*	*Area (ha)*	*Gridded RF (mm)*	*RO coeff (%)*	*Area (ha)*	*Gridded RF (mm)*	*RO coeff (%)*
Coastal	2 648	522	18	1 080	547	12	1 568	506	23
SR	11 993	724	12	8 119	809	12	3 874	545	14
BH	3 621	708	18	2 005	834	15	1 615	552	23
KW	2 956	585	20	341	647	1	2 615	576	23
Airport	1 845	470	10				1 845	470	10
Local Pat	420	473	20				420	473	20
Total	**23 483**	**657**	**15**	**11 546**	**793**	**13**	**11 938**	**542**	**17**
BH+KW	6 577	653	19	2 346	807	13	4 231	567	23

Note: RF - rainfall; Coeff - coefficient; BH - Brown Hill Creek; KW - Keswick Creek; SR - Sturt River; Pat - Patawalonga
Gridded RF estimate only

The urban (plains) part of the modelled catchment follows the drainage pipe network boundary and omits a small area of natural drainage on the north side of the Park Lands creek. The model will therefore underestimate by the size and frequency of flows from this area which may be important for flood management.

6. FARM DAM SCENARIO MODELLING: RESULTS, DISCUSSION

6.1 SCENARIOS

Inputs to the model, as calibrated for the current level of development (Ch. 5), were changed in order to assess the impact of different farm dam scenarios:

- without farm dam development for the total catchment
- with the current level of farm dams but usage increased from 30–100% of dam capacity
- with the maximum farm dam development based on the 50% rule for rural catchments at:
  - Minno Creek
  - Sturt River upstream of Minno Creek
  - Chambers Creek
  - rural catchment of Brown Hill Creek
- application of low flow bypasses for the 50% rule development level scenario.

6.2 WITHOUT FARM DAMS

The median catchment yield without farm dams (the median 'adjusted' flow) is not the pre-European natural flow as the effects of other land use changes have not been addressed.

Table 15 shows the median and mean adjusted catchment yields for the major subcatchments over the 102 year period, modelled with all the current farm dam volume of 692 ML removed. The increase in catchment yield in the *median* year in the Sturt River, Brown Hill Creek and Keswick Creek catchments is only 1.4%, 1.0% and 0.2% respectively above those given in Table 14, and in terms of the *mean* adjusted flow, 0.6%, 0.9% and 0.1%.

Table 15. Without farm dam development catchment yield in a median year

Major subcatchment	Median flow from 1900–2002			Mean flow from 1900–2002		
	WOFD (ML)	*Flow reduction with 30% water usage*	*Flow reduction with 100% water usage*	*WOFD (ML)*	*Flow reduction with 30% water usage*	*Flow reduction with 100% water usage*
Coastal	2 471	0.0%	0.0%	2 510	0.0%	0.0%
Sturt River	10 156	1.4%	3.9%	10 907	0.6%	2.7%
Brown Hill Creek	4 504	1.0%	2.2%	4 662	0.9%	2.1%
Keswick Creek	3 321	0.2%	0.4%	3 430	0.1%	0.4%
Airport	854	0.0%	0.0%	860	0.0%	0.0%
Pat-local	384	0.0%	0.0%	390	0.0%	0.0%
Total	**21 319**	**n.a.**	**n.a.**	**22 759**	**0.5%**	**1.8%**

Note: WOFD - without farm dam development, n.a - not applicable

This result indicates that the impact of the current level of farm dam development on catchment-wide streamflows is very small.

Table 16 shows wet and dry-year flows. In the driest years, percentage reductions in flow with farm dam development for the Sturt River and Brown Hill Creek catchments are 2.9% and 2.5% respectively. Both wet and dry-year flows would only be increased without farm dams by 0.1 GL/a and 0.2 GL/a respectively.

Table 16. Without farm dam development catchment yield in dry and wet years

Major subcatchment	Extreme dry year 3-year moving average (1912–14)			Extreme wet year 3-year moving average (1922–24)		
	WOFD (ML)	*Flow reduction with 30% water usage*	*Flow reduction with 100% water usage*	*WOFD (ML)*	*Flow reduction with 30% water usage*	*Flow reduction with 100% water usage*
Coastal	1 789	0.0%	0.0%	3 421	0.0%	0.0%
Sturt River	4 585	2.9%	6.1%	18 423	0.5%	1.8%
Brown Hill Creek	2 047	2.5%	5.0%	7 399	0.4%	1.2%
Keswick Creek	2 556	0.2%	0.6%	4 820	0.1%	0.2%
Airport	658	0.0%	0.0%	951	0.0%	0.0%
Pat-local	293	0.0%	0.0%	491	0.0%	0.0%
Total	**11 930**	**1.6%**	**3.3%**	**35 505**	**0.3%**	**1.2%**

Note: WOFD - without farm dam development

The flows are 3-year average flows matching the maximum and minimum 3-year moving average rainfall computed for all the 11 rainfall gauges used by the model.

6.3 DAM USAGE INCREASED TO 100% OF DAM CAPACITY

If the annual farm dam usage was increased from the assumed 30–100% of the storage capacity, flow reduced for the median flow year by 3.9%, 2.2% and 0.4% respectively for the Sturt River, Brown Hill Creek and Keswick Creek catchments from the 'no dams' condition (mean flow declines 1.8%, 1.2% and 0.2% respectively). In the driest years, the reduction in flow was 6.1%, 5.0% and 0.6% respectively.

This need not be the limit, since usage rates may be greater than 100% of dam capacity.

6.4 MAXIMUM FARM DAM DEVELOPMENT, WITH AND WITHOUT LOW FLOW BYPASSES

The impact of maximum farm dam development on the rural catchments of Minno Creek, Sturt River at upstream of Minno Creek, Chambers Creek the rural catchment of Brown Hill Creek was also analysed.

6.4.1 NORMAL YEARS

Current management policies allow maximum farm dam capacities to rise to 50% of the estimated median (adjusted) flow of their upstream catchments. Using this rule, the potential allowable additional farm dam development in these catchments identified above would be 3568 ML. When modelling the runoff, the additional farm dam volume is assumed to be added to the aggregated dam volume at the downstream end of each of the catchments. Both the 30% and 100% dam capacity usage rates were examined.

A low flow bypass is a device that diverts low flows around a farm dam, thus providing environmental flows to maintain the downstream water-dependent ecosystems. These flows would otherwise be intercepted by the dam, particularly in the summer months when the dam would be drawn down. Hence a low flow bypass would improve the frequency and duration of flows passing downstream.

The quantity of water allowed to bypass is called the low flow bypass threshold, which is expressed in litres per second per square kilometre of the upstream catchment area. Low flow bypass thresholds for Sturt River, Minno, Chambers and Brown Hill creeks are given in Table 17.

Table 17. Low flow bypass thresholds

Description	Sturt River	Minno Creek	Chambers Creek	Brown Hill Creek
Gridded RF	949	837	873	865
Low flow bypass, l/s/ km^2	14.67	8.76	10.44	10.05
Total low flow bypass, l/s	283.86	160.03	104.35	175.95
Total low flow bypass, ML/day	24.53	13.83	9.02	15.20

They are determined based on rainfall runoff relationship curve (Tanh curve) developed by DWLBC for the Mount Lofty Ranges region.

The impact of such an increase in the dam volumes on flow downstream, with and without low flow bypasses, is presented in Table 18.

Table 18. Impact of maximum farm dam development for rural catchments in a normal year

Rural catchment	Mean adjusted flow (1900–2002)	Median adjusted flow (1900–2002)	50% rule maximum farm dam development ML	Current FD volume	Additional FD volume	% Flow reduction modelled with 30% dam storage water used		% Flow reduction modelled with 100% dam storage water used	
						No LFBPs	*With LFBP*	*No LFBP*	*With LFBP*
Sturt River u/s Minno Ck	2 370	2 240	1 120	158	962	17.5%	16.8%	44.6%	30.5%
Minno Ck	2 150	2 030	1 015	107	908	18.6%	18.0%	46.3%	33.2%
Chambers Ck	1 570	1 420	710	134	576	16.2%	16.0%	42.5%	34.8%
Scotch College	2 430	2 310	1 155	33	1 122	17.5%	16.7%	46.5%	30.8%
Total	**8 520**	**n.a.**	**4 000**	**432**	**3 568**	**17.5%**	**16.9%**	**45.2%**	**32.1%**

Note: Percentage flow reduction based on mean adjusted flow for period 1900–-2002; LFBP: low flow bypass

With the annual dam usage assumed as 30% of the storage capacity, the reduction in the mean flow for the four catchments combined is 17.5%. With the low flow bypass incorporated, the impact is slightly reduced to 16.9%.

When the annual dam usage is increased to 100%, the total combined reduction is increased to 45.2%. By incorporating the low flow bypass, the impact is reduced to 31.2%.

6.4.2 EXTREME DRY-YEARS (1912–14)

In extreme three-year dry period (1912–14), the total mean annual flow modelled for the rural catchments of Sturt River at u/s Minno Creek, Minno Creek, Chambers Creek and Brown Hill Creek at Scotch College for this period was reduced to 2133 ML from the normal years' flow of 8520 ML. This is a reduction to 25% of normal flows (Table 18).

6.4.3 GRAPHICAL REPRESENTATION

Figures 18 and 19 summarise the impact of dam storage on catchment flow passing downstream in a normal and dry year situations. The Y-axis shows the mean annual percentage reduction in flow from the maximum (i.e. the 'without farm dams' scenario when 100% of the flow generated passes downstream) under the various scenarios modelled. The X-axis shows the three different scenarios for farm dam development and bypasses. The two sets of graphs are for scenarios under the assumptions of a 30% and a 100% dam capacity usage rate.

The figures show that under all scenarios, the impact (percentage reduction in flow passing downstream) is greater in the dry years than in normal years.

They also show that as more farm dams are allowed to develop within the catchments, the accurate assessment of the level of dam water use becomes an important factor in determining the impact on the downstream flows. In the extreme three-year dry period (1912–14), with maximum farm dam development (i.e. under the 50% rule) and with usage at 100% of dam capacity, there would be zero outflow from these catchments.

The graphs also show the significant influence that low flow bypasses have. When they are incorporated in the dam construction, the situation is dramatically improved with generally more than 50% of the water being passed downstream.

Low flow bypasses also have a very large effect on the flow duration curve (Fig. 20). With maximum farm dam development and no bypasses, over the whole 102 years, the duration of flow at the outlet of rural catchments is reduced to less than 40% of the time, thus having a severe impact on the water-dependent ecosystems. Low flow bypasses reduce the volume of flow intercepted and improve the frequency and duration of flows passing downstream back to the 'no dams' condition. For example, with maximum farm dam development, flow duration is raised from 40% back to greater than 80%.

Hence the incorporation of low flow bypasses becomes a crucial policy for sustaining low flows and the ecosystems dependent on them.

Figures 21 and 22 shows the modelled monthly flow patterns for the 30% and 100% dam capacity water usage scenarios without and with low flow bypasses. The effects on the volumes of flow passing downstream during the dry season months of summer are evident.

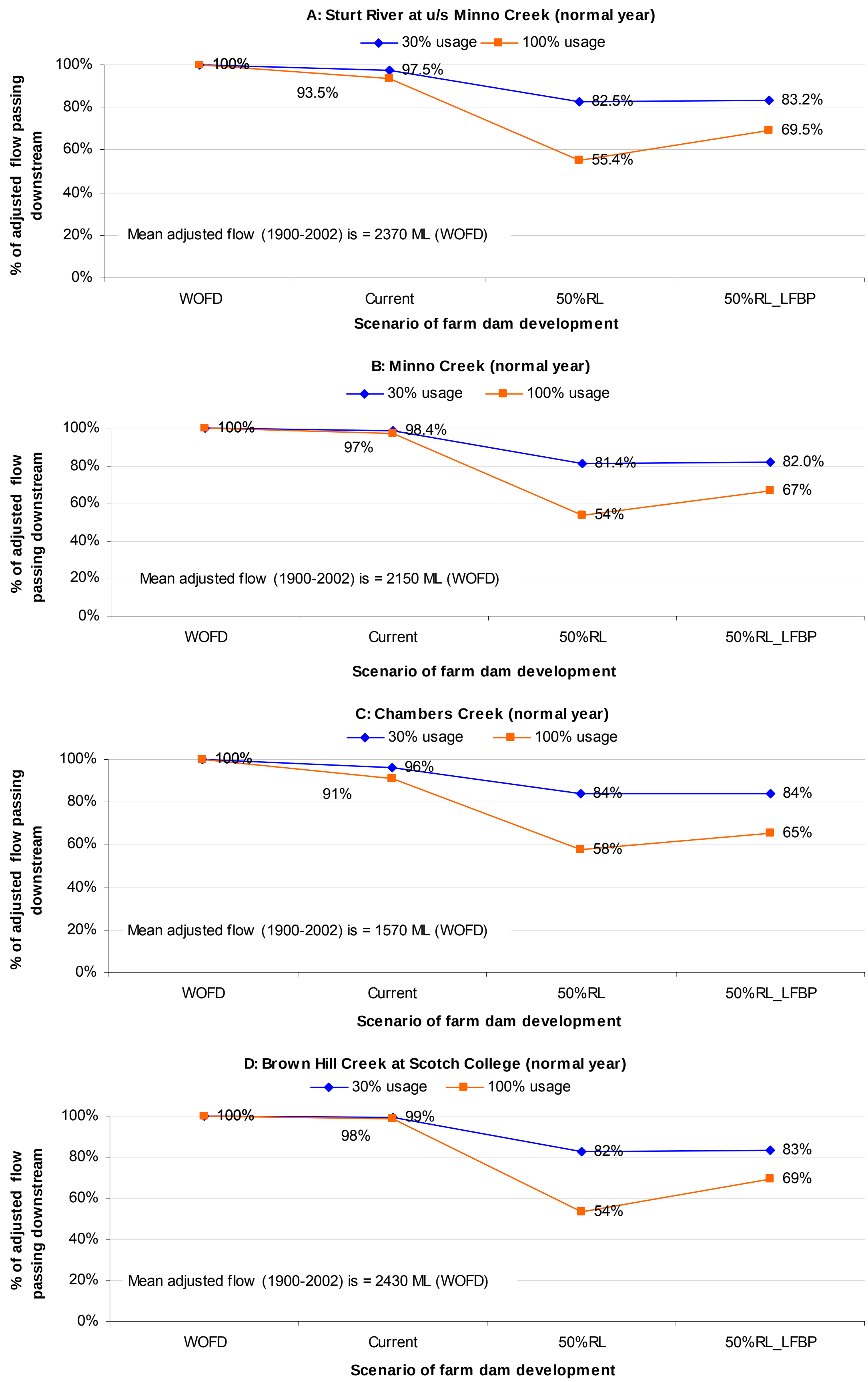


Figure 18. Impact of farm dams in a normal year

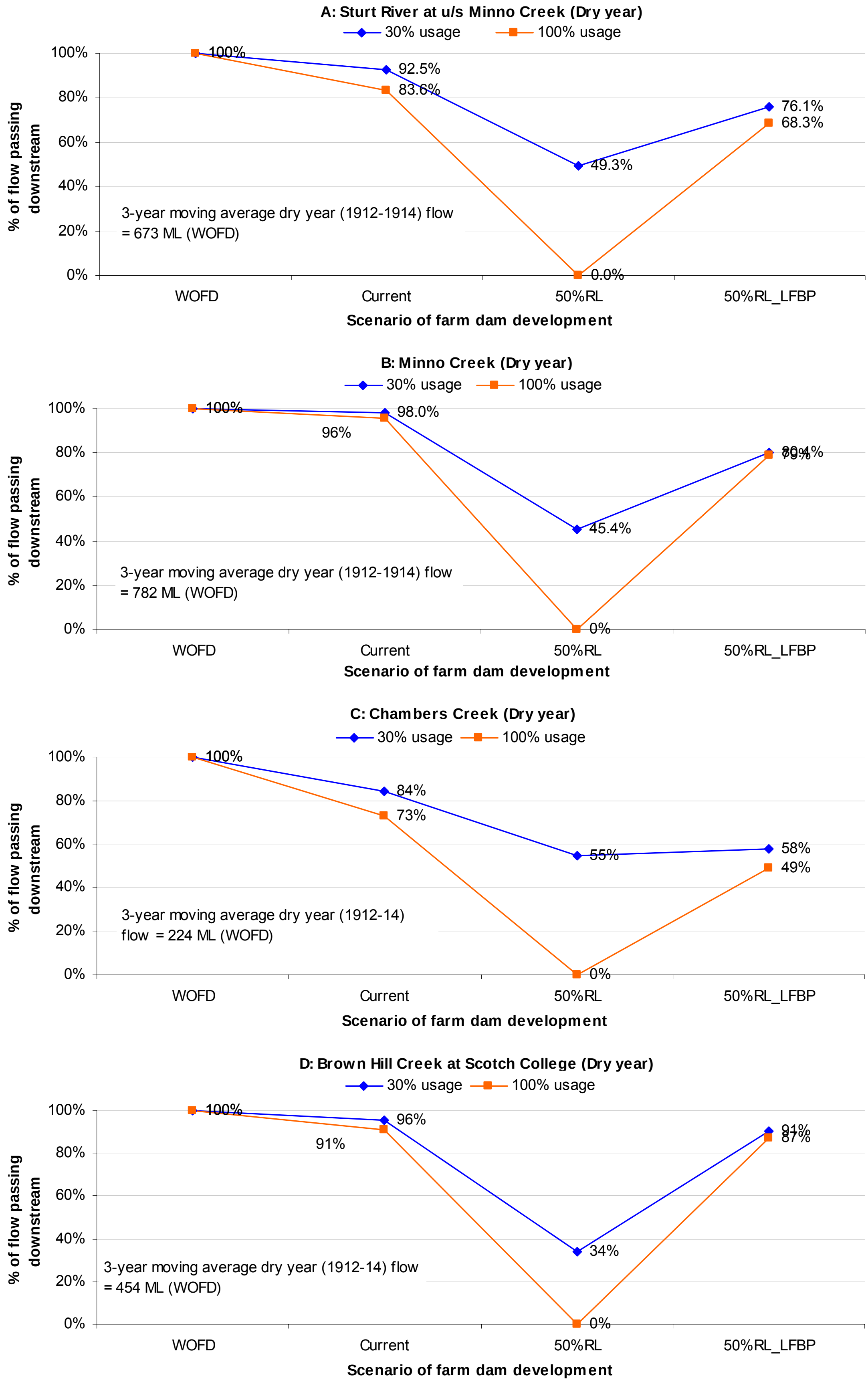


Figure 19. Impact of farm dams in an extreme dry year

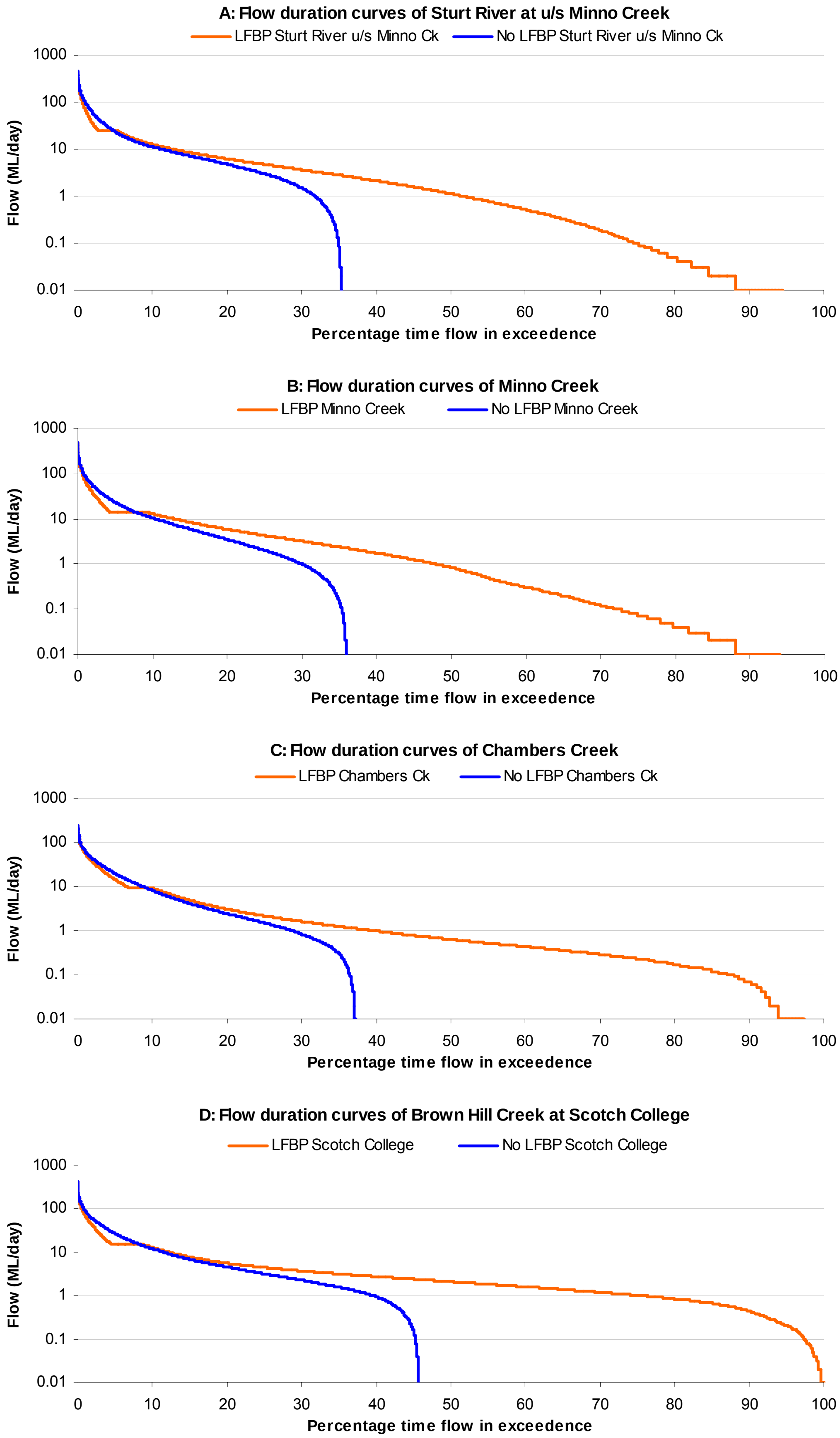


Figure 20. Flow duration curve with and without low flow bypass

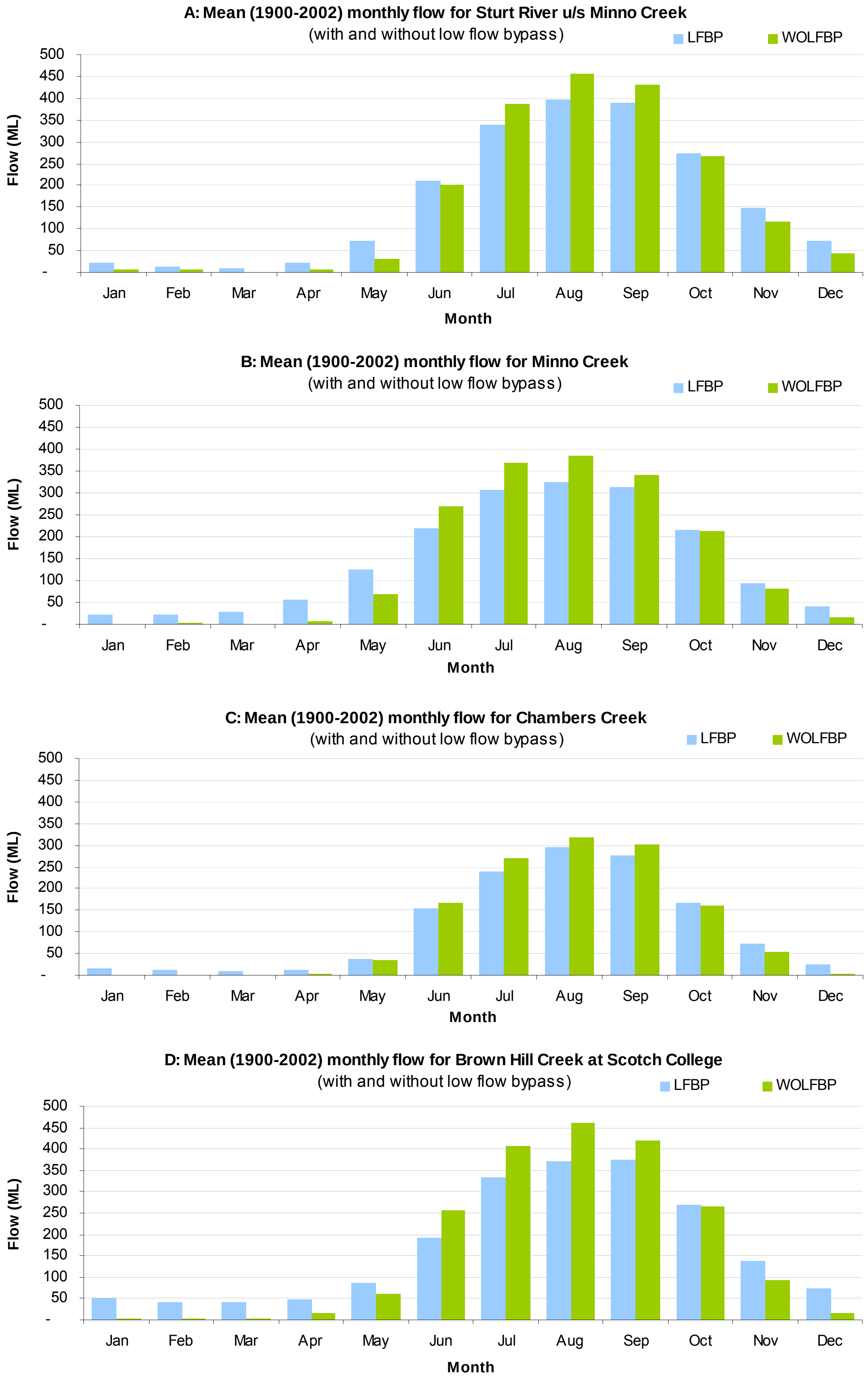


Figure 21. Monthly flow with and without low flow bypass for 30% dam water used

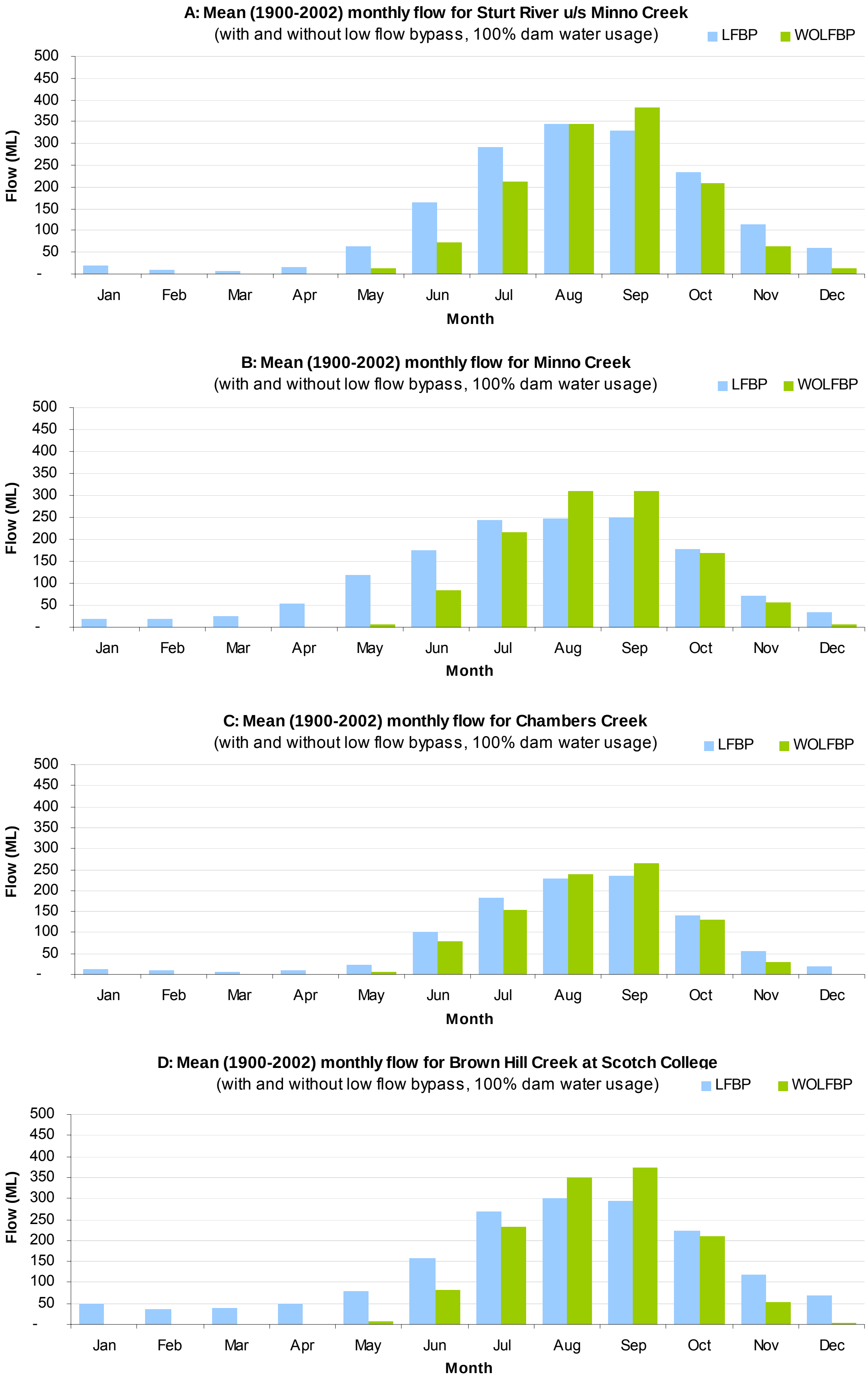


Figure 22. Monthly flow with and without low flow bypass for 100% dam water used

7. CONCLUSION

7.1 CATCHMENT MODEL

A catchment model has been established which has calibrated satisfactorily to selected recorded streamflow data, particularly in the mid-flow ranges. The accuracy of the results is dictated to a large extent by the accuracy of the flows recorded at the downstream gauging locations on the Sturt River at Anzac Highway and Brown Hill/Keswick creeks adjacent to the Adelaide Airport.

There are indications of losses in Brown Hill Creek and Sturt River where they emerge from the escarpment. A more thorough analysis of the data (including flow data not analysed) would be needed to reveal more information on the size and nature of these losses.

The modelled estimations of catchment flow differ from those previously reported by Tonkin Consulting (2000), particularly at the subcatchment level (Table 13). In general the model provides a higher estimate for runoff from the rural catchments and a lower runoff from the urban catchments. The estimate for total catchment is 20% lower than that of Tonkin Consulting (2000). Most of the difference arises from different estimates for the yield of the Coastal catchments.

7.2 CURRENT SURFACE WATER RESOURCE

The surface water resource is, by DWLBC definition, based on the catchment yield modelled with farm dams removed (median adjusted flow).

The modelled long-term (1900–2002) catchment outflow for the Patawalonga catchment under a no farm dams scenario is estimated to be 21.32 GL per annum (Table 16). However, the amount of flow generated within the catchments will be greater than that measured at downstream outlets, by virtue of transmission losses. The urban and rural parts of the catchment contribute about half each.

In the extreme three-year dry period (1912–14), total catchment outflow was reduced to 11.93 GL/a, and in the wet period (1922–24) increased to 35.51 GL/a (Table 17). The modelling has highlighted the high variability of annual runoff, particularly in rural catchments. The construction of farm dams exacerbates this variability (Table 19, App. C).

The median adjusted catchment yield for Morphettville Racecourse (Drain 3), Oaklands Park (Drain 4 and Drain 6) and the Park Lands creek at Victoria Park were 333 ML, 1125 ML and 931 ML respectively; in the dry years, 241 ML, 646 ML and 697 ML respectively. Reduction in flow during drought is less severe for these (mainly) urbanised catchments which, unlike the rural catchments (reduced to 25% of normal flows), continue to runoff at a relatively high efficiency even under drought rainfall conditions.

7.3 RUNOFF COEFFICIENT

The model indicates that the overall long term runoff coefficient for the lower rainfall, plains part, of the Patawalonga catchment (mainly urbanised) is 17%; for the hills part (largely rural, but with higher rainfall) it is 15%. The urban runoff coefficient is lower than that normally expected for urban catchments (of the order of 20% and above) and reflects the low flow recorded for the Sturt River at the Anzac Highway. It may be caused by data error or by transmission losses.

At the major subcatchments level, the modelled runoff coefficient for the urban parts of Brown Hill Creek, Keswick Creek and the Coastal catchments is 23% respectively. For the Sturt River, it is 14% and for the Adelaide Airport Drain catchment (which contains a very large proportion of open space), 10%.

7.4 CURRENT FARM DAM DEVELOPMENT AND ITS IMPACT

The GIS currently identifies 229 'farm dams' within the Patawalonga catchment, including open storages in the urban areas. Those estimated to have storage volume greater than 5 ML are regarded as being for irrigation; the remainder are regarded as being for stock and domestic purposes. The aggregated storage volume was estimated to be 692 ML. The 22 irrigation dams constitute 425 ML. Most farm dam development has been in the Sturt River catchment which has an aggregated storage volume of 565 ML.

Overall, current farm dam development has an insignificant impact (about 0.5%) on the quantity of catchment yield. At the major subcatchment level, only the Sturt River catchment has a comparatively higher impact (1.4% when modelled with annual dam water usage as 30% of its storage capacity, or 3.9% when modelled with 100% of dam water used). These figures are based on median flows (1900–2002); generally the percentage impact is about 1% lower using the mean flows.

In the extreme dry year, under the same range of usage assumptions, the model shows that the flows for the Sturt River catchment are reduced by 2.9–6.1%.

7.5 MAXIMUM FARM DAM DEVELOPMENT AND LOW FLOW BYPASS

If maximum farm dam development, based on the 50% rule, took place within the rural catchments of Sturt River and Brown Hill Creek, rural farm dam storage would rise to 4000 ML.

Under these conditions, estimation of impact is far more sensitive to the assumption on the rate of usage from the dams. The impact is also greatly dependent on whether a low flow bypass rule is adopted or not, and is magnified for extreme dry year conditions:

- In a normal year, based on mean flow, with no bypasses, overall reduction in outflow from the rural catchments would be 17.5–45.2% (for 30% and 100% dam volume usage rates, Table 19, App. C). With low flow bypasses, the reduction ranges from 16.9–32.1%.

- In the extreme dry year condition (1912–14), with usage at 100% of the dam capacity and no bypasses, there would be zero outflow from these catchments (Fig. 20).
- Low flow bypasses incorporated with farm dam structure will reduce the volume of flow intercepted, particularly in dry years, and greatly improve frequency and duration of low flows passing downstream back to the ‘no dams’ condition. For example, in dry years it improves zero flow passing downstream to more that 50% of flow (Fig. 19) and flow duration is raised from 40% back to greater than 80% (Fig. 20).

Thus the incorporation of low flow bypasses becomes an important strategy for sustaining low flows and ecosystems dependent on them.

7.6 INFORMATION GAPS

There were information gaps in this catchment modelling. Various assumptions had to be made which should be reviewed in any further stages of modelling. The information gaps identified included: estimation of farm dam volumes, level of usage from farm dam storages, irrigation water use by different land uses, and the source of water being used for irrigation. Where possible these were estimated by empirical formula, but in many cases data used were guestimated.

The catchment model did not incorporate the operations of some local wetlands in the runoff simulations due to the lack of daily inflow and outflow information from these wetlands. When the information is made available, it can be incorporated into the model to improve the flow calibration and runoff simulations. However, since flows in these wetlands are relatively small in relation to the total flow volume of the catchment, their impact on the estimated quantity of catchment yield is not expected to be significant.

There was also little information to assist the estimation of impervious areas or their connectivity to the drainage system on a regional scale.

The existence of infiltration losses (or gains) in stream channels appears likely, but is complicated by the possible inaccuracy of gauge records. For instance, the data indicate a possible loss of 1370 ML from Brown Hill Creek between Scotch College and Keswick Station, but this needs further investigation.

The accuracy of records at high flow may also be suspect. Since most flow volumes occurs at high flow rates, the estimation of the total flows might have been compromised by inaccuracy in estimation of high flows.

8. RECOMMENDATIONS

1. The model as completed has been successfully calibrated to selected flow data for the main subcatchments. The model results can therefore be used as a guide for overall resource assessment and allocation. However, the level of detail contained within any subcatchment of the model is preliminary only and should be checked (and augmented) if the model is to be used for decisions at the subcatchment level.
2. The yields produced under more extreme climatic conditions should be given due consideration in drawing up catchment plans.
3. The model results show that under present levels of development the influence of farm dams on overall catchment flows is small (of the order of 1%). Despite this, any future farm dam development should incorporate a low flow bypass structure. This would greatly improve the frequency of low flows passing downstream to sustain the water-dependent ecosystems.
4. A more regular validation and analysis of flow data would enable any anomalies to be checked and errors arrested quickly. Such an approach would assist in building a history of timely observation about catchment behaviour, beyond the level presently attained.
5. The rating curves of gauging stations (particularly those derived theoretically), which show anomalies in terms of amount, seasonality, duration or peak rates of flow should be reviewed. These should include Brown Hill Creek at upstream Keswick (AW50480) and at Adelaide Airport Morphett Road (AW504583); Morphett Road Transfer Station (AW504582); Sturt River at Mitchell Park (AW504576) and at Anzac Highway (AW504549).
6. The information gaps identified during this study should be addressed to improve the catchment modelling:
    a. A more thorough investigation of all flow data records should be undertaken to reveal more detailed information on infiltration losses and interactions between surface flows and groundwater. Local knowledge should be sought and progressively incorporated into the model, e.g. transmission losses may indicate run of river diversions to irrigation from Heathfield WWTP effluent discharges, while gains may be due to returns from excess local summer irrigation.
    b. In view of the major difference between the model and previous predictions of runoff from the Coastal catchments to the south of Glenelg, it is recommended that a gauging station be established on a representative drain in this area.
    c. Some of the flood warning stations maintained by the Bureau of Meteorology in Keswick catchment should be upgraded to better assess flow characteristics and catchment yield.
    d. In view of the greater reliability of runoff from urban catchments, better (standardised) means for estimating: i) the proportions of impervious area within urban catchments (e.g. field surveys) and ii) the efficiency of runoff from these areas, should be sought and adopted for future models.
    e. The accuracy of modelling of diversions from flow through farm dams, wetlands and other waterbodies is constrained by lack of data. The needs of data for modelling should be used as a case study to identify priorities and accuracy levels in relation to the prescription of the Mount Lofty Ranges catchments and the upgrading in the collection and central collation of such data.

APPENDICES

A. METHODOLOGY FOR DISAGGREGATING AND IN-FILLING RAINFALL DATA

Rainfall data is collected at 09:00 on a daily basis in the Bureau of Meteorology stations. Rainfall collected during weekends and public holidays is recorded at 09:00 on the next working day. Thus accumulated rainfall for those days when rainfall was not recorded must be disaggregated. The methodology used by SKM for disaggregation of rainfall data is based on the method outlined by Porter and Ladson (1993).

The method assumes that the influence of nearby stations, where records are complete, is inversely proportional to their distance from the gauged station. That is if a gauged station **S** has its rainfall accumulated over **m** days, and complete data are available from **n** rainfall stations nearby, on day **j** precipitation at **S** station is given by:

$$\mathrm{P}_{jS} = \frac{\sum_{j=1}^{m} \mathrm{P}_{jS} . \sum_{k=1}^{n} \{p_{jk} / d_k\}}{\sum_{k=1}^{n} \{1/d_k\}}$$

where $\sum_{j=1}^{m} \mathrm{P}_{iS}$ is total rainfall accumulated over **m** days for the gauged station **S**,

d_k is the distance from a rainfall station ***k*** to the gauged station **S**, and

p_{jk} is that proportion of rainfall fell on day **j** at **k** station over the total rainfall accumulated over **m** days at the same **k** station. That is:

$$p_{jk} = \frac{\mathrm{P}_{jk}}{\sum_{j=1}^{m} \mathrm{P}_{\mathrm{jk}}}$$

To this effect, an automated procedure was developed to redistribute the data. The procedure limits the search to only 15 rainfall stations closest to the station of interest. If no reference can be made from these 15 stations, then it is recommended that redistribution be carried out manually from other nearby stations closest to the station of interest. If no such reference station can be found, then redistribution may be carried out evenly over the period of accumulation.

For in-filling the missing rainfall records, the correlation method was used. The annual rainfall of a station **S** of interest was correlated with that of other nearby stations. The station with the highest correlation factor with S that had data concurrent with the missing period was used for in-filling the records. Again, the consultants developed an automated procedure for in-filling the data and it was limited to a search of 15 closest rainfall stations only.

B. ADEQUACY OF FLOW RATING CURVES

The following information on the adequacy of the flow rating curves for four of the gauging stations has been provided by Water Data Services, the company contracted to operate the stations (*per email message Nov 2004*):

- Brown Hill Creek at Scotch College (AW504901).
- The rating curve is good for flow rates to 1.5 m^3/s. Above 1.5 m^3/s, the flow rate was underestimated by approximately 10–20%. Above 3 m^3/s, more gauged flow measurements are needed.
- Brown Hill Creek at Adelaide Airport (AW504583).
- For flow rate up to 3 m^3/s, the rating curves are all right. However, recent gauging on flow indicates that for flow rate over 4m^3/s, the current rating curve is over-estimating by as much as 50%. WDS is currently looking into the matter further.
- Sturt River at Sturt Road (AW504576) and Anzac Highway (AW504549).
- Recent gauged flow measurements confirm that the rating curves for both sites seem reasonable. However, WDS suspects that at Anzac Highway, the ratings at high flow are affected by tailwater.
- Ratings of Brown Hill Creek @ u/s Keswick Creek (AW504580) look reasonable but need more gauging for flow over 4 m^3/sec.

C. WATERCRESS MODEL

WHAT IS WATERCRESS?

WaterCress stands for Water-Community Resource Evaluation and Simulation System. It is a PC based catchment water-balance model developed by Clark and Cresswell to simulate the movement of water at the daily time step through natural and engineered water systems (Cresswell 2000). A complete WaterCress catchment model is constructed as a series of '**nodes**'. Each node represents a component process of the system for which a water balance is computed each day. Nodes can consist of some, all or multiples of the following catchment processes, namely:

- demand for water components (town, industry and text-demand)
- catchment components (rural, urban and text-drain)
- storage components (reservoir, aquifer, tank, off-stream dams and external storage)
- treatment components (treatment and wetlands)
- transfer of water components (weir and routing environment).

The assemblage of these nodes is linked by gravity drains or pumped pipelines to mimic the movement of water in the natural or engineered system. The total assemblage then forms the model.

The dynamics of the simulation are set by the input of rainfall or flow data to the catchment components and (where required) by demands for water satisfied by taking supplies from storages via pipelines. On each day, flow (calculated from rainfall or input as a flow record) moves from the upstream to the downstream of the model according to the operation selected by the modeller.

Catchments may be classified as a rural, urban or 'text-drains'. The water balance calculations for a rural catchment (which represents the pervious part of the catchment) are complex and include the movement and redistribution of water within three notional moisture storages. The calculations for an urban catchment (which represents the impervious parts of a catchment, such as roofs and pavements) are simpler and do not involve water storage. A text-drain catchment is a text file established providing the flow sequence input to the model at daily time-steps.

PATAWALONGA CATCHMENT MODEL

The Patawalonga catchment model consists of catchment nodes (rural, urban and text-drain), storage nodes (off-stream dams) and transfer nodes (for diversions and flow routing) only. Catchment nodes form the majority of the model. Since the Patawalonga catchment is highly urbanised, the model contains as many urban as rural catchment nodes. The only text-drain node provides a daily record of the discharge of wastewater from the Heathfield WWTP into a rural catchment.

Prior to setting up the model, catchment data must be collected and processed to a format that can be used in the model. The basic catchment data consists of:

- rainfall and evaporation data

- the area of each subcatchment (or areas of different catchment surfaces)
- the surface area and volume relationship of individual farm dams and the water demanded from them.

Data for the construction of the Patawalonga catchment model are provided in Tables 18–19. Figure 13 shows a schematic diagram of the constructed model and Figure 14 shows the structure of the WaterCress model.

Rainfall and evaporation data

Each catchment node requires the input of a rainfall record. Rural (pervious) catchments also require the input of evaporation data. Rainfall data are entered as a text file (filename.rai) which contains rainfall data at the daily time-step (without any gaps). Evaporation data are entered (in a filename.evp file) which contains a set of mean monthly evaporation data from January to December. Daily evaporation is calculated from the monthly total. The same evaporation data are repeated for each year over the period of model simulation.

The rainfall data used for each subcatchment are generally those situated closest to the subcatchment and having the longest and most accurate data. Records are first edited to remove aggregations and fill gaps by correlation with nearest stations. Where necessary the records may be corrected for homogeneity using the same correlations.

Each edited daily rainfall data entry is multiplied by a constant factor equal to the ratio of the mean annual rainfall at the centre of the subcatchment (X, as mapped for the region including the subcatchment) to the mean annual rainfall for the record being used (Y). This ensures that the rainfall being applied to the catchment via the model has the same depth as that derived using the best information on the spatial distribution of rainfall.

Figure 23 shows an example of how data are entered for each subcatchment node. In this case it is a rural catchment node cat_B9b1 with rainfall entered from a daily rainfall file WestTce.rai (i.e. Adelaide West Terrace) and each daily rainfall multiplied by the rain station factor of 0.96 (since the subcatchment is located close to the West Terrace location, but to its west, where the rainfall is mapped as being on average 4% less than at West Terrace.

The monthly evaporation file Adel.evp is also entered. This record inputs the 12 monthly average values of Class A pan evaporation measured at Adelaide.

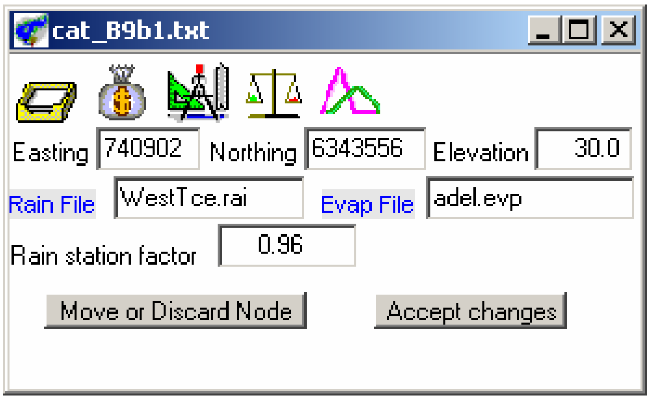


Figure 23. Entering rainfall and evaporation data

Urban and rural catchment nodes

Subdivision of catchment area

The Patawalonga catchment has been separated into 91 minor subcatchments falling within six major drainage subcatchments for which results are reported. Each of the minor subcatchments is separated into their pervious and impervious parts. The former are modelled as rural nodes and the latter as urban nodes. The basis for the subdivision of catchment areas depends on a number of factors (see Section 4.2.3).

Urban catchment nodes

Urban catchments generally consist of a mixture of pervious and impervious areas. Individual large areas of both types (e.g. sports ovals, golf courses, or car parks and large factory roofs) can be individually identified and summed, but many small and fragmented areas (e.g. individual roofs, roads, gardens within a typical residential area), make it impractical to attempt to estimate their totals by assessing and adding their individual areas. It is therefore usual to: i) identify and add large pervious and impervious areas within the subcatchment, then ii) estimate the pervious and impervious areas within the remainder of the (usually) residential areas by an empirical method.

Kemp (App. D) has estimated the percentage of impervious areas for many ‘typical’ medium sized urban catchments. His results vary from 70% to 11%, with an overall average of 28.2%. Industrialised/CBD type subcatchments have high percentages (obviously up to 100% for small totally paved subcatchments), while those subcatchments containing high proportions of parklands, golf courses, etc, will have the lower values.

All large pervious areas within each subcatchment were separately identified, summed and subtracted from the subcatchment area, for the preparation of an initial model (before calibration). The percentage of actual impervious area within the remaining (urbanised) area was then set at 40% for the majority of a typical residential areas, but was increased in steps to 50%, 65% and 70% with the last step being for highly industrialised catchments, such as those located in Mile End. The assumed pervious part of the urbanised area was then also calculated and added back to the initial summation of the large pervious areas. The separation of the total catchment area into its pervious (i.e. rural) and impervious (urban) parts is given in Table 19, Appendix C.

The urban catchment node simulates runoff from impervious areas. The total impervious area is calculated as the product of a notional number of houses each with a notional area of roof, house pavement and road area (Fig. 24). Runoff from each of the surfaces is calculated via an initial loss and continuing loss type hydrologic model. In addition to the initial loss and ongoing fraction (continuing loss), a value is entered for the connection, or degree of connectivity of the roof and house pavement areas to the street drain. For example, 0.85 for roof means 85% of the runoff from the roof area would discharge to the street drain, the remainder being ‘lost’.

The total runoff for each surface is therefore calculated as:

(No. of houses)*area*connection*(rainfall – IL)*(ongoing fraction). For rainfall > IL

Or zero for rainfall <= IL for that surface.

The total subcatchment runoff for the day is the sum of the runoff for each surface.

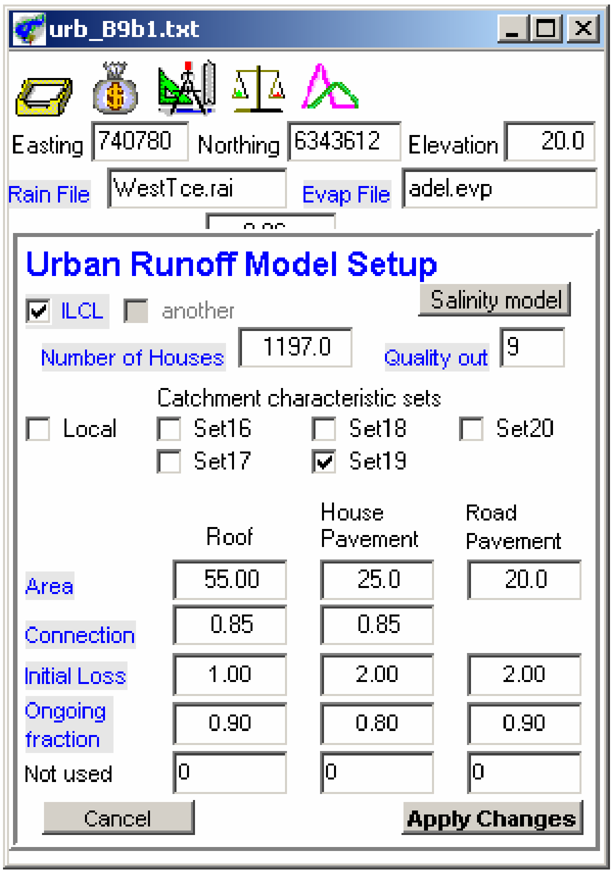


Figure 24. Entering data for urban node

The catchment characteristic sets used for Patawalonga catchment model after calibration are set No. 16, 17 and 19 as listed in Table 12.

In the absence of data, it is usual to choose a 'standard' allocation of these impervious areas per house and then adjust the number of houses so that the total impervious area for the catchment equals that estimated. In the Patawalonga model it is assumed that each notional 'house' occupies 100 km^2 (55 km^2 roof area, 25 km^2 paved area and 20 km^2 road).

Rural catchment nodes

The criteria used for separation of rural catchments are given in Section 4.

The area of each rural catchment is entered in a rural catchment node as shown in Figure 25 for the subcatchment cat_B9b1.

Rural catchment parameters

There are a number of runoff models, for example WC-1, AWBM and SDI models, that can be chosen for modelling the runoff from the rural catchment nodes. For this study the WC-1 model was used. The model requires the input of 10 catchment parameters as shown in Figure 26 (note: KS & KS2 are not presently used).

A description is given below to assist in understanding the operation of the WC-1 model.

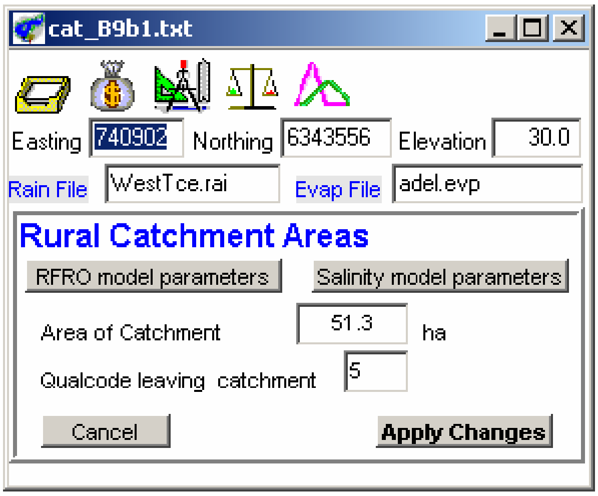


Figure 25. Entering catchment area for rural node

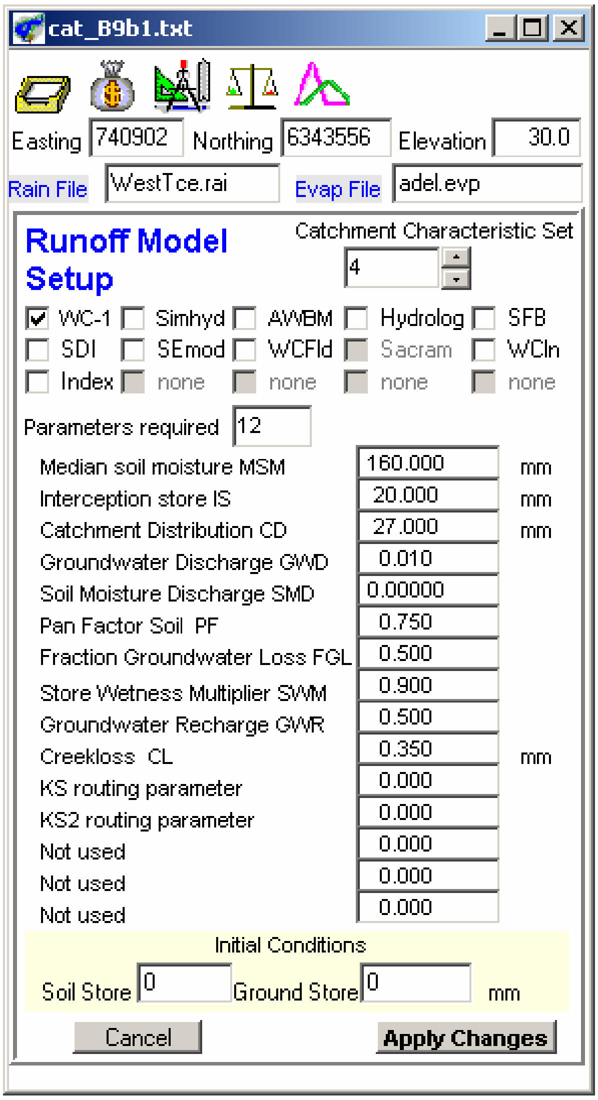


Figure 26. Input data for WC-1 runoff model

Rainfall runoff process

By definition, **runoff** is that total amount of water flowing into a stream. It can be **direct runoff** (surface or overland flow and interflow) and/or **groundwater discharge** (or baseflow). The conversion of rainfall to runoff is complex, being influenced by many factors associated with climate, landscape and human intervention. Nevertheless, using simple definitions, when rain falls onto the land surface it may be compartmentalised as being partly lost to interception by trees, vegetation, surface depressions, etc; partly contributing to flow over the land, and partly infiltrating into the subsurface.

That part of rain intercepted is generally referred to as interception loss. **Direct runoff** is that part of the rainfall that moves over the land surface and enters a wetland, stream or other waterbody by virtue of the rainfall rate locally exceeding the infiltration rate of the land surface. **Interflow** is that water that travels laterally through the soil aeration zone and discharges within a short time into a nearby stream or other waterbody. The quantity is usually small.

The part of rainfall that infiltrates into the ground may be partly used by vegetation as evapotranspiration or may percolate to the groundwater table. The groundwater may discharge to a stream as **baseflow** at a distance further downstream or be lost permanently to deeper aquifers. Baseflow is generally sustained between direct runoff events and for some time, but gradually diminishing after the end of the wet season.

In short, the distribution of rainfall to interception loss, surface runoff and infiltration into the ground depends on the catchment landscape, the rainfall frequency, intensity and duration and the properties of the subsurface soils and geology. The 10 parameters in WC-1 model attempts to simulate the rainfall runoff process just described.

WC-1 model

WC-1 model may be conceptualised as a 3-bucket storage model. The three buckets represent the interception store, the soil moisture store and the groundwater store. The model is structured to partition each day's rainfall into and progressively through the stores, in conjunction with rainfall that has entered previously. The process is shown in Figure 27. In the formulae, the subscript 't' represents the current day and 't-1' represents the previous day.

The 10 parameters and their functions:

IS sets the maximum initial abstraction from rainfall before any runoff can occur.

MSM (median soil moisture) sets the field capacity of the soil; it sets the maximum value of the soil moisture storage for 50% of the catchment area.

CD (catchment standard distribution) sets the range of soil moisture values about MSM.

SWM (store wetness multiplier) determines the rate at which water infiltrates from the interception store to the soil store.

GWD (groundwater discharge) is the proportion of the groundwater store that discharges as baseflow to the stream.

SMD (soil moisture discharge) is the parameter that governs the rate that interflow response to function of the soil storage.

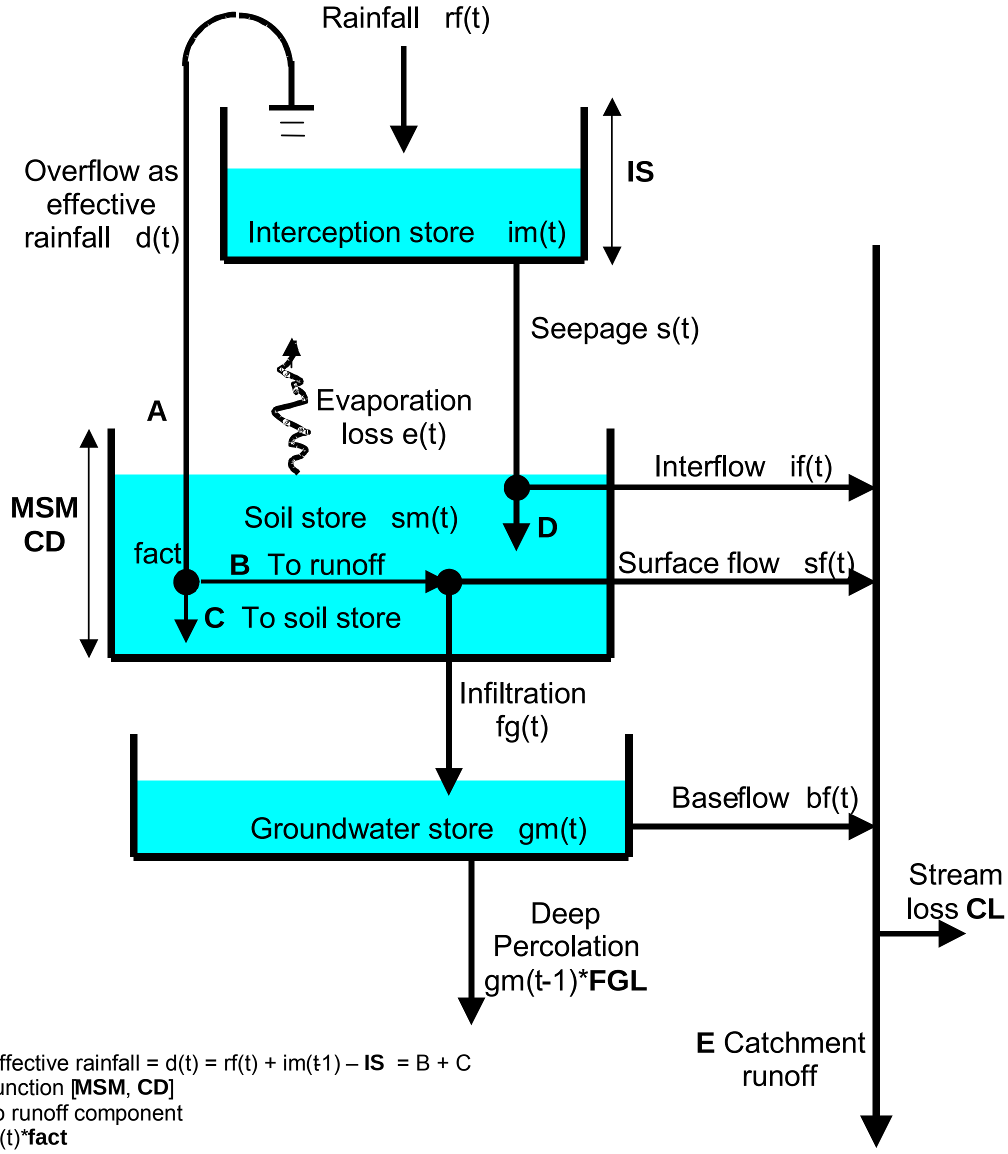
PF (pan factor) is the factor applied to the record of pan evaporation to calculate the daily rate of loss to evapotranspiration from the model.

GWR (groundwater recharge) is the proportion of effective rainfall that recharges the groundwater store.

CL (creek loss) is a factor that sets the level of water loss in the stream due to evapotranspiration.

FGL (fractional groundwater loss) depicts a portion of water from the groundwater store as permanent loss to the deeper aquifer systems.

Each set of 10 parameters forms a rural (pervious) catchment characteristic set; 10 sets were used in the Patawalonga model.



A	= effective rainfall = d(t) = rf(t) + im(t-1) – **IS** = B + C
Fact	= function [**MSM**, **CD**]
B	= to runoff component
	= d(t)***fact**
	= surface flow to stream + infiltration to groundwater store
C	= to soil store component = d(t)*(1-**fact**)
Surface flow	= sf(t) = d(t)*fact*(1-**GWR**)
Infiltration	= fg(t) = d(t)*fact***GWR**
Seepage	= s(t) = im(t-1)*(1-**SWM**)
Interflow	= if(t) = s(t)*[sm(t-1)***SMD**]
D	= to soil store component = seepage – interflow = s(t) – if(t)
Soil store	= sm(t) = C + D – e(t)
Evaporation loss	= e(t) = [Evap(monthly)/days]***PF**
Baseflow	= bf(t) = gm(t-1)***GWD**
Groundwater store	= gm(t) = gm(t-1) – bf(t) + fg(t) = gm(t-1)[1-**GWD**] + fg(t)
Deep percolation	= gm(t-1)***FGL**
E	= runoff = surface flow + interflow + baseflow = sf(t) + if(t) + bf(t)
Stream loss	= E(mm)*Evap(day)***CL**
t	= current day t-1 = previous day Evap = evaporation (mm)

Figure 27. WC-1 model

Interception store

The maximum capacity of the interception store is specified by the value IS. This simulates interception by trees, vegetation and groundcover and storage in surface depressions. When the interception store reaches its specified capacity, it overflows to the soil store as effective rainfall d(t) where t represents the current daily time step. Part of the water in the interception store percolates down to the soil storage as 'seepage flow' s(t). The factor SWM determines the transfer rate of seepage. Where water travels laterally through the aerated soil material to a stream before reaching the groundwater table, part of the seepage flow is apportioned as interflow. SMD, which is usually a very small number, is used to determine the proportion of interflow. Interflow is a component of surface runoff entering a stream. For the Patawalonga catchment model, this parameter is set to zero.

Soil store

Most of the surface runoff is calculated on the basis of the surface area of saturated soil within the catchment. The runoff is the product of the extent of the saturated surface area of the catchment and the effective rainfall (d)t less the proportion that goes to GWR.

Two parameters, both measured in mm, are used to determine the extent of the saturated surface area: MSM and CD. The first specifies the maximum soil moisture storage capacity at the median point within the catchment and the second determines the standard deviation from this value of the soil moisture storage capacities across the remainder of the catchment. If the calculated daily soil storage value is equal to MSM, then 50% of the catchment area will be saturated and will contribute to surface runoff. The runoff volume is the product of 50% of the catchment area times the effective rainfall less the groundwater recharge. If soil storage is less than MSM minus three times CD, the saturated area will be zero, the soil is completely dry and the catchment would not produce any surface runoff. On the other hand, if soil storage reaches MSM plus three times CD or above, then 100% of the catchment area is considered saturated and contributing to surface runoff.

A more elaborate explanation on the calculation of surface runoff from a contributing saturated catchment area can be found in Cresswell (2000). The explanation includes a hortonian component of surface flow, which has been not included here, but is generally small.

Groundwater store

Part of the water held in the soil store infiltrates down to the groundwater store, which in turn can generate baseflow. Part also percolates down to the deeper regional aquifer where the water is permanently loss from the system. Baseflow is part of the runoff in a stream. Water infiltrating down to the groundwater store is calculated as the product of the contributing saturated catchment area, multiplied by the effective rainfall (d)t and the rate of GWR. Baseflow is then calculated as the product of the current level of the groundwater store and the rate of GWD. The water percolating down to the deeper regional aquifer is calculated as the product of the groundwater store and the FGL.

Text drain node

Heathfield WWTP is located outside the Patawalonga catchment but just upstream of the Upper Sturt River. It discharges its daily effluent into the Sturt River. To simulate the wastewater discharges, a flow file containing the daily records of the discharge volume is entered in the text drain node (Fig. 28). In this case, the discharge records are contained in the file 504931_HF_Fr1981a.flo. The daily flow is obtained by dividing the discharge of that month by the number of days of the month, where only monthly discharge records exist,

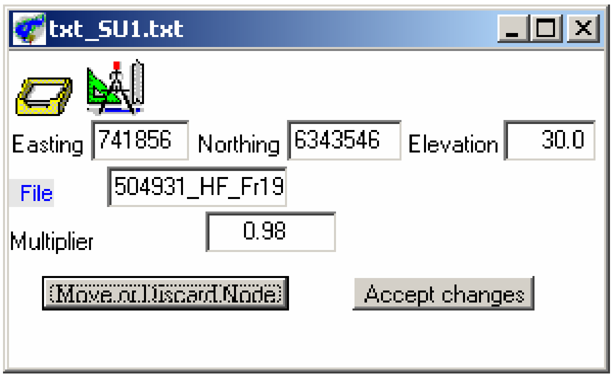


Figure 28. Text drain node representing HWWTP wastewater discharge

Farm dam nodes

The key information required for the farm dam nodes includes:

- aggregated dam storage volume (ML)
- surface area (km^2) and volume (ML) relationship (defined by F1 and F2 factors)
- 'internal annual use as a fraction of storage' which is the annual use of water as a fraction of the storage capacity (assumed 30% and 100% for the study)
- 'demand distribution' which is the monthly pattern of use of dam water (take type '3' for summer irrigation only)
- monthly pan factor is used to adjust the records of pan evaporation to estimate the evaporation losses from the surface area of the dams (take 0.7 for each month).

The data are entered as shown in Figure 29.

There are 229 farm dams identified in the Patawalonga catchment, with 22 (greater than 5 ML) being the irrigation dams and the remaining 207 the stock and domestic dams. The dams are located mainly in the Adelaide Hills catchments. For modelling purposes, the surface area and storage capacity of the farm dams located within each subcatchment are both aggregated and treated as a single large dam. The dam is then modelled in the WaterCress model as an off-stream dam node.

The use of the off-stream dam node allows some or all of the catchment runoff to not fill the dam directly but to be diverted to it by a limited capacity pump or weir. This provides a more flexible means for predicting the proportion of catchment runoff entering the dam. (With an on-stream dam, all catchment runoff will drain into the dam until it is filled. Only then will it overflow to downstream. By selecting a diversion factor equal to one for the off-stream dam, the dam will act as an on-stream dam).

The diversion factor is selected after investigation of the spatial distribution of farm dams within each subcatchment. The factor should approximately equal the proportion of the catchment area in which the runoff is likely to be impacted by the farm dams within the catchment.

In the model set up, there is no distinction made between irrigation dams and stock and domestic dams. All the volumes are aggregated and treated as irrigation dams.

In the absence of field information on the actual level of dam storage used annually, the usage is assumed to be 30% of its storage capacity. This level of usage is adopted by many studies in South Australia. It is considered reasonable on a macro-catchment level, as backed up by DWLBC study (McMurray 2003). Modelling based on this percentage of usage also gives a more conservative natural flow with some farm dam storage carry over to next year.

Irrigation is assumed to occur only in the summer months and the distribution of monthly usage drawn from the dam storage is shown in Figure 15.

Farm dam data located in the Airport Drain catchment have not been included in the model as the data appear to be dubious.

Diversion weirs and routing nodes

Diversion weirs and routing nodes are added to Patawalonga catchment model to better calibrate the flow records at various gauging stations.

During calibration, it was noted that for certain reaches of a stream, in-stream water losses appeared to be taking place, but these could not be calibrated using the creek loss parameter, CL. Hence in such a situation a weir node is used to divert part of the flow away from the system. The key information used by a diversion weir includes:

- baseflow to pass (ML/day)
- diversion fraction (a constant)
- maximum diversion rate (ML/day)
- specifying the month in which diversion will occurs (monthly).

An example is shown in Figure 30. The location of the diversion weirs and the information related to the nodes can be found in Tables 19–20.

Routing nodes are used to improve the daily flow calibrations by reducing high flows and extending low flows. The node simulates the detention of water in a catchment and its later release. This can greatly improve the daily time-step calibrations. The node uses two variables RF1 and RF2 to calculate the proportion of inflow which is retained in temporary storage within the component and is released later as defined by the function shown in Figure 31.

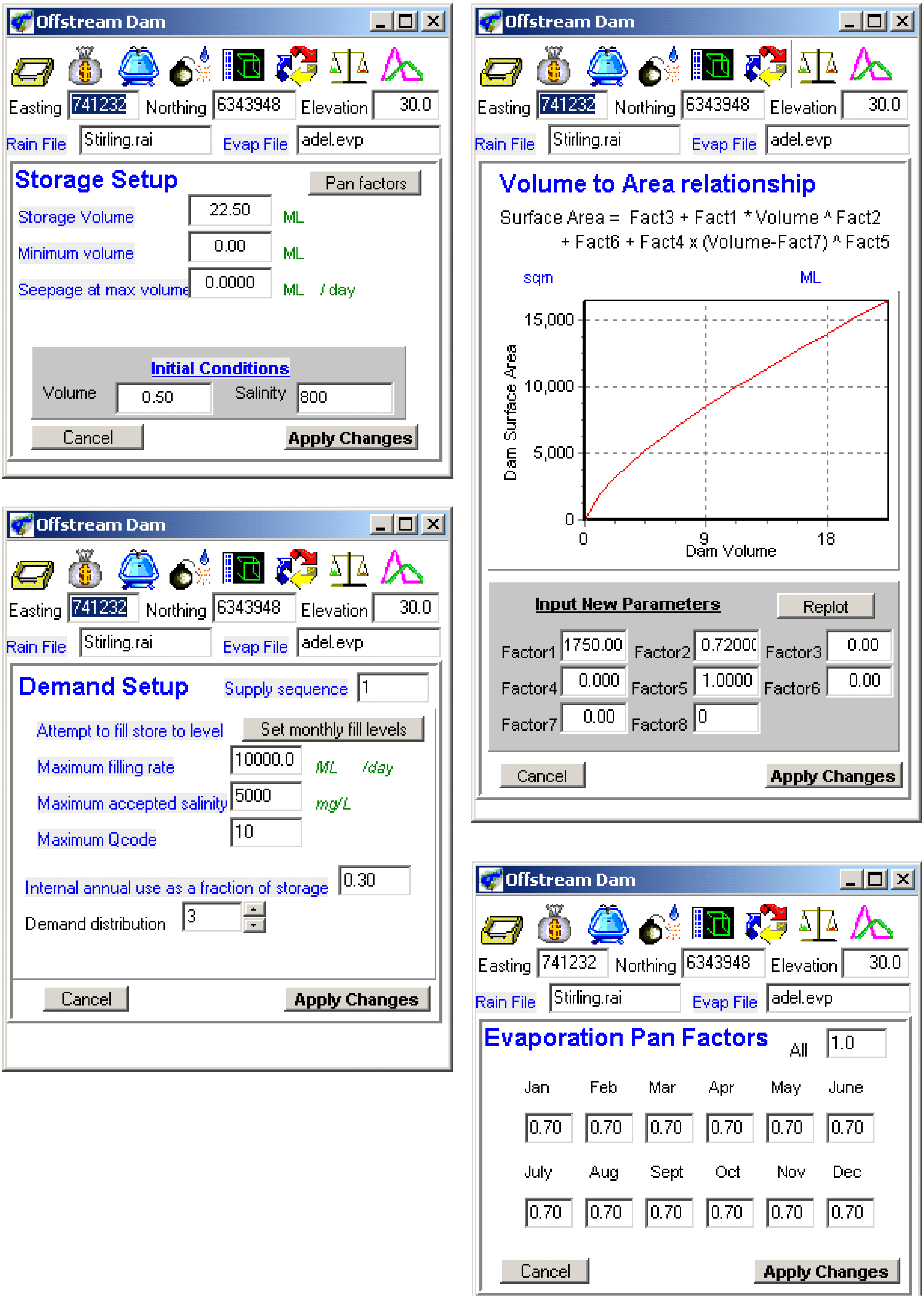


Figure 29. Entering data for farm dam node

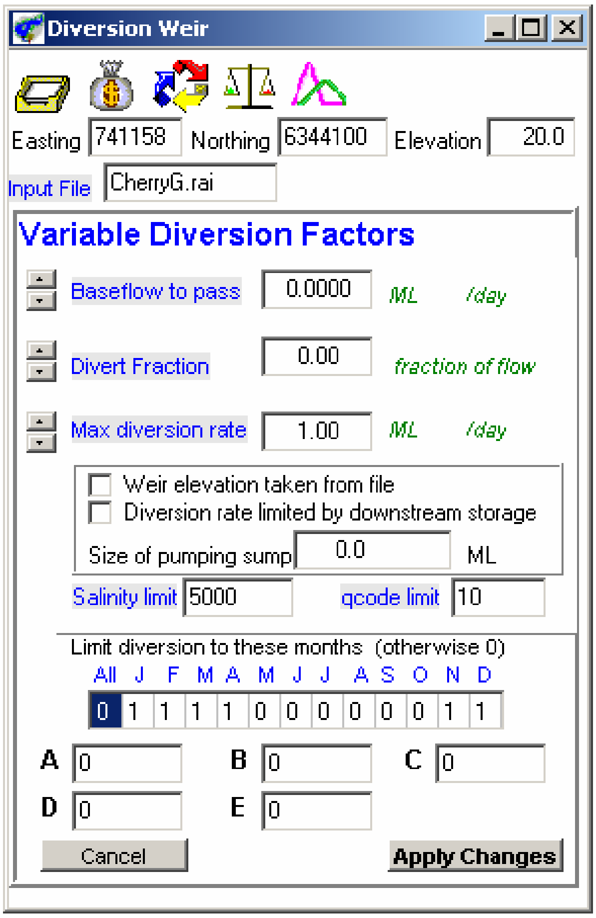


Figure 30. Entering data for diversion weir node

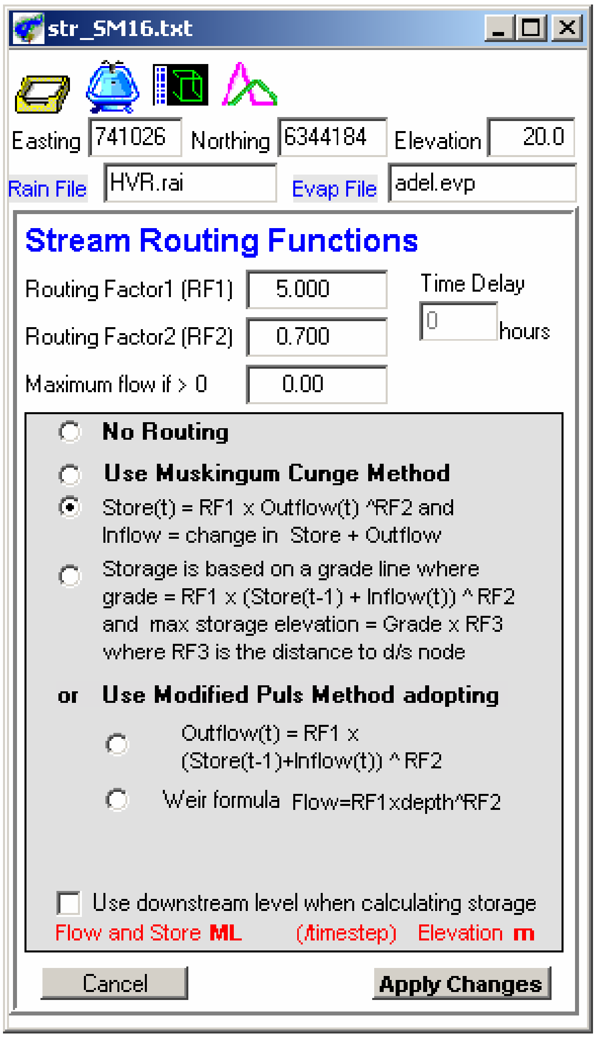


Figure 31. Entering data for routing node

Stream flow data

Streamflow data used for flow calibration are listed below:

- AW504518 Sturt River @ u/s Minno Creek Junction (19.3 km^2)
- AW504519 Minno Creek @ u/s Sturt River Junction (18.3 km^2)
- AW504521 Chambers Creek @ Coromandel Valley (10 km^2)
- AW504530 Sturt River @ u/s flood control dam (60.2 km^2)
- AW504576 Sturt River @ u/s Sturt Rd Mitchell Park (73.3 km^2)
- AW504582 Adelaide Tce Pipe @ d/s West Street (0.9 km^2)
- AW504549 Sturt River @ d/s Anzac Highway (115 km^2 m)
- AW504901 Brown Hill Creek @ Scotch College (17.5 km^2)
- AW504581 Morphett Road Pipe @ transfer station (1.25 km^2)
- AW504583 Brown Hill Creek @ Adel Airport/Morphett Rd (65.8 km^2)

Table 19. Input data to Patawalonga catchment model (a)

Subcatchments			Rural and urban inputs									Rainfall					Farm dams				
No.	SUB_CAT	Sub cat1	Rural char set	Urban char set	Rural node	Urban node	Dam node	Final rural cat	Final urban	% imperv area	Catch area (ha)	Point station (PS)	Isohyet rain at PS, Y	Centroid of isohyet mean, X	Rain factor X/Y	No. of FD	Dam area (m^2)	VOL EST (ML)	F1	F2	O/S dam diversion factor
1	Sturt_Up_1	SU1	1	19	1	231	2	513.8	31.0	6%	544.8	M023745	1 050	1 027	0.98	21	23 105	32.1	1 750	0.74	0.90
2	Sturt_Up_2	SU2	1		3		4	213.7			213.7	M023745	1 050	985	0.94	18	27 727	42.6	1 700	0.74	0.90
3	Sturt_Up_3	SU3	1	19	5	232	6	313.1	6.2	2%	319.3	M023745	1 050	959	0.91	18	16 972	22.5	1 750	0.72	0.80
4	Sturt_Up_4	SU4	1		7		8	293.9			293.9	M023709	910	947	1.04	15	17 852	28.2	1 700	0.71	0.90
5	Sturt_Up_5	SU5	1	19	9	233	10	439.1	3.2	1%	442.4	M023711	750	865	1.15	18	16 231	21.4	1 750	0.73	0.80
6	Sturt_Up_6	SU6	1		11		12	120.8			120.8	M023711	750	825	1.10	5	6 868	11.1	1 300	0.69	0.80
7	Sturt_Minno_01	SM19	3	19	46	234	47	495.2	22.2	4%	517.4	M023704	825	953	1.15	10	12 464	17.7	1 500	0.70	0.80
8	Sturt_Minno_02	SM20	3		48		49	178.4			178.4	M023704	825	815	0.99	1	4 307	8.2	1 020	0.68	1.00
9	Sturt_Minno_03	SM21	3		50			295.7			295.7	M023704	825	845	1.02	0					
10	Sturt_Minno_04	SM22	3		51		52	69.7			69.7	M023704	825	749	0.91	1	25 430	71.2	1 300	0.70	1.00
11	Sturt_Minno_05	SM23	3	19	53	235		87.3	42.3	33%	129.7	M023704	825	709	0.86	0					
12	Sturt_Minno_06	SM24	3	19	54	150		97.5	91.3	48%	188.8	M023711	750	738	0.98	0					
13	Sturt_Minno_07	SM25	3		55		56	74.7			74.7	M023704	825	848	1.03	3	4 035	6.4	1 200	0.68	0.90
14	Sturt_Minno_08	SM26	3		57		58	74.1			74.1	M023711	750	835	1.11	2	1 855	2.5	1 000	0.68	0.70
15	Sturt_Minno_09	SM27	3	19	59	151	60	112.2	46.0	29%	158.2	M023711	750	783	1.04	1	624	0.7	850	0.68	1.00
16	Sturt_Minno_10	SM28	3		61		62	22.3			22.3	M023711	750	812	1.08	1	567	0.6	850	0.68	1.00
17	Sturt_Minno_11	SM29	3	19	63	152		84.3	33.5	28%	117.8	M023711	750	768	1.02	0					
18	Sturt_Mid_01	SM1	1		13		14	110.5			110.5	M023711	750	810	1.08	4	3 159	4.1	1 220	0.68	0.80
19	Sturt_Mid_02	SM2	9	16	15	153	16	118.0	60.4	34%	178.3	M023711	750	777	1.04	3	2 160	2.6	1 130	0.68	0.50
20	Sturt_Mid_03	SM3	8		17		18	38.7			38.7	M023709	910	941	1.03	3	18 379	40.2	1 500	0.70	1.00
21	Sturt_Mid_04	SM4	8		19		20	106.3			106.3	M023709	910	926	1.02	4	3 984	5.2	1 250	0.68	0.90
22	Sturt_Mid_05	SM5	8	16	21	154	22	101.4			101.4	M023709	910	917	1.01	15	17 096	24.3	1 700	0.72	0.90
23	Sturt_Mid_06	SM6	8		23		24	45.9			45.9	M023709	910	907	1.00	7	19 575	38.5	1 500	0.70	1.00
24	Sturt_Mid_07	SM7	8		25		26	447.8			447.8	M023709	910	878	0.97	13	8 730	10.6	1 600	0.72	0.80
25	Sturt_Mid_08	SM8	8		27		28	104.6			104.6	M023709	910	829	0.91	14	11 786	14.9	1 600	0.72	1.00
26	Sturt_Mid_09	SM9	8		29		30	155.0			155.0	M023709	910	796	0.88	1	554	0.6	800	0.68	0.90

Subcatchments		Rural and urban inputs										Rainfall				Farm dams					
No.	SUB_CAT	Sub cat1	Rural char set	Urban char set	Rural node	Urban node	Dam node	Final rural cat	Final urban	% imperv area	Catch area (ha)	Point station (PS)	Isohyet rain at PS, Y	Centroid of isohyet mean, X	Rain factor X/Y	No. of FD	Dam area (m^2)	VOL EST (ML)	F1	F2	O/S dam diversion factor
27	Sturt_Mid_10	SM10	9	16	31	236	32	62.2	22.3	26%	84.5	M023721	665	769	1.16	0					0.50
28	Sturt_Mid_11	SM11	9		33		34	55.8			55.8	M023709	910	783	0.86	1	594	0.7	750	0.68	0.60
29	Sturt_Mid_12	SM12	9		35		36	95.7			95.7	M023709	910	781	0.86	4	3 631	4.6	1 300	0.68	1.00
30	Sturt_Mid_13	SM13	9	16	37	155		285.1	108.3	28%	393.5	M023721	665	736	1.11	0					
31	Sturt_Mid_14	SM14	9	16	38	156	39	163.9	40.1	20%	203.9	M023711	750	741	0.99	1	19 798	55.7	1 300	0.68	1.00
32	Sturt_Mid_15	SM15	9		40			70.1			70.1	M023711	750	715	0.95	0					
33	Sturt_Mid_16	SM16	9	16	41	157		56.7	7.2	11%	63.9	M023721	665	694	1.04	0					
34	Sturt_Mid_17	SM17	10	19	42	158	43	218.2	81.3	27%	299.5	M023711	750	709	0.94	2	9 541	20.0	1 250	0.68	1.00
35	Sturt_Mid_18	SM18	10	19	44	159	45	839.3	176.7	17%	1016.0	M023721	665	641	0.96	5	31 006	77.4	1 450	0.71	0.70
36	Sturt_L01_Dr22	SL1	5	16	64	160		96.8	42.3	30%	139.0	M023703	650	625	0.96	0					
37	Sturt_L02_Dr21	SL2	5	16	66	161		459.5	187.7	29%	647.2	M023703	650	669	1.03	0					
38	Sturt_L03_Dr21	SL3	5	16	67	162		132.4	76.5	37%	208.9	M023703	650	582	0.89	0					
39	Sturt_L04_Dr20	SL4	5	16	68	163		42.4	28.3	40%	70.7	M023004	465	555	1.19	0					
40	Sturt_L05_Drain 6	SL5	5	16	69	164		396.8	192.2	33%	589.0	M023703	650	593	0.91	0					
41	Sturt_L06_Dr4	SL6a	5	16	70	165		455.7	247.5	35%	703.2	M023703	650	580	0.89	0					
42	Sturt_L06_Dr4	SL6b	6	17	125	71	72	30.5	56.7	65%	87.3	M023703	650	530	0.82	0					0.10
43	Sturt_L07_Dr9	SL7	5	16	126	73		21.0	14.0	40%	35.1	M023004	465	524	1.13	0					
44	Sturt_L08_Dr8	SL8	5	16	127	74		19.1	12.7	40%	31.8	M023004	465	518	1.11	0					
45	Sturt_L09_Dr19	SL9	5	16	128	75		38.8	25.8	40%	64.6	M023004	465	505	1.09	0					
46	Sturt_L10_Dr7	SL10	5	16	129	76		51.6	34.4	40%	86.0	M023004	465	521	1.12	0					
47	Sturt_L11_Dr3_a	T11a	5	16	130	77		204.6	136.4	40%	341.0	M023010	610	551	0.90	0					
48	Sturt_L11_Dr3_b	T11b	5	16	131	78	79	82.0	53.9	40%	135.9	M023004	465	511	1.10	0					0.10
49	Sturt_L12_Dr2_a	T12a	5	16	132	80	87	245.4	163.6	40%	409.0	M023010	610	526	0.86	1	563	0.6	800	0.68	1.00
50	Sturt_L12_Dr2_b	T12b	5	16	133	81	82	266.9	136.0	34%	402.8	M023004	465	501	1.08	0					0.10
51	Sturt_L13_Sturt_CKDrain_a	T13a	5	16	134	83	84	131.6	82.3	38%	213.9	M023004	465	554	1.19	0					0.10
52	Sturt_L13_Sturt_CKDrain_b	T13b	5	19	135	85	86	25.9	7.4	22%	33.4	M023004	465	475	1.02	0					0.10

Subcatchments		Rural and urban inputs										Rainfall					Farm dams				
No.	SUB_CAT	Sub cat1	Rural char set	Urban char set	Rural node	Urban node	Dam node	Final rural cat	Final urban	% imperv area	Catch area (ha)	Point station (PS)	Isohyet rain at PS, Y	Centroid of isohyet mean, X	Rain factor X/Y	No. of FD	Dam area (m^2)	VOL EST (ML)	F1	F2	O/S dam diversion factor
53	Sturt_L14_Dr1	T14	5	19	136	88	89	247.3	158.2	39%	405.5	M023010	610	493	0.81	0					0.10
54	Sturt_L15_Dr16	T15	5	19	137	90	91	33.5	22.3	40%	55.8	M023004	465	474	1.02	0					0.10
55	PatCkCat_01_ Dr18_a	LP1a	5	19	190	189		25.5	17.0	40%	42.4	M023004	465	489	1.05	0					
56	PatCkCat_01_ Dr18_b	LP1b	5	19	192	191		166.7	111.1	40%	277.8	M023004	465	473	1.02						
57	PatCkCat_02_ GlenelgNorth	LP2	5	19	194	193		12.8	8.5	40%	21.3	M023004	465	468	1.01	0					
58	PatCkCat_03_ WestBeach	LP3	5	19	196	195		68.4	10.0	13%	78.4	M023002	462	464	1.00	0					
59	KW_Cat_01_ GlenOsmond_Ck	K1	5	19	117	147	118	681.2	228.2	25%	909.4	M023005	620	647	1.04	2	848	0.9	930	0.68	0.70
60	KW_Cat_02_ EasternSub	K2	5	19	143	119	120	380.3	237.9	38%	618.2	M023005	620	640	1.03	2	5 300	9.2	1 250	0.68	0.70
61	KW_Cat_03_ Parklands	K3	5	19	144	121		226.9	82.5	27%	309.4	M023000	505	563	1.11	0					
62	KW_Cat_04_ WestParklands	K4	5	19	145	122		45.4	53.9	54%	99.3	M023000	505	518	1.03	0					
63	KW_Cat_05_ Keswick	K5	5	19	146	123		673.4	346.1	34%	1019.5	M023000	505	508	1.01	0					
64	Coastal_01_ SouthCoastal	C1	5	19	167	166		314.1	86.4	22%	400.5	M023721	665	516	0.78	0					
65	Coastal_02_Dr10	C2	5	19	169	168		529.9	150.2	22%	680.0	M023721	665	565	0.85	0					
66	Coastal_03_Dr11	C3	5	19	171	170		293.8	195.9	40%	489.7	M023721	665	535	0.80	0					
67	Coastal_04_Dr13	C4	5	19	173	172		36.2	24.2	40%	60.4	M023004	465	487	1.05	0					
68	Coastal_05_Dr12	C5	5	19	175	174		139.0	92.7	40%	231.7	M023004	465	517	1.11	0					
69	Coastal_06_Dr14B	C6	5	19	177	176		32.9	22.0	40%	54.9	M023004	465	475	1.02	0					
70	Coastal_07_Dr14C	C7	5	19	179	178		221.7	147.8	40%	369.5	M023004	465	497	1.07	0					
71	Coastal_08_Dr14A	C8	5	19	181	180		52.7	35.1	40%	87.8	M023004	465	472	1.02	0					
72	Coastal_09_15A	C9	5	19	183	182		58.1	38.8	40%	96.9	M023004	465	474	1.02	0					
73	Coastal_10_Dr15B	C10	5	19	185	184		87.0	58.0	40%	145.0	M023004	465	481	1.03	0					

	Subcatchments							Rural and urban inputs						Rainfall					Farm dams		
No.	**SUB_CAT**	**Sub cat1**	**Rural char set**	**Urban char set**	**Rural node**	**Urban node**	**Dam node**	**Final rural cat**	**Final urban**	**% imperv area**	**Catch area** (ha)	**Point station** (PS)	**Isohyet rain at PS, Y**	**Centroid of isohyet mean, X**	**Rain factor X/Y**	**No. of FD**	**Dam area** (m^2)	**VOL EST** (ML)	**F1**	**F2**	**O/S dam diversion factor**
74	Coastal_11_Glenelg	C11	5	19	187	186		19.2	12.8	40%	32.0	M023004	465	470	1.01	0					
75	BH_01	B1	2		92		93	251.5			251.5	M023704	825	895	1.09	3	3 235	4.4	1 200	0.68	0.80
76	BH_02	B2	2	19	94	229	95	191.7	8.3	4%	200.0	M023704	825	900	1.09	1	512	0.6	750	0.68	1.00
77	BH_03	B3	2		96		97	113.8			113.8	M023005	620	754	1.22	2	3 068	4.5	1 100	0.68	1.00
78	BH_04	B4	2	19	98	230	99	341.7	2.9	1%	344.6	M023704	825	910	1.10	6	4 379	5.6	1 350	0.68	1.00
79	BH_05	B5	2	19	100	206	101	286.7	25.3	8%	312.0	M023704	825	991	1.20	4	7 772	12.3	1 350	0.70	0.80
80	BH_06	B6	2	19	102	205	103	512.0	16.9	3%	528.9	M023704	825	756	0.92	5	4 421	5.6	1 350	0.69	0.90
81	BH_07	B7	4	19	104	148	105	254.7	94.5	27%	349.1	M023010	610	625	1.03	1	707	0.8	850	0.68	0.50
82	BH_08_Urrbrae	B8	4	19	106	149	107	379.6	67.8	15%	447.4	M023005	620	643	1.04	3	21 010	48.6	1 350	0.71	1.00
83	BH_09_a	B9a	4	19	138	108		260.0	173.3	40%	433.3	M023010	610	548	0.90	0					
84	BH_09_b1	B9b1	4	19	139	109	110	51.3	119.7	70%	171.0	M023000	505	483	0.96	0					
85	BH_09_b2	B9b2	6	19	140	111	112	41.2	96.1	70%	137.3	M023000	505	480	0.95	0					
86	BH_10_Mooringe	B10a	6	19	141	113	114	43.9	81.1	65%	125.0	M023002	462	478	1.04	0					
87	BH_10_Mooringe	B10b	7	19	142	115	116	62.1	144.9	70%	207.0	M023002	462	479	1.04	0					
88	AirportDr_Cat_01	AP1	5	17	198	197		462.1	262.2	36%	724.3	M023002	462	474	1.03	0					
89	AirportDr_Cat_02_AdelAirport	AP2	5	17	200	199		884.5	63.1	7%	947.6	M023002	462	469	1.02	8	18 252	34.9			
90	AirportDr_Cat_03_WestBeach1	AP3	5	17	202	201		26.5	17.7	40%	44.1	M023002	462	462	1.00	0					
91	AirportDr_Cat_04_WestBeachReserve	AP4	5	17	204	203		127.6	1.6	1%	129.2	M023002	462	465	1.01	0					
	Grand Total							**17 898**	**5 585**	**24%**	**23 483**										

Table 20. Input data to Patawalonga catchment model (b)

Location of gauging station	Node #	Area (ha)	Remarks	
AW504518	10	1 935	Dam node	SturtMinno
AW504519	152	1 827	Urban node	MinnoCk
AW504521	30	1 000	Dam node	ChambersCk
AW504530	157	6 017	Urban node	SR_FloodControlDam
AW504549	84	11 498	Dam node	SR_AnzHw
AW504561	189	42	Urban node	GlenelgCat_FrederickSt
AW504575	112	6 245	Dam node	BH_AdelAirPt
AW504576	65	7 472	Dam node	SR_MitchellPk
AW504580	110	3 152	Dam node	BH_KeswickCk
AW504581	114	125	Dam node	MorphettRd_TransferStn
AW504582	72	87	Dam node	AdelTcePipe_WestSt
AW504583	116	6 577	Dam node	BH_AdelAirPt_MorphettRd
AW504901	103	1 751	Dam node	BH_ScotchCollege
AW504931	227		Text drain	Heathfield WWTP discharge file

Diversion nodes

Subcatchment	Node #	BASEFLOW	Div fraction	Max DR	Limit diversion	Remarks
B6	212	0	1	5	All	
K5	213	0	0.9	3	May–Oct	
K1	214	0	0.9	5	All	
K2	215	0	1	2	All	
B6a	216	0	1	5	All	
SM29	221	0	0.7	1	Jan–Apr; Nov–Dec	
SU5	222	0	1	0	All	
SM9	224	0	0	1	Jan–Apr; Nov–Dec	
SM2	226	0.5	0.55	8	All	
B9b1	237	0	0.9	3.5	All	d/s of urban node N#109

Miscellaneous	Node #	Area (ha)	Remarks
Dummy catchments and other nodes not used in modelling	219	700	rural node
	220	850	town node
	238		routing node
	211		on-stream dam

D. CONTRIBUTING AREAS TO IMPERVIOUS CATCHMENT RUNOFF

From: Kemp, David (DTUP)
Sent: Wednesday, 18 August 2004 11:34 AM
To: Teoh, Kim (DWLBC)
Subject: RE: Brown Hill Creek

Kim, the area I gave you represents the total impervious area connected to the street drainage system, including roads, roofs, driveways etc. Other impervious areas exist within the catchment, but these drain to pervious areas and therefore contribute no runoff most of the time.

David.

-----Original Message-----

From: Teoh, Kim (DWLBC)
Sent: Wednesday, 18 August 2004 10:17 AM
To: Kemp, David (DTUP)
Subject: RE: Brown Hill Creek

David,

Is this impervious area meaning consists of roof, house/industrial pavement and road areas or something else?

Kim Teoh
Engineering Hydrologist
Surface Water Group
Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

Table 21. Contributing areas to impervious catchment runoff (provided by Dr David Kemp)

	Area (ha)	**%Imp**	**Imp**	**Perv**
Belair Road	332	21	69.7	262.3
Hawthorn	140	25	35	105
Urrbrae	375	11.3	42.3	332.7
Kitchener	51	22	11.22	39.78
Anzac	260	25	65	195
AW504580	132	30	39.6	92.4
Junction	400	41.9	167.7	232.3
Morphett Road	153	27	41.3	111.7
Mile End	233	59.2	137.9	95.1
Keswick	65	35	22.75	42.25
Goodwood Rd	194	27	52.38	141.62
South Rail Xing	37	25	9.25	27.75
Park 23	86	70	60.2	25.8
Tapleys	283	33.4	94.7	188.3
Glen Osmond Road	64	28	17.9	43.1
Hutt Street	18	50	9	9
Pulteney / King William	65	50	32.5	32.5
Parkside	40	28	11.2	28.8
parklands	123	0	0	123
Windsor	190	23.1	43.9	146.1
Charles	300	23.1	69.3	230.7
Beaumont	380	21.2	80.5	299.5
Glenside	310	26.0	80.5	229.5
overall	4 231	28.2	1 193.8	3 034.2

UNITS OF MEASUREMENT

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

Name of unit	Symbol	Definition by other metric units	
millimetre	mm	10^{-3} m	length
metre	m		length
kilometre	km	10^{3} m	length
hectare	ha	10^{4} m^{2}	area
litre	L	10^{-3} m^{3}	volume
kilolitre	kL	1 m^{3}	volume
megalitre	ML	10^{3} m^{3}	volume
gigalitres	GL	10^{6} m^{3}	volume
millimeter per year	mm/a		
megalitres per year	ML/a		
gigalitre per year	GL/a		

GLOSSARY

Abbreviations commonly used within text

Board	Patawalonga Catchment Water Management Board
cat	catchment
CBD	central business district
CD	catchment standard distribution
CFS	Country Fire Services
CL	creek loss
DIV	diversion
d(t)	effective rainfall where t represents the current daily time step
d/s	downstream
DWLBC	Department of Water, Land and Biodiversity Conservation
EST	estimate
FGL	fractional groundwater loss
GIS	geographic information system
GWD	groundwater discharge
GWR	groundwater recharge
IL	initial loss
imp	impervious
IS	interception store
LFBP	low flow by pass
MSM	median soil moisture
Perv	pervious
PF	pan factor
PIRSA	Primary Industries and Resources, South Australia
O/S	off-stream
QC	quality code
RF	rainfall
RO	runoff
S&D	stock and domestic
s(t)	seepage flow where t represents the current daily time step
SKM	Sinclair Knight Merz
SMD	soil moisture discharge
SWM	store wetness multiplier
u/s	upstream
WOFD	without farm dam
WOLFBP	without low flow bypass
WWTP	wastewater treatment plant

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Personal communications

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