Technical Report

Adelaide Coastal Waters Study

Stage 2 *Research Program 2003 - 2005*

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Audit of contemporary and historical quality and quantity data of stormwater discharging into the marine environment, and field work programme

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Audit of contemporary and historical quality and quantity data of stormwater discharging into the marine environment, and field work programme

Authors

Jeremy Wilkinson, John Hutson, Erick Bestland and Howard Fallowfield

Flinders University of South Australia
GPO Box 2100,
Adelaide SA 5001

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Executive Summary

The degree to which the quality and quantity of stormwater runoff from catchments and drainage systems in the ACWS area has been characterised varies greatly. There are 23 major and minor catchments in the ACWS study area ranging from the Gawler River in the north to the South Sellicks catchment. Of the 23, six are minor coastal areas in the southern area which have little or no surface drainage. The Barker Inlet receives runoff from 4 of these catchments and is the subject of a study by EPA, so will not be the subject of further investigation by the ACWS.

The Metropolitan Adelaide water supply network operated by SA Water has a major impact on the natural flows of a number of the catchments, in particular the Torrens and Onkaparinga. Where water supply management operations and infrastructure effectively split the catchments, only those areas downstream of the water supply systems have been considered as stormwater contributing areas and for the purpose of catchment area and landuse characterisation. The Gawler River and Smith / Thompson Creek drain into the northern zone of the coast, the southern limit of which is Barker Inlet mouth. To the south of Barker Inlet to Port Stanvac, the Torrens and Patawalonga systems and the Patawalonga Coastal catchment are drained by more than 10 storm drains of varying size. The southern central zone receives runoff from the Field River, Christie Creek and the Onkaparinga River.

South of the Onkaparinga Estuary there are 4 catchments of greater than 3000 Ha, Pedler, Maslin, Willunga and Aldinga Creeks. These are predominantly in agricultural and horticultural use and only produce runoff to sea during the wettest months of August, September and October.

The stormflow season is heavily affected by landuse. Those catchments with heavy urbanisation respond to rainfall all year round. The predominantly rural catchments have extreme soil moisture deficit and only produce significant runoff from July to October.

Approximately 70 % of all stormwater run-off is derived from only 30 % of the land with drainage to the coast (i.e. not impounded for water supply).

Of annual flows from the major stormwater sources for two years of overlapping record, the Torrens contributed 29 % of the runoff, the Patawalonga 18%, the Gawler River, Smith Creek and Onkaparinga River produced between 12 and 15 % of the annual runoff. Christie Creek produced 9 % of the annual runoff from only 2 % of the total land area.

Christie Creek presents an anomaly when compared to the other creeks with catchments with a large proportion residential landuse. The catchment discharges, annually, around 4.5 GL more water than would be expected from a catchment of that size with that degree of urban development. That's 130% more flow, or put another way, the current discharge is 2.3 times greater than might be expected. The actual flow volume is equivalent to what might be expected from and catchment of 87 km^2 rather than 37 km^2. This matter is under investigation and it is hoped that the anomaly can be explained in the next IS1 report.

The heavily urbanised Torrens and Patawalonga catchments have composite samplers and hydrometric stations which have provided a continuous record of water quality and quantity since 1996 and 1997, respectively. Weekly composite samples are analysed for a broad suite of determinants including nutrients, metals and suspended material. The Torrens and Patawalonga are heavily urbanised. In 1996 81% of suspended solids, 50 % of nitrogen and 67 % of phosphorus annual load from the Torrens was discharged within a period of two weeks.

Prior to urban development inundation of wetlands provided settlement and attenuation of flow events. The Patawalonga concrete channel was constructed to alleviate flooding, and provides a rapid transit conduit for polluted run-off entering the system. Patawalonga Lake provided an estimated 43 % of annual solids transported by the creek, however, periodic flushing of the lake on high flows would discharge large sudden loads into the coastal zone. Barcoo Outlet largely bypasses the Patawalonga Lake, which is used for stormwater detention. A report in 1974 suggested a number of stormwater mitigation initiatives some of which have recently been implemented and others that are under consideration.

There have been a small number of analyses for pesticides in ACWS stormwaters. These suggest that this potential impact on the coastal ecosystem is not a high priority for further investigation, although more recent data would be of value.

Since its commissioning in 1981 the annual volume of flow from Heathfield WWTP into the Upper Sturt river has risen from 55 to 515 ML, the nitrogen load has risen from 1.5 to 11.8 tonnes/year. Rainfall events of 6 mm or greater in the Sturt catchment produce a storm runoff response within 20 minutes.

The Field River and Christie Creek are monitored in the same way as the Torrens and Patawalonga. Monitoring commenced in 2001, therefore only three years of record are available for these sites. Additional ambient grab sampling is carried-out on a monthly basis. The Field River and Christie Creek are heavily urbanised and produce runoff in response to storms throughout the year. Of the southern creeks, south of and including the Onkaparinga River, only Pedler Creek has hydrometry. All of these sites are grab sampled monthly and analysis for metals, nutrients and suspended materials is carried-out. The Gawler and Onkaparinga Rivers had hydrometry near their outlets (or tidal limit) from the early 1970s to 1988. Flow gauging on the Gawler River was reinstated in 2001. The gauging site in the Onkaparinga has not been reinstated. Both catchments have a very minor urban component and only flow significantly in the winter from June to October.

There is a body of historical data from the early 1970s to early 1980s. The majority of this data was generated from the Gulf St Vincent Water Pollution Studies of the EWS Department of the SA Government. The data focuses on storm runoff from the Central Metropolitan zone; the Torrens, Patawalonga and Holdfast Shores storm drains. The results are focussed on nutrients, suspended and dissolved contaminant loads. Additional summaries of data for the Onkaparinga and Gawler Rivers for 1978 to 1983 exist. These data offer some limited potential for comparing historical and contemporary water quality from a number of the major stormwater systems in the ACWS area.

The ACWS stormwater sampling strategy will concentrate on characterising those discharges which are currently under-represented in the data or are not being investigated by other studies. On this basis the focus of the IS1 SP1 field effort will be on characterising the northern streams; Gawler River and Smith Creek, the five major Holdfast Shores storm drains, and the high flow discharges from the Onkaparinga and those creeks south of the Onkaparinga. Additional grab samples may be collected on selected storms from the existing composite flow proportionally monitored sites. A timetable and program of sampling is provided.

There are two additional composite samplers available to ACWS IS1; these will be deployed on an event response basis. Pipework has been installed in two of the Holdfast Storm Drains to enable sampling. Additional sampling of the Torrens will be undertaken to augment off-shore stormwater plume tracking activities of other ACWS program areas.

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1. Introduction

This report presents an audit of available data collated by the Adelaide Coastal Waters Study (ACWS). The aim of the audit is to assess the suitability of the data for determining;

- the overall loadings of direct stormwater discharges to the ACWS study area,
- the magnitude of storm-induced shock loadings of contaminants from major, minor and storm drain catchments within the study area, and
- the relative contributions of contaminant loads from stormwater, wastewater (and at a later date atmospheric and groundwater sources).

The shortcomings identified in the data will drive the monitoring activities to be undertaken in the field component of the IS 1 sub-program 1 – stormwater monitoring.

This report is not intended to present findings based on existing water quality data. Current and historical data has been used to generate typical loads from wastewater and stormwater and these data are presented in a separate report.

2. Description of the Major Stormwater Sources.

The ACWS study area comprises a north to south survey of the Adelaide coastline from the Gawler River down to Sellick's Beach (Figure 1). The stormwater systems included in this document are only those that discharge directly to the coast.

Figure 1. General location of the ACWS study area

The stormwater drainage systems whose end-points discharge into the ACWS study area have been classified into two main groups each with several sub-groups (Table 1). The main grouping is determined by whether the system is a natural or semi-natural creek or river (class 1), or a storm drain (class 2). The sub-classes in each group merely rank each stormwater system on the basis of size and likely impact. The minor coastal areas, sub-class 1.3, are the smaller indeterminate areas which do not specifically drain into one of the larger catchments, may not have a defined creek and may not produce surface runoff. Sub-class 1.8 is for areas of catchments within impounded and managed water resource zones that are effectively hydrologically isolated from the storm drainage network that discharges to sea. Sub-class 1.9 is for systems that enter the Barker Inlet.

The Barker Inlet is the focus of a major study by EPA. This work will involve composite sampling of the inlet mouth and feeder creeks with the emphasis on nutrient fluxes and budgets. It is anticipated that the results of this study will augment ACWS investigations, and for this reason Barker Inlet will not be discussed in this document. The Class 2 systems are the man-made storm drain network. The first three sub-classes are separated on the basis of catchment area and/or modelled flood flow estimates for the two year return period flood (Q_2). The two-year flood was chosen arbitrarily on the basis that this was the smallest of the available runoff estimates. As will be shown later, the catchment area of the storm drains does not necessarily determine the magnitude of the two-year flood. The steeper catchments will respond more rapidly and the flows accumulate and concentrate to give shorter duration pulses of greater magnitude than those draining flatter areas.

Sub-class 2.4 are the smaller or otherwise uncharacterised storm drains. These were identified by SARDI and their survey covered the whole of the coastline from Largs Bay to Seacliff (the full list is reproduced as Appendix I). A further visual assessment of certain of these sites is anticipated as part of the field study.

Table 1. Classification of major and minor storm drainage systems in the ACWS study area.

Group	Sub-group	Description	
1		**Semi-natural or natural creek/river systems**	
	1	Major catchments	> 20,000 ha
	2	Major creeks	> 2,000 ha
	3	Minor coastal area	< 2,000 ha
	8	Water supply sub-catchments	
	9	Systems draining to Barker Inlet	
2		**Storm drain network**	
	1	Major storm drain	Q > 200ML*
	2	Intermediate storm drain	100ML < Q > 200ML
	3	Minor storm drain	Q < 100ML
	4	Small beach or dune drain	

*Q is estimated from annual rainfall and volumetric runoff coefficients as presented in Section 5.1.

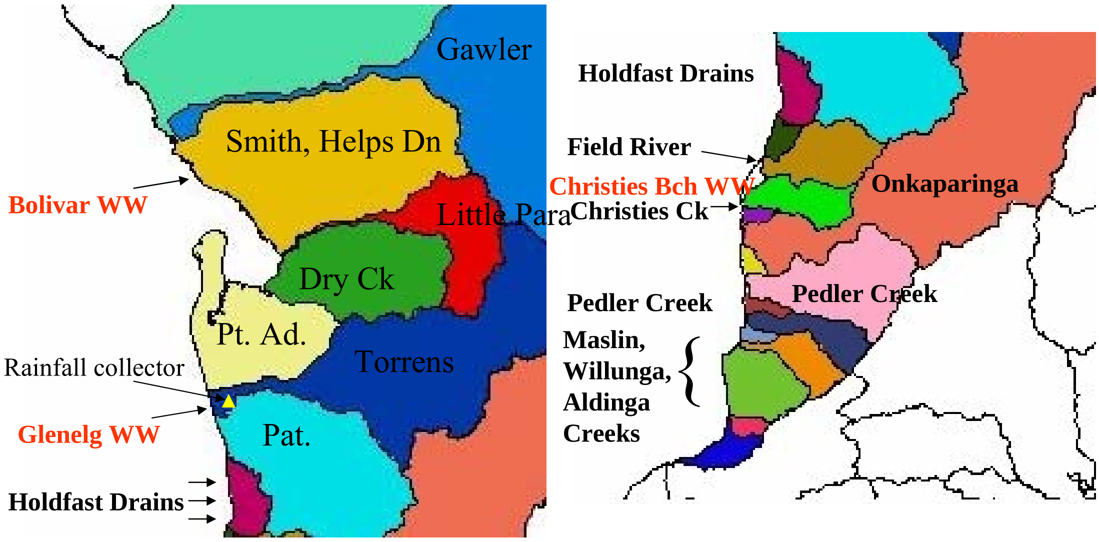


Figure 2. The stormwater catchments of the Adelaide Coastal Waters Study area as listed in Table 3 below.

Table 2 demonstrates that the storm drain systems that discharge directly to the coast comprise a very small component of the total land area. The major catchments comprise the majority of the drainage area discharging to the coast. The area given in Table 2 is the coastal runoff area, i.e., the effective area of the catchment from which regular runoff to the coastal zone is derived. This additional variable is necessary because of the impact of water resource operations on the natural flow regimes of the larger creeks and catchments. The presence of reservoirs and diversion weirs, in these catchments, has a number of implications:

- In general only runoff derived from downstream of reservoirs will reach the coast.
- Runoff quality at the coastline will only reflect the influences of the landuses in the area downstream of the reservoirs.
- Water quality issues in the upper reaches of the impounded catchments will be of minor relevance in the coastal zone.

- Extreme events may cause reservoir spillage, in which case this displaced water may not reflect the landuse in that catchment since it may have a high proportion volumetrically of River Murray water.
- Rainfall-runoff modelling may require adjustment of catchment areas to suit the lower rainfall that occurs in the coastal strip.

Table 2. Total catchment area of each stormwater system classification

	Area (km^2)	Group
Major catchment	**1691.7**	1.1
Major Creek	**294.7**	1.2
Coastal catchment	**25.2**	2.0
Minor coastal area	*54.9*	1.3
Barker Inlet drainage	*407.8*	1.9
Water supply network	*1004.3*	1.8
Total	3478.6	

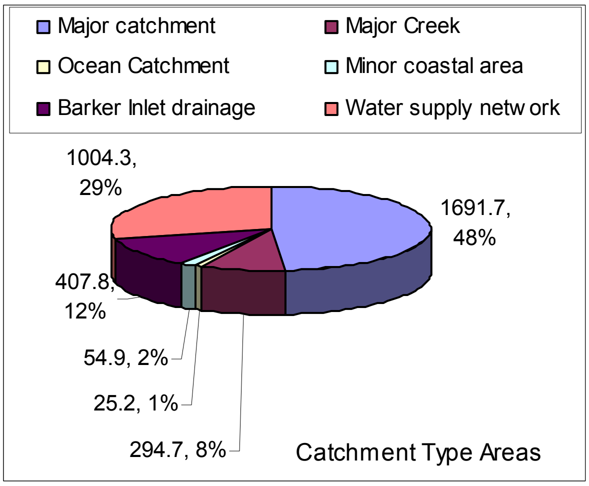


Table 3 provides a listing of the outlets of major and minor rivers, creeks and stormwater drainage systems within the ACWS area. The systems are listed from north to south in order of their occurrence along the coastline. The table includes total catchment area in hectares to indicate the extent of the catchment.

Table 3. North to south listing of major and minor stormwater drainage systems in the Adelaide Coastal Waters Study area, including areas contributing to the water supply system.

Number	Name	Area (ha)	Group	Classification (% area impounded)
1	a. Gawler River	88330	1.1	Major catchment
	b. South Para and Barossa reservoirs	23600	1.8	Water supply network (21.1%)
2	Thompson Ck, Smith Ck	20560	1.1	Major catchment
3	Helps Rd, Adams Creek	12400	1.9	Barker Inlet drainage
4	a. Little Para River	1161	1.9	Barker Inlet drainage
	b. Little Para reservoir	8300	1.8	Water supply network (87.7%)
5	Dry & Cobbler Creeks	14224	1.9	Barker Inlet drainage
6	Port Adelaide	12992	1.9	Barker Inlet drainage
7	a. Torrens drainage	21848	1.1	Major catchment
	b. Torrens watershed	28287	1.8	Water supply network (56.4%)
8	Patawalonga Basin	21239	1.1	Major catchment
9	Coastal catchment (9.1 to 9.10)	2521		Urban stormwater
9.1	Pier St, Glenelg	148	2.2	Intermediate storm drain
9.2	The Broadway, Glenelg South	96	2.2	Intermediate storm drain
9.3	Marine St, Somerton Park	83	2.2	Intermediate storm drain
9.4	Harrow Rd, Somerton Park	341	2.1	Major storm drain
9.5	Downing St, Hove	23	2.3	Minor storm drain
9.6	Wattle Ave, N Brighton	213	2.1	Intermediate storm drain
9.7	Jetty Rd, Brighton	22	2.3	Minor storm drain
9.8	Edwards St, Brighton	472	2.1	Major storm drain
9.9	Young St, Seacliff	600	2.1	Major storm drain
9.10	Wheatland St, Seacliff	11	2.3	Minor storm drain
10	Waterfall Creek	958	1.3	Minor coastal area
11	a. Field River	3616	1.2	Major Creek
	b. Happy Valley Reservoir catchment	1913	1.8	Water supply network (34.6%)
12	Christie Creek	3779	1.2	Major Creek
13	a. Lower Onkaparinga River	17188	1.1	Major catchment
	b. Upper Onkaparinga system	38329	1.8	Water supply network (69.0%)
14	Incorporated with Onkaparinga (OCWMB)	475	1.3	Minor coastal area
15	Incorporated with Pedler Ck (OCWMB)	508	1.3	Minor coastal area
16	Pedler Creek	10738	1.2	Major Creek
17	Incorporated with Pedler Ck (OCWMB)	677	1.3	Minor coastal area
18	Maslin	3392	1.2	Major Creek
19	Incorporated with Willunga Ck (OCWMB)	468	1.3	Minor coastal area
20	Willunga	3027	1.2	Major Creek
21	Aldinga Creek	4919	1.2	Major Creek
22	Sellicks - minor	654	1.3	Minor coastal area
23	South Sellicks catchment	1753	1.3	Minor coastal area
	Total	**347864**	**Ha**	

2.1 Major catchments

The major catchments include the Gawler, Smith Creek system, the Torrens, Patawalonga and Onkaparinga catchments (Table 3). These catchments, except the Patawalonga, each comprise some significant water resource infrastructure which has an impact on the natural flow regime and the total volume discharged to sea.

Gawler River

The first and largest catchment within the ACWS study area is that of the Gawler River. The North Adelaide and Barossa Catchment Water Management Plan 2001-2006 provides good background information on the system and is the main source used here (see NABCWMB, 2000). The catchment is situated approximately 50 km north of Adelaide covering around 1100 km^2. The river has two main sub-catchments which join at Gawler Township to drain along the narrow corridor of the Gawler River to sea. The two sub-catchments are the North and South Para systems, with areas 711 and 399 km^2 respectively. At its highest point the catchment reaches 592 m above sea level in the Wirra Wirra peaks. Mild, wet winters and hot, dry summers characterise the seasonal climate cycle of the catchment. Winter rainfall is frontal in nature and rainfall events tend to be of lower intensity and longer duration than in the summer months (see Appendix II). June, July and August are the wettest months. Intense convective summer rainstorms have resulted in significant floods. After prolonged dry periods the dry soil matrix may be hydrophobic resulting in bypass flow of intense storm rainfall into desiccation cracks and very rapid runoff with little storage or retention of water in the catchment.

The South Para arm of the Gawler system is impounded by the South Para Reservoir (44.8 GL) which isolates a significant area of the upper section of the catchment. The reservoir only spills in very wet years. The South Para reservoir isolates 229 km^2 of the most runoff generating part of the catchment. Rainfall in the Gawler Catchment is significantly influenced by orographic enhancement with annual average rainfall varying between 770 mm in the Barossa Ranges (Pewsey Vale) and 400 mm on the coastal plains (NABCWMB, 2000).

Due to the South Para Reservoir, the majority of the flow in the Gawler River is generated in the North Para system. Pikusa (1999) identified the key run-off producing sub-catchments as the Upper Flaxman Valley and the tributaries draining off the Barossa Ranges including Jacob and Tanunda Creeks (and Angaston Creek if gauged would be similarly important, NABCWMB, 2000). Pikusa (1999) found that the Barossa Valley floor made an insignificant contribution to the total runoff.

Plate 1. The gauging station on the Gawler River at Virginia Park (photo: Surface Water Archive, DWLBC)

The Gawler River did not flow in 2002 and in the period of the 1970s and 1980s discharged around 25 GL/y (Table 4). Since the impoundment of the South Para River these flows have been reduced significantly. Virginia Park is the lowest gauged section on the Gawler River (Plate 1). Downstream of this location the channel follows a series of meanders and straightened sections. There are significant losses in flow downstream of the gauge; these include seepage into the channel, overbank spillage, and storage in Buckland Park Lake (Appendix II). Buckland Park Lake is the terminal lagoon of the river, and a significant seasonal wetland for native water fowl and migratory birds. When full the Lake spills over a causeway into a mangrove channel and out to sea. The combined effect of the losses of water downstream of the Virginia Park gauge is that the gauge does not give a true representation of the volume that actually enters Gulf St Vincent. An assessment of these losses and an indication of the likely flow to see are presented in Section 5 below.

Smith Creek (Munno Para)

This catchment is not well documented. The catchment lies alongside the southern margin of the Gawler River corridor and comprises a number of natural channels and a network of storm drains and linear manmade open channels. In the upper part of the catchment the natural channels drain low denuded hills, where these creeks meet the Sturt Highway they drain into the network of lined concrete channels. These channels follow the road grid collecting storm runoff from the surface water drains of the Munno Para residential area. A stormwater retention lagoon, the Stebonheath Flow Control Park, has been constructed at Munno Para. This retains flows from the upper 84.4 km^2 of the catchment. Downstream of the lagoon, where rainfall is around 400 mm a year, infiltration is likely to prevent any significant runoff from occurring. This observation is supported by Smith (*pers. comm*.) who indicated that the catchment is relatively dry and doesn't contribute a significant volume of flow to the Gulf, unlike the adjacent Helps Road Drain which is more urbanised and has a rapid "flashy" response to rainfall. Helps Road Drain runs off into the Barker Inlet system. At the coast, the Smith Creek joins or runs parallel to the Bolivar WWTP Outflow channel. Thompson Creek joins the channel where it turns to the south-west to run between the coastal lagoons (see Appendix II). In 1991, ECA *et al*. indicated a catchment area of 142.5 km^2 for the Smith Creek catchment and an annual yield of 11.5 GL. The current discharge is estimated as being around 5 GL as a result of the Stebonheath Flow Control Park, the recently constructed stormwater detention wetland on Smith Creek. Should a significant winter storm event generate flow to sea in the Smith Creek, grab sampling will be undertaken in a similar manner to the Gawler River.

Torrens River

The River Torrens Catchment Water Management Plan 2002-2007 provides good background information on the system and is the main source used here (see TCWMB, 2000). The Torrens system has a catchment area of around 500 km^2 and is considered in two distinct regions, a watershed – the upper catchment, and the urban/rural area (see Appendix II). The watershed provides around 20 % of all potable water (35,000 ML) to Metropolitan Adelaide. The watershed contains two major impoundments, Millbrook Reservoir and Kangaroo Creek Reservoir, and the main channel operates as part of the River Murray inter-basin transfer system. For the purposes of the current study, the area of interest is the catchment that contributes stormflow to the discharges that actually reach Gulf St. Vincent. Since Kangaroo Creek Reservoir effectively partitions the catchment, the dam wall is the upper extent of the catchment for storm runoff, isolating flows from the upper catchment from the downstream system. Sixth Creek is within the watershed but joins the main stream downstream of Kangaroo Creek Dam. Thus the effective catchment area is the urban/rural area (162 km^2) plus Sixth Creek (44 km^2), a total of (206 km^2), which is only two fifths of the total catchment area. ECA *et al*. (1991) list this effective stormwater catchment area as 221.1 km^2. This makes the stormwater active catchment equivalent to that of the Patawalonga (see Table 2). There are minor issues in this regard which require further clarification. These are the scale, if any, of compensation flows downstream of Kangaroo Creek Dam, and what impact transfers from the Kangaroo Creek Dam to Gorge Weir might have on discharges to sea. Gorge Weir is a diversion weir for transfer and storage in the Hope Valley Reservoir. As far as the authors are aware, Kangaroo Creek Dam has never spilled.

The urban/rural catchment is home to some 500,000 people living in 156,000 residences, there are around 18,000 commercial and industrial premises (including most of Adelaide's CBD). Annual average rainfall in the urban/rural catchment varies from around 700 mm towards the hills and only 400 mm in the coastal plain. The upper part of the urban/rural catchment includes First to Fifth Creeks. First Creek, above Waterfall Gully, is predominantly undisturbed native vegetation and includes the Cleland Conservation Park. The Third to Fifth Creek contains some horticulture and the Morialta and Black Hill Conservation Parks (TCWMB, 2000). The lower most 3.5 km of the Torrens River is canalised and forms a large storm drain.

The current outlet of the Torrens, Breakout Creek, was constructed in the 1930s. The original channel linked up with the West Lakes system, forming a large wetland known as the Reedbeds, and eventually connecting to the upper reaches of the Port River (Lewis, 1975). The swamps would have provided a transition from relatively fast to slow flowing water affording settlement, seepage and evaporation of storm flows. The creation of Breakout Creek effectively "short-circuited" this system resulting in direct discharge of turbid stormwater into a coastal zone that would have previously received little turbid freshwater. Plate 2 is one of the few documented photographs that demonstrated the impact of turbid flood-waters from the Torrens River; this picture appeared in the Gulf St. Vincent Water Pollution Studies Report (Lewis, 1975).

Plate 2. Turbid floodwaters from the Torrens River in October 1974.

Schulz et al. (2000) undertook a thorough examination of existing water quality data for all of the Torrens monitoring sites of which there are numerous throughout the catchment. Notable conclusions in relation to loadings to the coastal zone were downward trends in suspended solids, total nitrogen and lead at the Holbrooks Road monitoring station. They also highlighted the transient nature of loadings to the coastal zone from the Torrens citing a major runoff event in spring 1996. Of the total loads discharged over a three year period, 81% of the suspended solids, 50 % of the nitrogen and 67 % of the phosphorus were discharged within the space of two weeks.

The Patawalonga System

Before European settlement, the Patawalonga outlet was the only break in sandhills extending from the Outer Harbour south to Seacliff (Lewis, 1975). At that time the Sturt River, Brownhill and Keswick Creeks flowed into an extensive area of swamps behind sandhills, where the water either seeped out beneath the sandhills or via the outlet (Lewis, 1975). The swamps were drained and filled in the mid 1950s and efficient networks of storm drains established. The completion of the concrete lining of the suburban Sturt River channel effectively replaced an efficient stormwater detention and settlement system that discharged at a low and steady rate with a rapid transit system delivering large slugs of turbid freshwater to the coastal zone after each significant rainfall event.

Plate 3. The Patawalonga Outlet in 1974

Plate 4. Stormflow in the Sturt River upstream of ANZAC Highway, following 15 mm of localised rainfall on 27 November 1973 (after, Haughey, 1974).

In addition to the Sturt River and Brownhill and Keswick Creeks, the Patawalonga System includes the Airport Drain. There is also a small local area that drains to the Patawalonga Lake (see Appendix II). Until recently the Patawalonga System drained through the Patawalonga flood gates (Plate 3). The Patawalonga Lake acted as a settling pond for stormwaters; the rapid flows in the concrete channels (Plate 4) resulted in the flushing of the bulk of particulate material downstream. When the turbid waters entered the lake (or basin) the reduction in flow velocities resulted in the deposition of silt and associated particulates. It has been estimated that the Lake removed around 43 % of suspended solids. In the early 1970s recreational activity in the lake was banned due to faecal contamination and the lake bed was dredged and the contaminated material land-filled on the Airport site. Since then the Barcoo Outlet has been constructed, this is a siphonic system that diverts flow, at the upstream end of the lake, underneath the beach to a discharge point a few tens of metres off shore. Flow into the Patawalonga Lake is controlled by sluices which release water into the lake when the capacity of the Barcoo Outlet to drain is exceeded. This system bypasses the Patawalonga Lake effectively short-circuiting contaminated storm flow, from the Sturt River, Brownhill Creek and Airport Drain directly to the coastal zone without the beneficial settlement afforded by Patawalonga Lake.

The Development Assessment Commission advised that the PCWMB should investigate options for upstream water quality treatment in order to reduce the impact of the Patawalonga discharge. Appendix III provides a summary of the findings of the Patawalonga Catchment Management Board Plan for 2002 to 2007. In an early report (Haughey, 1974), a long list of potential locations for stormwater detention ponds was presented, none of these options were implemented since there was insufficient incentive to do so. PCWMB (2002) has since revisited some of these options and the following locations were highlighted; (i) Oaklands Park where a total of 37 Ha of land in State, Commonwealth and Public ownership exists, (ii) the Morphetville Wetland at the racecourse which has been completed (PCWMB, 2003), (iii) South Parklands, and (iv) within the Adelaide Airport boundaries. The risk of “Bird Strike” to aircraft at Adelaide Airport is a serious obstacle to a storm detention lagoon being possible at that location. A wetland at Blackwood Reserve is possible as well as upgrading of the Urrbrae Wetland (PCWMB, 2002).

The average rainfall in the catchment ranges from around 1200 mm in the upper reaches of the Brownhill Creek Catchment, 680 mm in Blackwood on the Sturt Catchment and only 460 mm along the coastal margin (PCWMB, 2002). Flood peaks in the upper part of the catchment occur between 6 and 12 hours after moderate to heavy rainfall in winter. In the summer very heavy rainfall is needed to stimulate significant flow. On the plains, relatively small quantities of rainfall (6 mm) will cause a flow peak which can occur around 20 minutes after the rainfall (Haughey, 1974). Around 310,000 people currently live in 114,000 dwellings and there are around 9,600 commercial and industrial premises. Of the streams that comprise the Patawalonga, the Sturt River is the largest with a catchment area of some 120 square kilometres. The lower portion of the catchment is completely urban. Downstream of Sturt Road, the river channel is a concrete-lined channel (see picture beside). Runoff from the urban catchment discharges directly into this channel via the surface water drainage network.

The human population has impacted directly on the Sturt River via the Coromandel WWTP and the Heathfield WWTP. The Coromandel plant was decommissioned in 1983, and the Heathfield plant commenced discharging in May 1981 (Shultz and Thomas, 2000). Since it commenced operation, the increase in population served by the plant has caused the volume discharged to rise from 0.15 ML/d to 1.4 ML/d in 1997/8 (Shulz and Thomas, 2000). The effluent has low organic and suspended solids content, but is high in nutrients. Table 4 summarises the loads of total nitrogen and phosphorus from Heathfield WWTP and concentrations in the receiving waters. Minno Creek is a parallel branch of the Upper Sturt system and is presented as a control, i.e. a non-WWTP impacted sub-catchment of similar size. The Heathfield works discharges via the Heathfield Creek into the Sturt upstream of the confluence with Minno Creek. Figure 3 demonstrates the relative locations of the Heathfield Works, the Minno Creek confluence and the Anzac Highway monitoring sites. Although the median concentrations presented in Table 4 below indicate a significant reduction in the nutrient concentrations from Heathfield Creek to the Minno Creek confluence, their concentrations remain significantly elevated relative to those of Minno Creek. During dry periods the majority of the flow is effluent. During one extended dry period (December 1994 and April 1994) Schulz and Thomas (1996a) noted that 80 % of phosphorus and 95 % of nitrogen were removed from Heathfield Creek to the Minno Creek confluence. This downstream reduction in nutrients highlights the potential for within channel uptake to reduce the potential impact of dry weather flows on the coastal zone. Table 4 summarises the increases in flow volume from 1982 to 1997/8 and similar increases in loads of nutrients resulting from the Heathfield discharge. Schulz and Thomas (2000) suggested that remobilisation of nutrients sourced from Heathfield WWTP under high flows could be considerable. Despite this possible mechanism, the annual loads of nutrients and monthly loads of nutrients from the Patawalonga system remain small relative to the direct WWTP discharges (see below and Wilkinson et al., 2003).

The Heathfield WWTP has been recently upgraded to provide additional capacity and much improved treated wastewater quality in terms of lower nutrients concentrations. The load of nitrogen and phosphorus will be much reduced. Improvements in quality commenced in October 1993 when a third bio-reactor was commissioned and construction of the new upgrades is expected to be completed late in 2004. The target for phosphorus reduction is from an average of 11 mg/L to 3 mg/L.

Table 4. Impact of the Heathfield WWTP on the Sturt River (data from Shulz and Thomas, 2000).

	Loads (t/y)		Median concentrations (mg/L)				
	1982	1997/8	Minno Creek (control)	Heathfield Creek	Sturt upstream of Minno Ck	Sturt upstream of Sturt Rd	Sturt downstream of Anzac Hwy
Nitrogen	1.5	11.8	0.40	17.10	1.79	0.79	0.89
Phosphorus	0.7	4.2	0.055	6.40	1.93	0.30	0.13
Flow (ML)	55	515					

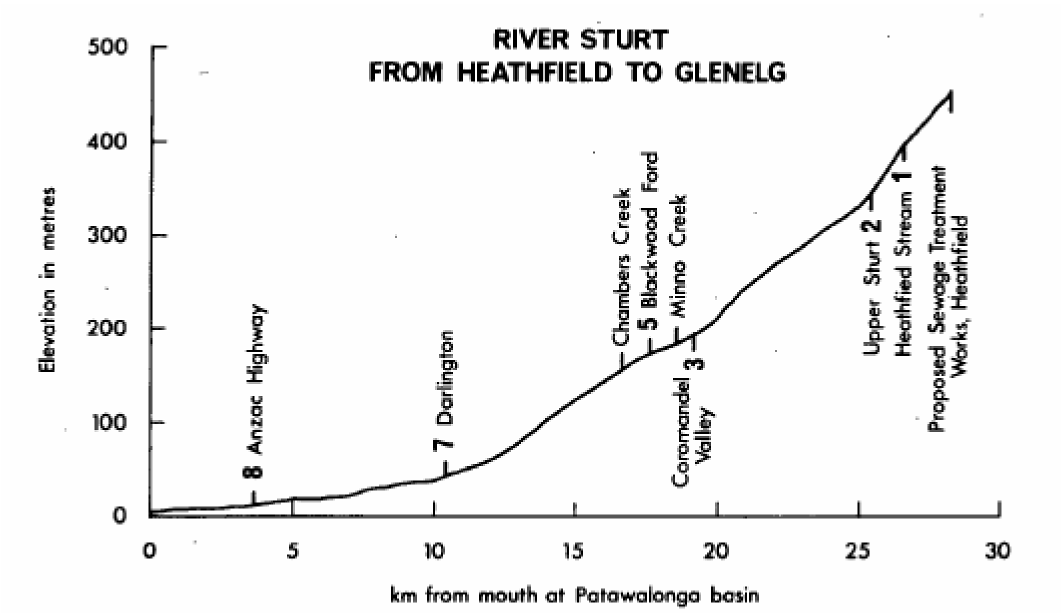


Figure 3. Elevation plan of the Sturt River from the Heathfield WWTP to Patawalonga Lake (after Haughey, 1974).

The other significant sub-catchments of the Patawalonga system are Brownhill and Keswick Creeks and the Airport Drain. Brownhill Creek has an area of approximately 36 km^2 in a catchment whose drainage area is largely defined by the network of manmade storm drains and channels. Keswick Creek has a catchment area of 31 km^2 and is similar in nature to Brownhill Creek. The Airport Drain drains 17 km^2. Other areas within the Patawalonga Catchment Water Management Board area include a small 3 km^2 catchment that drains directly into the Patawalonga Lake and the Coastal catchment (25 km^2) which incorporates the major drains listed in Table 2 and drains the area from Glenelg to Seacliff. A summary of land use in the main catchments is provided in Section 5 below (see also Appendix V).

The Gulf St Vincent Water Pollution Studies investigated the impact of the Torrens and Patawalonga catchments in relation to the decline in seagrass. Figure 4 below demonstrates an early attempt to relate seagrass decline with turbid stormwater slicks from the Patawalonga. The diagram indicates a good correspondence between the stormwater flows and the seagrass decline. Notice also, the presence of the Glenelg WWTP which discharges 300 m off shore within the same zone of decline. Given that the elevated nutrient levels associated with the WWTP have led to excessive epiphyte growth, it would be unrealistic to target either the river discharge or the WWTP in this case. It seems likely that the epiphyte growth would result in the enhancement of particulate entrapment on the plants in addition to the blocking of sunlight by the turbid stormwaters. Thus the combined impact of wastewater and stormwater is more potentially damaging than either source alone. Hopefully the marine biological studies of the other sub-programmes might be able to disentangle these effects to some degree.

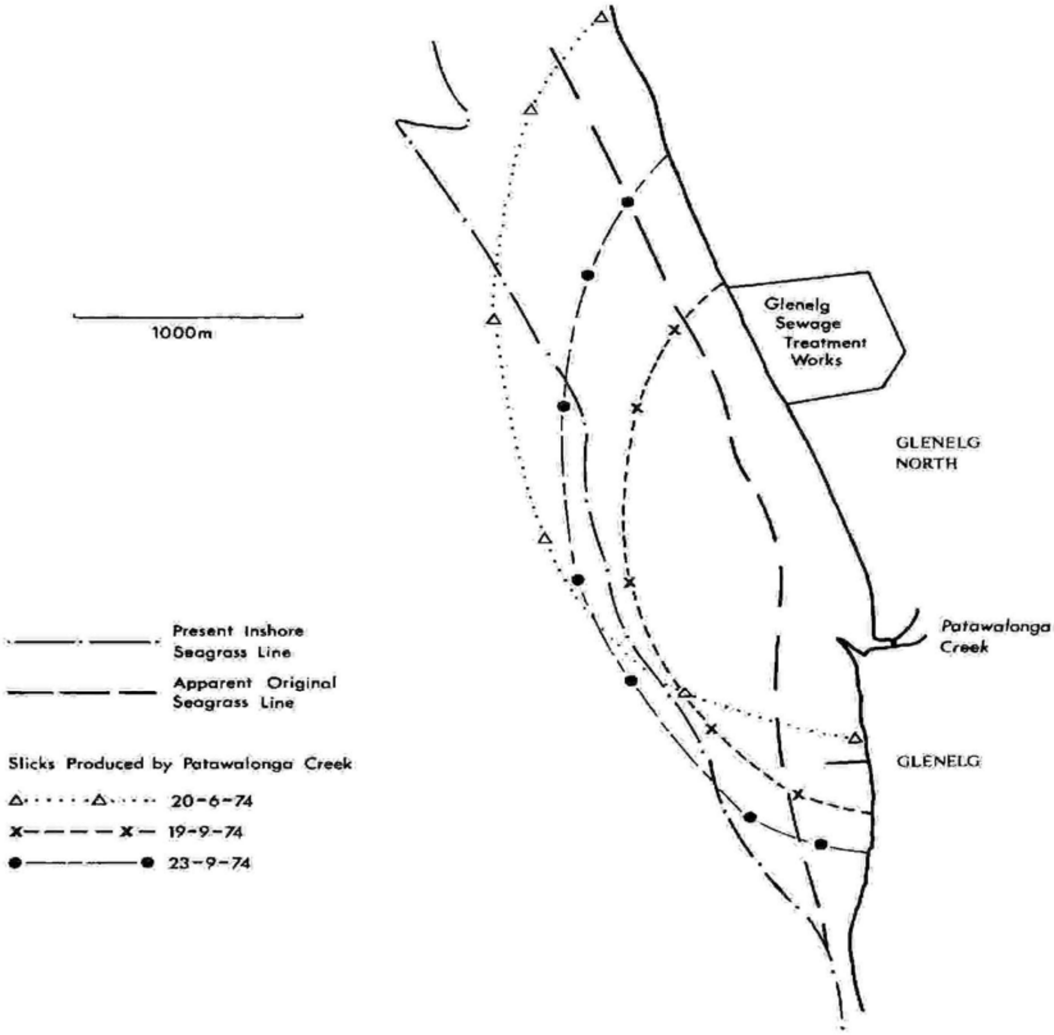


Figure 4. Observed limits of turbid coastal stormwater slicks from the Patawalonga system, showing seagrass line of retreat (after Lewis, 1975).

The Onkaparinga

The Onkaparinga has a large catchment with area of 555 km^2; the catchment is highly impacted by water resource management activities. The Mount Bold Reservoir system, Clarendon diversion weir and the estuary effectively split the catchment into four zones:

1. The watershed to Mt. Bold Reservoir (383.3 km^2).
2. The transfer channel from Mt Bold to Clarendon diversion weir (57.7 km^2).
3. The natural channel from Clarendon Weir to the estuary (86.0 km^2), and
4. The estuarine catchment (28.2 km^2).

The effective catchment area for stormwater generation is 172 km^2, however, there will frequently be no flow beyond Clarendon Weir, and occasionally overspilling of Mt Bold Reservoir will occur. The main channel enters a meandering estuarine channel, the functioning of the estuary means that the determination of loads to the ocean is complicated since cycling of nutrients occurs in the estuary. Prior to dredging in 1985, 100% tidal exchange occurred in the lowest 4 km length of the estuary (Manning, 1986). Dredging was estimated to increase mixing by 20% and reduce the longitudinal range of mixing. Tidal modelling and drogue studies indicated that for an average tide, a packet of water with a mid-tide position of 1.6 km from the estuary mouth would exit the estuary on the ebb. For a spring tide this distance increases to 2.5 km (Manning, 1986). The advection time from the upper tidal limit of the estuary to its mouth was estimated as 50 days by Bye (1984) at a discharge of 0.1 m^3/s (8.64 ML/d).

The total developed area in the Lower Onkaparinga catchment is around 24.6 km^2. The majority of this area drains into the estuary, either directly of via wetlands. These suburbs include Noarlunga Centre, Noarlunga Downs, West Hackham and the southern area of Port Noarlunga. The estuary also receives seepage from the Christie Beach WWTP sludge lagoons located in the estuarine wetlands. Determination of the loads of contaminants from these lagoons is beyond the scope of the current study, although further investigation may provide existing estimates from consultant studies in the grey literature.

The hydrological record for the Onkaparinga is incomplete from 1988, onwards when the lower gauging site was abandoned. Modelling to derive these flows is described in Section 5.

2.2 The major creeks

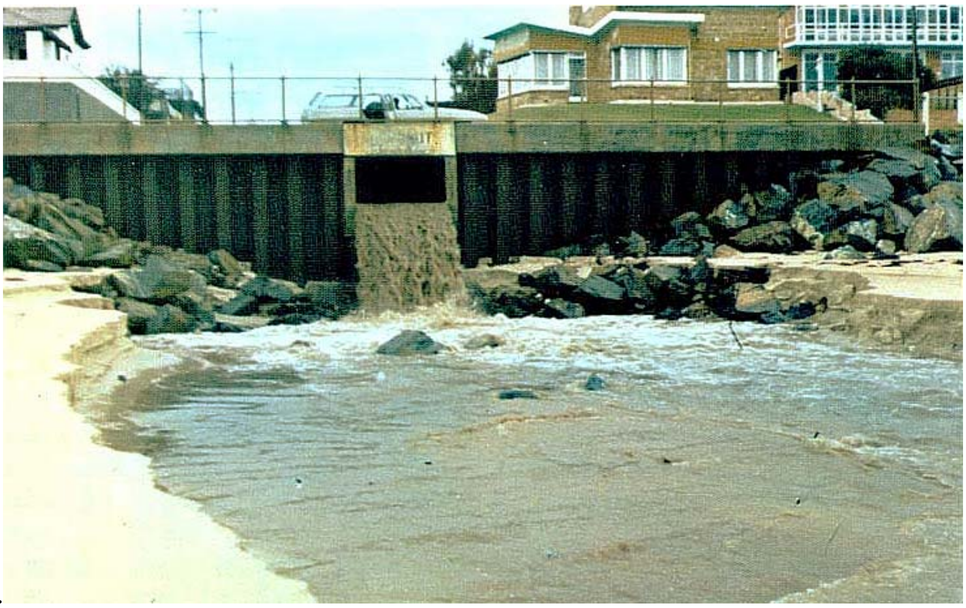
There are six creeks in the Southern Metropolitan Region with catchment areas in excess of 30 km^2. These include the Field River, Christie Creek, Pedler, Maslin, Willunga and Aldinga Creeks. The two most significant creeks, from a point of view of urban stormwater runoff, are the Field River and Christie Creek. The other creeks are essentially rural creeks with high proportions of their land area under horticulture or grazing. The Field River has a small effective catchment area, draining some 36 km^2 of which 70 % is urbanised. The catchment is located between O'Halloran Hill to the north and the Christie Creek catchment to the south. The Field River catchment contains the Happy Valley reservoir that impounds a catchment of just over 19 km^2 of the total area. The Christie Creek Catchment has an approximate area of 38 km^2. The catchment is bounded by the Field River Catchment to the north and the Onkaparinga River Catchment to the south. The headwaters of Christie Creek are the southern Mt Lofty Ranges, and five major tributaries drain these hills to converge near the mid-point of the catchment. The main channel then meanders through the coastal hills to the sea. The catchment is heavily urbanised, with >60 % in urban development. Within this urban sector, Christie Creek and its tributaries have been highly modified with realignment and artificial lining of the watercourse to address flooding and erosion issues. There are two main commercial areas in the middle of the catchment, one near South Rd and the other near Panatalinga Rd. An industrial area lies in the lower extremity of the catchment, whilst the upper portions of the catchment are of rural character. At the shore zone, only Field River discharges directly from its channel across the beach into the sea.
The five other creeks tend to pond behind the beach and only break-out when storm flows occur. Of these, the Aldinga Creek, or Washpool Creek, enters the Washpool water body before discharging over the shingle beach. This tendency to pond means that the water draining at the beach zone will have undergone some settlement. Microbial activity may reduce nutrient concentrations, and the variations in concentration that occur in the flowing stream will tend to be integrated out. In addition, these creeks tend to be ephemeral, in that there is no flow for large periods, especially in summer.

2.3 The storm drains

Construction of the major storm drains which drain the Patawalonga Coastal catchment from Glenelg to Seacliff began in the late 1950s under the South-western Suburbs Stormwater Drainage Scheme (Lewis, 1975). A full listing of all of the storm drains from Largs Bay to Seacliff is provided in Appendix I. These drains will be referred to as the Coastal catchment in subsequent reports and presentations.

Plate 5a and 5b show the outlet of the Edwards Street drain in Brighton in 1974 and 2004. In 1974 the drain is discharging highly turbid water and in 2004 there is much foam and the water is coloured by organic matter. Foaming is common in natural waters containing significant quantities of organic matter. A proportion of leaves entering the drain system will contain saponins, these are natural soaping agents which when released into the water by breakdown of the parent material can reduce surface tension and contribute to foaming (e.g.

Wegner and Hamburger, 2002). Black sediment also settles out along the margin of the outflow channel that flows into the sea. It is possible that changes catchment activity between the 1970s and recent years may have had an impact on the water quality from the storm drains. For example, they may currently be less building and development work than in the 1970s and consequently a lower availability of loose erodable soil. In addition there may be greater production of leaf litter and also more pollutants from increased car numbers and road use since 1974. Alternatively, the elimination in leaded fuel may have reduced the lead burden from road runoff.



a.

b.

Plate 5. The Edwards Street Drain in Brighton discharging turbid storm runoff in (a) 1974 and (b) a more coloured foaming discharge in 2004 (note: foaming commonly results from the breakdown of organic matter such as leaf debris).

Gross pollutant traps (GPTs) are fitted on the Young Street, Edwards Street and Pier Street drains. The drains act as centrifugal collectors of solids and gross pollutants. During dry periods the GPT is a reservoir of water, filled with organic debris which breaks down microbially. The oxygen demand drives the chemistry anaerobic resulting in the production of methane, carbon dioxide and other by products of anaerobic digestion. When the next storm event comes through the system, this toxic plug of filthy water is displaced and flushed into the coastal zone. Simple visual inspection suggests that the GPTs need to be emptied after each major storm to prevent them from polluting the shoreline. It is anticipated that the samples collected during the monitoring phase of the study will indicate to what extend the GPTs are a problem.

3. Availability of Flow Data

One of the essential requirements for the assessment of loads of pollutants to the coastal zone is the provision of quality flow data. The best case is when a catchment is gauged near to the tidal limit such that the gauging station measures the outflow from the majority of the catchment area. In the absence of a well maintained gauging station, it may be sufficient to provide a temporary gauging point with a stable cross-section and a means of recording water level changes. Estimation of the discharge over a range of flow conditions using some appropriate technique, e.g. velocity-area gauging, provides a stage-discharge relationship for the conversion of water level to discharge. The results of this rating may used in conjunction with simple rainfall-runoff modelling techniques for comparison with adjacent catchments and for the estimation of past flows. Where establishment of a reliable gauge is not feasible, modelling techniques may suffice to provide indicative estimates of flow and hence facilitate the comparison of gauged and ungauged sites.

Table 5 below summarises the availability of flow data and estimates for the stormwaters discharging to the Adelaide coastal zone. This table includes the surface water archive numbers of each location, as listed by the Department for Water, Land and Biodiversity Conservation. As can be seen, the major catchments have or have had some form of hydrometry for a significant period, although funding decisions in the past curtailed the monitoring of the Gawler River and the Onkaparinga from 1988. The Virginia Park gauging station on the Gawler River was re-established with the creation of the Northern Adelaide and Barossa Catchment Water Management Board (NABCWMB). It has been suggested that the Gawler River rarely flows to sea (Smith *pers. comm*.). It is certainly true that the river only flows for a small proportion of days in the year. Comparison of flow data for the Gawler and Torrens River indicates that the mean annual flow and the 95 % annual flow for the two rivers are comparable. It seems unlikely that major flow events that have travelled the Gawler reach from Gawler Junction to Virginia Park would be soaked away before reaching Gulf St Vincent.

In the Onkaparinga, modelled estimates of the discharge at Old Noarlunga, above the tidal limit of the estuarine system, have been generated for this project. The calibration period of the model demonstrated an excellent fit to the observed data (see Section 5). The Thompson/Smith Creek system has no gauging and has not been gauged in the past. NABCWMB has indicated an intention to gauge the adjacent Helps Road catchment, and it has been suggested that only a small proportion of the run-off in the Thompson Creek system outflows to sea (Smith *pers. comm*.).

Table 5. Summary of flow information available for ACWS stormwater systems

Number	Name	Area (ha)	Flows	Details (surface water archive number 'AW##..')
1	Gawler River	111930	Y	Hydrometry at Virginia Park; AW505510, 1972-88, 2001-present
2	Thompson Ck, Smith Ck, Adams Ck	32960	P	Hydrometry at Stebonheath; AW505540, 3160 Ha, 1993-present
7	Torrens River	50136	Y	Hydrometry at Holbrooks Rd; AW504549, 1978-present
8	Patawalonga Basin (exc. Coastal catchment)	21239	Y	Hydrometry, Sturt River d/s ANZAC Hwy, Brownhill Creek at Adelaide Airport; AW504549 and AW504583, 1990-present and 1993-present, respectively
9	Coastal catchment (9.1 to 9.11)	2521		
9.1	Pier St, Glenelg	148	P	VRC estimated run-off
9.2	The Broadway, Glenelg South	96	P	No data
9.3	Marine St, Somerton Park	83	P	No data
9.4	Harrow Rd, Somerton Park	341	P	VRC estimated run-off
9.5	Downing St, Hove	23	P	No data
9.6	Wattle St, N Brighton	213	P	VRC estimated run-off
9.7	Jetty Rd, Brighton	22	P	No data
9.8	Edwards St, Brighton	472	P	Estimated flow 1978-81 (Steffensen, 1985)
9.9	Young St, Seacliff	600	P	Estimated flow 1978-81 (Steffensen, 1985)
9.10	Wheatland St, Seacliff	11	P	No data
9.11	Marino Surface Drainage	147	P	VRC estimated run-off
11	Field River	5526	Y	Hydrometry d/s Galloway Rd. AW503546, 2001-present
12	Christie Creek	3779	Y	Hydrometry d/s Main South Rd. AW503547, 2001-present
13	Onkaparinga River	55517	P	Hydrometry; at Noarlunga, AW3\503522, 1973-1987. Additional modeling
16	Pedler Creek	10738	P	Water level at Stump Hill Rd; AW503543, 8420 Ha, 2000-present
18	Maslin / Ingleburn Creek	3392	N	
20	Willunga Creek	3027	N	
21	Aldinga Creek	4919	N	
22	Sellicks – minor	654	N	

Of the major and minor creeks draining the southern metropolitan zone, from O'Halloran Hill south to Sellicks Creek, the Field River, Christie Creek and Pedler Creek have been gauged since 2000 or 2001. There is good potential to extend these records by modelling, should this be required. The Pedler Creek gauge only catches runoff from around 80% of the catchment area. This is unlikely to result in major errors in load estimates, given that the rain falling in the coastal strip is much less than in the upper reaches of the catchment and that runoff from the coastal margin is infrequent. The four remaining creeks, from Maslin to Sellicks Creek are ungauged. It is not anticipated that gauging will be required. Modelling alone should be sufficient to estimate the loads from these sites.

There is no actual hydrometry for the Coastal catchment. Steffensen (1985) estimated discharge for the calculation of loads for the drains at Young Street (Drain 10) and Edwards Street (Drain 11). The average estimated flows for the four years 1978 to 1981 were 587.5 ML and 300 ML, respectively. While the figure for Edwards Street was low compared to recent estimates, the value for Young Street was within 1 %. Section 5.1 presents estimates of annual discharge based-on volumetric run-off coefficients and the percentage directly connected impervious areas presented in grey literature.

4. Availability of Water Quality Data

There are a variety of recent and historical water quality data available for the stormwaters. The coverage in terms of frequency, numbers of samples, period of record and determinants recorded varies from location to location. Some locations have no data at all and other sites are the subject of relatively intensive monitoring.

4.1 Historical water quality data

The reports that summarise these data include the body of data held in the Gulf St Vincent Water Pollution Studies reports produced by the South Australian Engineering and Water Supply Department (e.g. Lewis, 1975; Steffensen, 1985). Table 6 summarises the sites with historic data available. The sites with the best coverage are those that drain the Central Metropolitan zone, i.e. the most heavily urbanised areas at the time the monitoring was undertaken. This includes the Torrens, Patawalonga and five of the major storm drains along the Holdfast Shores. The main focus of the monitoring was total dissolved and suspended solids, organic carbon, pH; nitrogen and phosphorus (see Steffensen 1985). Limited data for the Gawler system, part of a larger survey of surface waters in South Australia by Glatz (1985), included the same determinants as those for the Central Metropolitan stormwaters reported by Steffensen, and in addition a number of heavy metals. Although the numbers of samples was low (n=14), the results for the Gawler indicated elevated nitrogen concentrations.

The storm drains are characterised by around 30 to 50 historical samples for five of the largest drains (Table 6). The water quality data available for the storm drains come from grab samples collected between 1973 and 1978 and include nutrients and suspended and dissolved solids (see Steffensen, 1985). Recent preliminary sampling and visual investigation has confirmed that the five drains reported on by Steffensen (1985) and Lewis (1973) are the largest of the storm drains. Resampling of these storm drains is highly recommended.

Although they produce only a minor contribution volumetrically to the overall storm flow to the coastline, they have a highly visible local impact (Plate 6), and they may contribute a not insignificant pollutant load. Steffensen (1985) presented estimates of the loads of nutrients and suspended sediment from two of the largest drains, Young St and Edwards St, the data are presented in Appendix V. Between 1978 and 1981, the Young St. drain contributed the equivalent of 1 % (9.5 t/yr on the average) of the total nitrogen from Glenelg WWTP, the Patawalonga system, Torrens and Edwards St. drain, and 4.5 % (an average of 500 t/yr) of the suspended solids form the same sources. A recent project at Flinders University investigated runoff entering the Harrow Road drain from the Somerton Park Industrial Precinct (Miller, 1999). The results demonstrated the build-up wash off effect, with greater metals' concentrations in road runoff after longer dry periods. In addition, there was a clear difference between the runoff from residential and industrial roads, the volume of runoff from the industrial area was also greater due to the greater proportion of impervious surfaces. The mean lead concentrations of all 18 samples are presented in Table 7.

Table 6. Summary of historic water quality data available for stormwaters within the ACWS study area.

Number	Name	Details
1	Gawler River	14 grab samples at Virginia Park from 1978 to 1983 (see Glatz, 1985), major ion chemistry, heavy metals, nutrients and suspended solids, colour and pesticides
2	Thompson / Smith Ck	None
7	Torrens River	80 grab samples Seaview Rd, 39 grab samples Holbrooks Road, Gulf St Vincent WPS 1972-82 (Steffensen, 1985), phys-chem, nutrients. Also metals in Haughey (1973). 32 grab samples at Holbrooks Road from 1978 to 1983 (see Glatz, 1985), major ion chemistry, heavy metals, nutrients and suspended solids, colour and pesticides
8	Patawalonga Basin	74 grab samples, Patawalonga at King Street Bridge 1972-1980 (Steffensen, 1985). 13 grab samples - Sturt River at Anzac Highway, 1971-73 (Haughey, 1974)
9	Coastal catchment (9.1 to 9.11)	
9.1	Pier St, Glenelg	None
9.2	The Broadway, Glenelg South	30 grab samples 1973-77 (Steffensen, 1985), phys-chem, nutrients.
9.3	Marine St, Somerton Park	None
9.4	Harrow Rd, Somerton Park	30 grab samples 1973-77 (Steffensen, 1985), phys-chem, nutrients.
9.5	Downing St, Hove	None
9.6	Wattle St, N Brighton	35 grab samples 1973-77 (Steffensen, 1985), phys-chem, nutrients.
9.7	Jetty Rd, Brighton	None
9.8	Edwards St, Brighton	49 grab samples 1973-79 (Steffensen, 1985), phys-chem, nutrients.
9.9	Young St, Seacliff	44 grab samples 1973-78 (Steffensen, 1985), phys-chem, nutrients.
9.10	Wheatland St, Seacliff	None
11	Field River	None
12	Christie Creek	None
13	Onkaparinga River	18 grab samples at Noarlunga from 1978 to 1983 (see Glatz, 1985), major ion chemistry, heavy metals, nutrients and suspended solids, colour and pesticides
16	Pedler Creek	None
18	Maslin / Ingle burn Creek	None
20	Willunga Creek	None
21	Aldinga Creek	None
22	Sellicks – minor	None

Plate 6. The Harrow Road storm drain discharges in two sizeable channels across the Hove beachface, 4 January 2004 (Photo J Wilkinson).

The stormwater discharges across the beachface in large stream-ways and clearly displaces the seawater along the shoreline creating a highly visible coloured strip. As indicated above, the visual quality of the runoff appears to have changed and it is necessary to assess to what extent the physical and chemical composition has changed in order to establish a true contemporary indication of the relative impacts of these sources.

Clearly the sites that have only limited numbers of samples offer little more than an indication of the prevailing water quality. Where greater numbers of samples exist, there is some potential to make comparisons with contemporary monitoring. Although the sampling frequencies may be different, it should be possible to highlight broad changes over the 20 to 30 years that have elapsed between the two sets of data. Section 6.2 gives a brief summary of recent sampling of stormwaters in the ACWS study area.

Table 7. Metals concentrations in road runoff feeding the Harrow Road drain (after Miller, 1999).

Antecedent dry period (days)	Lead µg/L	Copper µg/L	Zinc µg/L	Cadmium µg/L	Iron µg/L
5	98	21	386	6	1140
9	105	22	267	8	1610
13	198	108	1270	6	2060

4.2 Recent stormwater sampling in the ACWS study area.

Since the establishment of the catchment water management boards in 1995 there has been a drive to characterise and monitor the quality and quantity of surface waters draining Adelaide and its environs. This has been particularly the case for the Torrens, Patawalonga, and Onkaparinga regions which have a heavy urban burden. One of the recommendations of the Gulf St Vincent Water Pollution Studies was the need for composite sampling to adequately characterise loads of pollutants delivered by the main metropolitan stormwaters (Steffensen, 1985). This recommendation has been implemented in the Torrens and Patawalonga systems and also in the highly urbanised Field River and Christie Creek. These rivers have flow proportional samplers that take 500 mL of sample from every 10 ML that pass the station. Each sample is passed into a bulk collector which is emptied for analysis on a weekly basis (Nicholson and Clark, 1992) (see Appendix VI for a description of the methods and analysis). Since a greater number of samples are collected during high flows, the concentration in the bulk collector is biased towards the quality of the stormflow water. This system ensures the capture of samples during the period of peak flow. The timing and magnitude of possible peak concentrations of contaminants in the stormwater cannot be estimated, however, the consistency of the data is greater than that which might be achieved from a program of irregular grab sampling. Table 8 summarises both composite and grab sample based monitoring carried out in each catchment.

Table 8. Summary of contemporary data for the stormwaters in the ACWS study area.

Number	Name	Details
1	Gawler River	None
2	Thompson Ck, Smith Ck	None
7	Torrens River	Flow proportional composite weekly samples by WDS at Holbrooks Road since 1996 and regular grab sampling by AWQC.
8	Patawalonga Basin	Flow proportional composite weekly samples by WDS at Anzac Highway on the Sturt since 1994 and Brownhill Creek at Adelaide Airport since 1997. Additional grab sampling by AWQC.
9	Coastal catchment (9.1 to 9.11)	None
11	Field River	Flow proportional composite weekly samples by WDS at Young St. since 2001 and monthly grab sampling at Hallet Cove since 1999 by AWQC for OCWMB includes nutrients, dissolved and total metals.
12	Christie Creek	Flow proportional composite weekly samples and monthly grab samples d/s of Galloway Road at O'Sullivan Beach Primary School since 1999 analysed by AWQC.
13	Onkaparinga River	Monthly grab sampling at Noarlunga above and below the tidal limit, and in the lower estuary u/s of New Road since 1999 by OCWMB.
16	Pedler Creek	Monthly grab sampling 50 m d/s of Commercial Road since 1999 by OCWMB.
18	Maslin / Ingleburn Creek	Monthly grab sampling at the creek mouth since 1999 by OCWMB.
20	Willunga Creek	Monthly grab sampling at the creek mouth since 1999 by OCWMB.
21	Aldinga (Washpool) Creek	Monthly grab sampling at drain junction u/s of lagoon since 1999 by OCWMB.
22	Sellicks – minor	Monthly grab sampling at beach discharge adjacent to car park since 1999 by OCWMB.

4.3 Pesticide detections

Glatz (1985) reported grab sample results for pesticides for the Gawler River at Virginia Park, the Torrens at Holbrooks Road and the Onkaparinga at Old Noarlunga. Samples were collected between 1978 and 1988 (Table 9). The Gawler River was sampled four times and the herbicides lindane and dachtal were detected in one sample (both 0.01 μg/L). In the Torrens, there were six detections from 8 samples, lindane was detected twice and dachtal four times. The lindane concentrations were 0.02 and 0.16 μg/L. Dachtal was detected at between 0.06 and 0.08 μg/L. Two of the dachtal detections came from samples collected within a few hours of each other. Only two samples were collected from the Onkaparinga and no pesticides were detected.

Table 9. Summary of pesticide detections in grab samples from rivers in the ACWS area.

	ANZECC (2000) trigger level for protection of 95 % of species	Gawler River	Torrens River	Brownhill Creek	Sturt River	Onkaparinga
1978-83						
Sample n		4	8	-	-	2
Detections		1	6	-	-	0
Lindane	0.2	0.01	0.02, 0.16			
Dachtal	-	0.01	0.08, 0.08, 0.08, 0.06			
1996-7						
Insecticides						
Sample n		-	6	8	3	-
Detections		-	1	0	0	-
Dieldrin	ID*		0.03			
Herbicides						
Sample n		-	3	4	3	-
Detections		-	2	5	0	-
Simazine	3.2		3.6, 2.9	4.9, 3.7, 1.9, 0.59		
Atrazine	13			0.6		

Note: All values in ug/L. 1978-83 data from Glatz, 1985. 1996-7 data from Schultz et al. (2000) and Schultz and Thomas (2000). *ID – Insufficient data.

Following the establishment of the Catchment Water Management Boards, later grab sampling from the Torrens at Tapleys Hill Road Bridge, between February 1996 and January 1997, showed two detections of the herbicide simazine at 3.6 and 2.9 μg/L from three samples analysed (Schultz *et al*., 2000). The insecticide dieldrin was detected once at 0.03 μg/L from seven samples. In a parallel study of the Patawalonga catchment, Schultz and Thomas (2000) present data on pesticides in the Sturt River at Anzac Highway and Brownhill Creek at the Adelaide Airport Trash Barrier. At Anzac Highway, four samples were analysed for insecticides without detection, and three for herbicides. None were detected. For Brownhill Creek, the analyses of eight samples for insecticides produced no positive results; however, the herbicides simazine and atrazine were detected. Simazine was present in the four samples analysed with values of 4.9, 3.7, 1.9 and 0.59 μg/L. Atrazine was detected once at 0.6 μg/L.

ASTE (2002) indicates the organochlorine pesticides lindane and dieldrin have been withdrawn from use in Australia. The ANZECC/ARMCANZ (2000) trigger values for the protection of 95 % of freshwater species are 0.2 μg/L for lindane, 13 μg/L for atrazine and 3.2 μg/L for simazine. For dieldrin, there are insufficient data to derive a trigger value and dachtal is not listed. The simazine concentrations of 3.6 and 3.7 μg/L in the Torrens and Brownhill Creek occurred on days with a total flow of 179.5 and 165.6 ML/d, respectively. The instantaneous flux of simazine would be 7.48 mg/s and 7.09 mg/s, and if representative of the daily situation 0.646 and 0.613 kg/day, respectively. Simazine is listed as slightly to practically non-toxic to aquatic organisms (Kidd et al. 1991; WSSA, 1994) and has been observed to break down rapidly in freshwater (half-life 30 days) (WSSA, 1994). Atrazine is listed as a “Restricted use Pesticide” in the US (Ware, 1984), and as slightly toxic to fish and other aquatic life (USNLM, 1995).

These results show that pesticides are present in stormwaters in the ACWS area in detectable concentrations. At certain sites (Brownhill Creek and the Torrens); the rate of detection has been relatively high. The numbers of samples analysed is small and the period over which these have been collected is limited, and insufficient data are available to assess whether the values detected are representative of general behaviour. The concentrations are low, however, given that stormwater flows out into the coastal zone on a transient basis and is likely to displace seawater off shore, unlike wastewater discharges which are continuous, herbicides in bulk stormwater may be a minor contributor to the overall stormwater impact on offshore seagrass communities. There may be a case for further investigation of herbicides in stormwaters, although it is not envisaged that this will be done within the current ACWS framework because of the cost associated with such analyses.

5. Annual and Seasonal Flow and Landuse

This section of the report summarises the typical annual discharge from the major catchments and creeks where hydrometric or flow estimates are available. The data presented demonstrates the overall discharge from each of these catchments and the typical seasonal runoff volume and runoff per unit area. The hydrology is linked to landuse and used to inform the proposed sampling strategy.

5.1 Estimating indicative mean annual and monthly flows

Since adequate or current estimates of discharge from several of the stormwater systems were unavailable in the literature it was necessary to calculate or model flows to provide this information. The rationale and general approaches used are presented below.

Rainfall based estimates of runoff from the Coastal catchment, Onkaparinga Estuary catchment and Smith Creek

Initial estimates of annual yield from the various catchments, based on existing data and estimated flow values in published literature are presented below.

Prior to presenting flow estimates for various ungauged locations draining to the ACWS study zone, it is necessary to give a brief and simplified background to how the flows are estimated. For the purpose of comparing the typical annual flow and loads of dissolved and suspended constituents entering the ACWS study zone it is necessary estimate the proportion of rainfall falling on each catchment that actually reaches the drainage network and hence runs off to the sea. This proportion is described by the volumetric runoff coefficient (VRC). The VRC for any given area varies according to the rainfall intensity and duration of individual rainfall events. For the purpose of estimating loads entering the ACWS study zone it is sufficient to use a VRC representative of run-off averaged over a long time scale. The VRC values used in this report are thus lower than values that might be expected for short term intense storms.

The VRC for different land areas vary according to the composition of the land surfaces in that area. Where the proportion of impervious surfaces is high, the VRC will be greater. Where there is little development the VRC will be lower, since the potential to soak-up and evaporate-off incident rainfall is higher. In studies of drainage for flood protection it is common to assume that the run-off from pervious surfaces is zero (e.g. Kinhill, 1997).

Impervious surfaces are categorised on the basis of direct connection to the drainage network. For example, drive-ways, car parks and road surfaces are connected directly to the drainage network, whereas, often according to the age of the property, roof drainage may be connected to the network or may simply drain onto the garden of the property. The area of impervious surfaces connected directly to the drainage network is referred to as the “directly connected paved” area or DCP. Those areas that are not directly connected are referred to as “supplementary paved” areas or SP. AR&R (1987) suggest a typical impervious fraction of 0.35 for residential areas. For roads and footpaths the value is 0.85.

Of the impervious surfaces there will be an initial loss caused by the wetting of the surface, this is often assumed to be 1mm of the rainfall.

Tonkin (1992) provides typical volumetric runoff coefficient (VRC) values of 0.25 for residential areas and 0.8 for industrial and commercial landuse. Kemp (1993) found that runoff from an urban Glenelg catchment increased from around 0.24 for smaller storms to around 0.3, when lawns became saturated during larger storms.

The Holdfast Storm Drains which drain the Patawalonga “Coastal catchment” are part of the “South Western Suburbs Drainage Scheme”. Kinhill (1997) and Brown and Root (2001) estimated VRCs for several of the drains discharging into Holdfast Bay. The VRCs are based-on the proportions of DCP areas in each catchment. VRCs for flow events of different return periods are presented. The VRC values for the 5 year return interval storm (ARI) have been used in conjunction with estimates of mean annual rainfall and catchment area to calculate total annual run-off for each drain (Table 11). For drains where no directly estimated VRC is available either the mean of the other sites has been used, or where DCP is available annual flow is approximately 0.9 DCP multiplied by annual rainfall (Kemp pers. comm..). In fact, the flows estimated from the 5 year ARI were within +/- 3% of the 0.9 DCP based values, suggesting that this approach gives a good approximation of annual mean flow. The mean annual rainfall estimate used was 520 mm at Glenelg.

Table 11. Estimated mean annual flow for the Patawalonga Coastal catchment.

Drain no.	Street Name	Area (km2)	DCP %	SP %	VRC	Flow ML/a	Yield mm
15B	Peir St	1.48	22.0	24.0	0.20	153	103.8
	Broadway	0.96	-	-	-	*108*	112.1
	Marine St	0.84	-	-	-	*94*	112.1
14C	Harrow Rd	3.41	28.0	17.0	0.25	442	129.8
12	Wattle Ave	2.13	29.0	19.0	0.26	288	135.0
11	Edwards St	4.72	20.0	25.0	0.18	441	93.4
10	Young St	6.00	21.7	12.9	0.19	591	98.6
	Marino	1.49	20.9	14.6	**0.19**	145	97.6
	Other Drains	4.19	-	-	-	*470*	112.1
		Total Area	**Average**	**Average**	**Average**	**Total Flow GL**	**Average**
		25.21	***23.60***	***18.75***	***0.216***	**2.73**	**112.1**

Notes: *Data from Kinhill (1997), †data from Brown and Root (2001), ‡flow estimated using average VRC and total Coastal catchment area minus sum of specified catchments. **VRC = 0.9 DCP/100.

The flow to the Onkaparinga Estuary downstream on Old Noarlunga was estimated the same way as for the Coastal catchment. Mean annual rainfall of approximately 520 mm was assumed and a catchment area of 28.18 km^2 with runoff from the residential proportion of the catchment (87.5%; Manning, 1986) with VRC=0.223, this gives a mean annual discharge of approximately 2.42 GL.

Estimating runoff to sea from Smith Creek was problematic. ECA *et al*. (1991) estimated annual runoff from Smith Creek of 11.5 GL. Since that estimate was published, the Stebonheath Flow Control Park has been constructed. This is estimated to retain all but 3.3 GL of the mean annual flow in the upper 84.4 km^2 of the catchment, and this is proposed to be a good estimate of what might actually flow to sea (Swiatnik, *pers. comm*.). Estimates of runoff from the remaining 134.48 km^2 area downstream of the wetland, assuming an impervious fraction of 0 and a VRC of 0.1, suggest a value of 5.2 GL per year. The sum to the two values (8.5 GL) is suspected to be an overestimate of flow from the catchment and the later figure of 5.2 GL is being used at the current time. A further complicating factor associated with the Smith Creek system is that, by virtue of its proximity to and the tendency for overbank spilling, that the northern Thompson Creek arm of Smith Creek might receive and drain flood water from the Gawler system (see maps in Appendix II). Field observations may or may not confirm this to be the case.

Modelling losses from the Lower Gawler

Flow in the Gawler River downstream of Virginia Park is significantly affected by losses and storage in Buckland Park Lake. Overbank spillage at flows in excess of 10 m^3/s (≡ 864 ML/d) (see ID&A, 2002) is a major loss of discharge to sea. This effect is beneficial since floodwaters are retained inshore in much the same way as would have occurred in the Torrens and Patawalonga systems prior to flood abatement works. Buckland Park Lake, which acts as a small reservoir, has an area of approximately 100 ha and a mean depth of around 0.75 m (Possingham, *pers. comm.*). This affords around 750 ML storage. By capping daily flows to into the lake to 864 ML/d and using a simple water balance model including evaporation and rainfall data for the nearby Bolivar WWTP lagoons, it has been possible to estimate the monthly loss to storage, and the resulting discharge to Gulf St Vincent. Table 12 below shows the reduction in mean annual flows for selected periods. For April 2001 to April 2003, the loss due to over bank spillage was 1.9 GL and the reduction in flow due to storage in Buckland Park Lake 0.5 GL, resulting in an annual flow to sea of 10.3 GL rather than the 12.7 GL indicated by gauged discharge at Virginia Park. In addition the water balance model has been used to indicate the monthly total flows to sea, these estimates have been useful to direct the field monitoring program (Section 6).

Table 12. Mean annual flow in GL from the Gawler River at Gawler Township (gauge AW505505), Virginia Park (gauge AW505510), capped discharge following overbank spillage, and final overspill from Buckland Park Lake to sea.

Period	Gawler Junction AW505505	Virginia Park AW505510	Flow capped at 10 m^3/sec	Buckland Park Lake Overspill to Sea
1973-1977	28.8	24.9	19.5	18.7
1978-1982	35.0	33.2	22.4	21.6
1983-1987	18.8	18.2	15.7	14.8
1988-1992	48.2	*no data*	*no data*	*no data*
1993-1997	14.1	*no data*	*no data*	*no data*
1998-2002	7.9	*no data*	*no data*	*no data*
1993-2003	11.0	*no data*	*no data*	*no data*
April 01 to March 03	11.2	12.7	10.8	10.3

The reduction in monthly discharge to sea from the Gawler is demonstrated in Figure 7. In July 1981, the model suggests that 30 GL of floodwater spilled out of the Lower Gawler. It is likely that a proportion of overbank spillage of this magnitude would discharge via all outlets to sea. For floods of much lesser magnitude, it is likely that the majority of water would remain inshore.

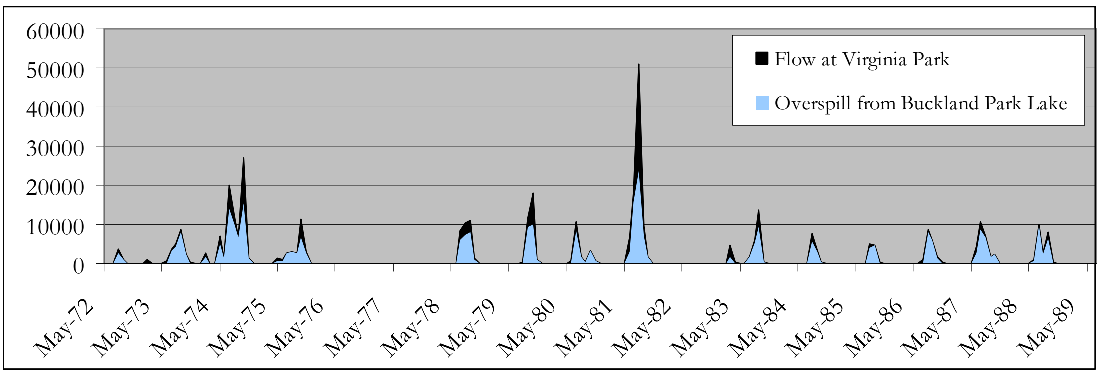


Figure 7. Gauged flow at Virginia Park and estimated monthly flow to sea from the Gawler River after loss to overbank spillage and storage in Buckland Park Lake (flows in ML).

Modelling discharge in the Onkaparinga at Old Noarlunga

Discharge to the Onkaparinga Estuary has also had to be estimated, since the gauging section upstream of Old Noarlunga on the Onkaparinga was rationalised in 1988. Flow records began in 1973 and these data have been used to calibrate the model and estimates for the later period have been used assuming that no major changes had occurred in the catchment hydrological response (Figure 8). The model used is based on a four box, three pathway adaptation of the IHACRES modelling approach described by Littlewood and Jakeman (1993) (see Appendix VII). Occasional extreme flows in the Onkaparinga are associated with spills from Mt Bold (Figure 8). The model does not provide estimates of over-spilling from the Mount Bold / Clarendon Weir system.

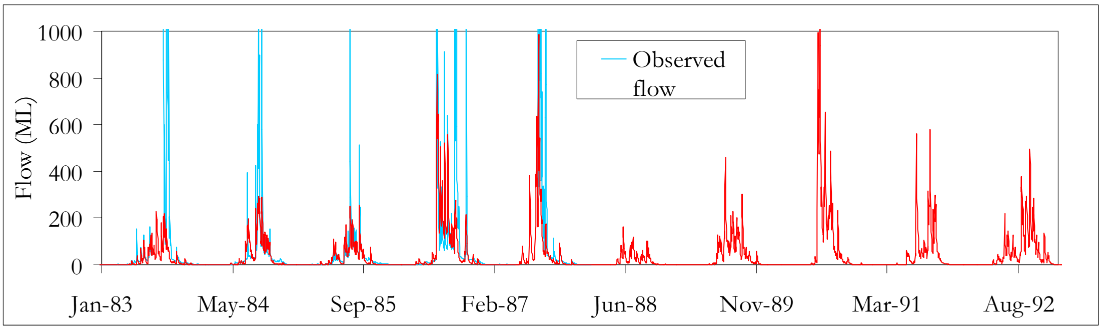


Figure 8. Modelled daily flow (in ML) for the Onkaparinga catchment at Old Noarlunga.

5.2 Flows and seasonality of major rivers and creeks

The overall mean annual discharges from the major and minor creeks are listed in Table 10. Where available summaries of gauged flows are presented, other values are estimated from mean annual rainfall and volumetric runoff coefficients. Flows in the Gawler River were modified using a water balance modelling approach. For the Onkaparinga, discharge into the estuary was estimated using a rainfall runoff model calibrated from the gauged period of discharge. Catchment areas presented in Table 10 are the effective stormwater catchment as discussed earlier; they are based on the area of each catchment downstream of the water supply network infrastructure. Flemming and Daniell (1997) reported annual stormwater yields for the North Adelaide Plains, for urban land they estimated a yield of 130 ML/km^2 and for rural land and open spaces 58 ML/km^2.

Table 10. Mean annual discharge, catchment area and runoff per unit area for selected major rivers and creeks in the ACWS study area.

	Effective catchment area (km^2)	Mean annual flow (GL)	Catchment Yield (ML/km^2 = mm)
Gawler River (to Sea)[1]	883.0	10.3	11.7
Smith Creek[2]	205.6	5.2	25.3
Barker Inlet[2]	407.8	10.3	25.3
R. Torrens[3]	218.5	22.4	102.6
Patawalonga[3]	212.4	19.7	92.6
Coastal catchment[2]	25.2	2.7	108.4
Field River[1]	36.2	2.8	77.3
Christie Creek[1]	37.8	8.1	214.3
L. Onkaparinga[4]	138.7	9.5	68.5
O. Estuary[2]	28.2	2.4	85.8
Southern Creeks[5]	244.9	2.3	9.5

1. Annual mean of flows for April 01 to April 03. 2. Estimated from rainfall and volumetric runoff coefficients (see Section 5.2 below). 3. Average data for October 94 to November 03. 4. Modelled data for the period October 94 to November 03. 5. Flow in Pedler Creek at Stump Hill Road for April 01 to April 03 multiplied up to total southern creek catchment area. NOTE: Ten year flows are consistent with two year flow period of 2001/3

Figure 5 presents the indicative mean annual flows for the major and minor stormwater systems in their correct geographical sequence from north to south. Barker Inlet, the Coastal catchment and the Southern Creeks are presented as summed inputs because of their relatively small component parts. The total estimated annual stormwater flow to sea is around 96 GL per annum. It is emphasised that this value is not the same as the total stormwater generated within the ACWS area. Losses due to stormwater detention measures and harvesting mean that this figure is lower than the value that might be estimated as the total stormwater generated.

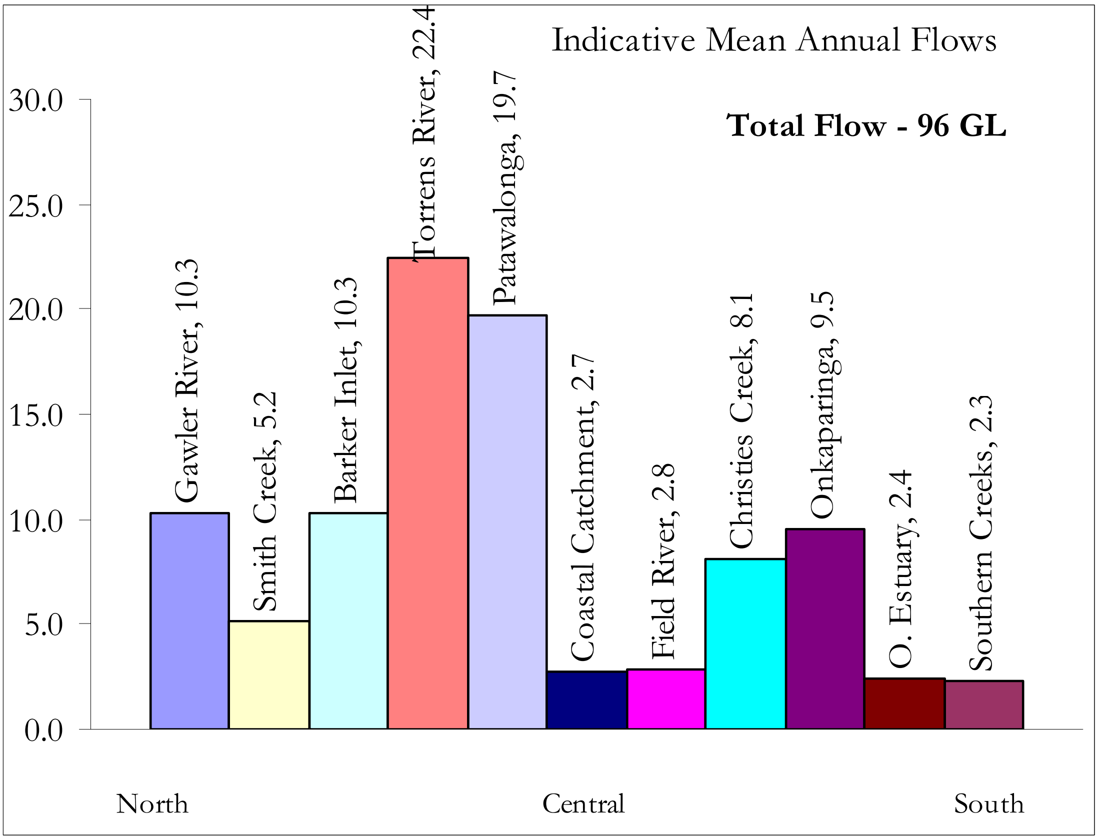


Figure 5. Indicative mean annual flow from the rivers, creeks and storm drains in the ACWS area.

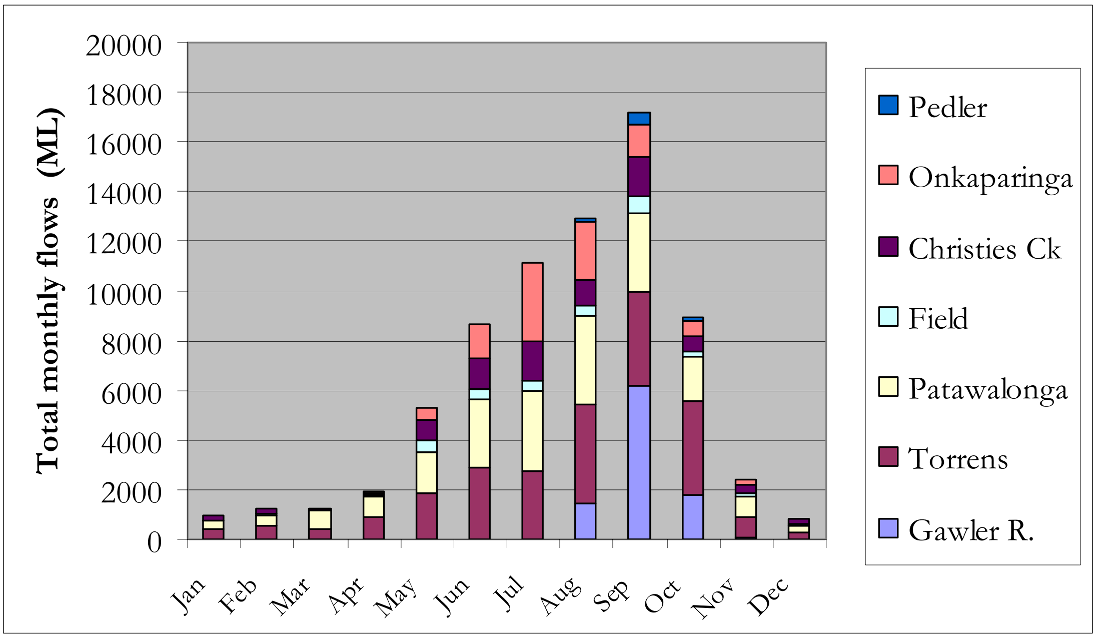


Figure 6. The seasonal pattern in stormwater discharge to the Adelaide coastline, showing summed mean monthly discharge for selected major rivers and creeks.

Figure 5 demonstrates that there are major stormwater sources throughout the ACWS area, however south of the Onkaparinga Estuary, stormwater inputs are relatively minor (2.4 %). The Torrens and Patawalonga deliver around 40 % of the annual stormwater.

An investigation of the mean monthly flow totals for the major stormwater sources indicates that the timing and magnitude of the various contributions is quite variable (Figure 6). As can be seen, the six months of May to October inclusive represent the hydrological winter, and November to April is the dry season. The Torrens and Patawalonga are major contributors to flows throughout the year, whereas the bulk of discharge from the Onkaparinga is in the months June through to the end of September. The Gawler River and southern creeks (represented by Pedler Creek) produce the majority of their discharge to sea late on in the winter period in August, September and October. This general timing of typical monthly flows informs the monitoring program of IS1 sub-program 1, in that it is possible to target field resources and effort to periods when a hydrological response is expected (see Section 6).

5.3 Landuse in relation to hydrology.

The purpose of this section is to demonstrate how stormwater flows to Gulf St Vincent vary from the Gawler River in the north down to Sellicks Creek in the south and how the distribution of flows is a consequence of landuse. This relationship is obvious to those who have a basic knowledge of hydrology but may not be apparent to the lay reader. In addition to highlighting the location of the major stormwater discharges this investigation assists in decision making regarding the targeting of future field and laboratory work to characterise the key inputs to the coastal zone.

Landuse impacts very heavily on the hydrology of the catchments that drain the ACWS study area. Figure 9 provides a graphical presentation of the data in Table 10. This figure shows that annual discharge and yield is not necessarily related catchment area. For example the Gawler River has an effective catchment area approximately four times greater than that of the River Torrens and yet the annual flow volume is less than a half of that from the Torrens. Similarly the summed area of the southern Creeks is around 7 times the area of the Field River and yet the annual flow from these creeks is less than that from the Field River.

As indicated in Section 5.1 the type of land cover has a very strong influence on catchment runoff and yield. Effectively, developed areas provide a sealed (waterproof) surface on the catchment and undeveloped areas soak-up rainfall.

Figure 10 and Table 13 present the generalised landuse for the creeks and rivers of interest in the ACWS area. The Gawler River is excluded, awaiting the preparation of data. The landuses presented lump together a broad range of categories on the basis of perceived water quality impact (Appendix IV). The landuses listed in Appendix IV have been lumped as follows:

- Low impact land - land that has minimal use such as bush and conservation land.
- Grazed land - land used for animals includes all kinds of animal stocking practices from intensive dairy lots to low grade sheep grazing.
- Horticulture and other cropping - includes areas where plant growth primary production is carried-out.
- Urban, suburban and industrial land - includes areas with development and man-made structures including roads etc, where there will be a high density of impervious surfaces for land drainage.

The dominant landuse groups in each catchment are highlighted in bold. The catchment area used is the effective stormwater runoff catchment, i.e. impounded areas that are part of the greater Adelaide water supply system are excluded from the figures. The overall distribution of general landuse groups is shown in Figure 11, of the total land area included in Table 13, 36 % is developed land. Land in low impact use covers 16 % of the area, and the farming-related groups cover the remaining 46 % of the area.

In general the catchments with a high proportion of developed land have the highest catchment yield and produce the most runoff. In fact, approximately 70 % of all stormwater run-off is derived from only 30 % of the land with drainage to the coast (i.e. not impounded for water supply).

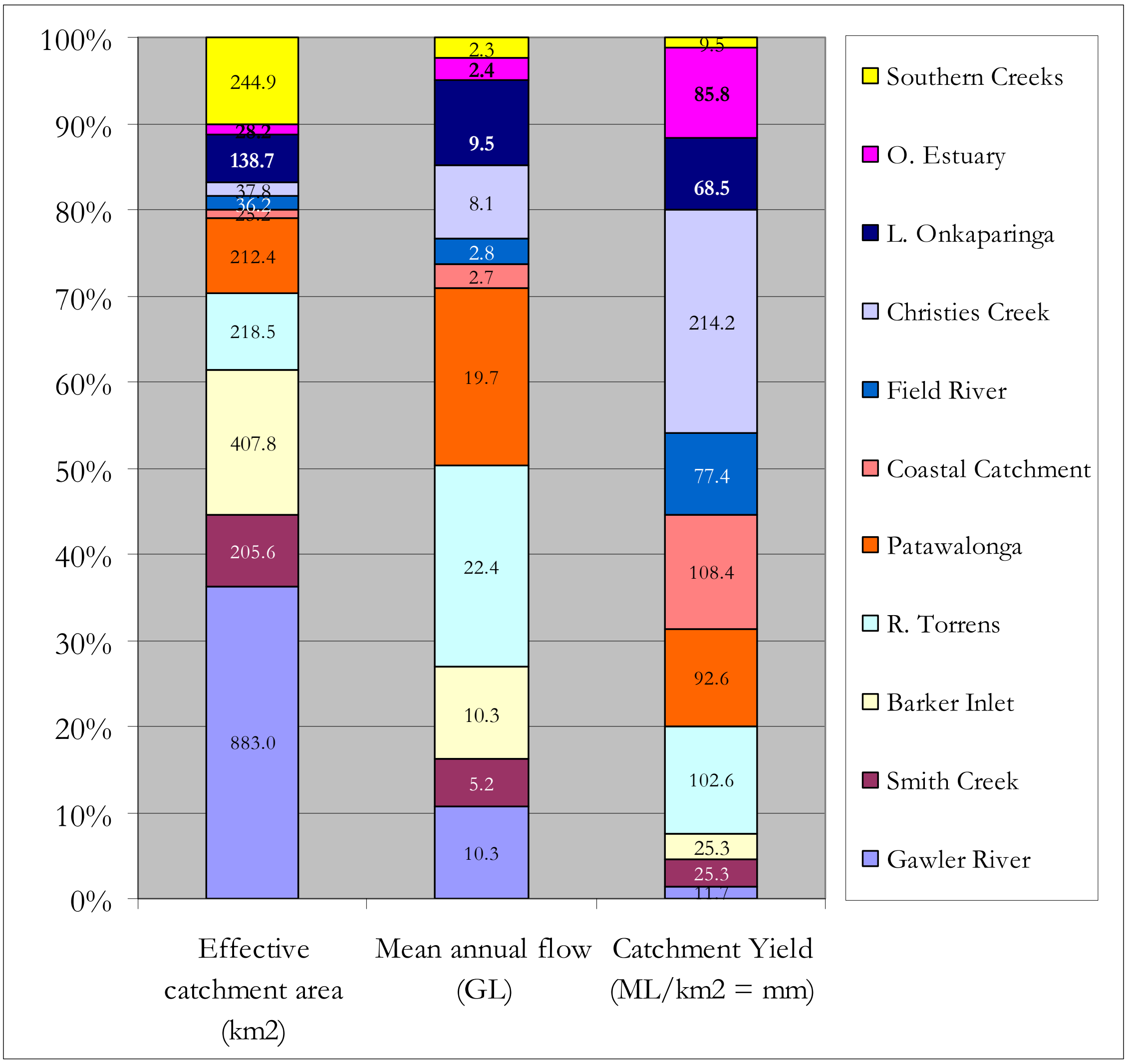


Figure 9. Effective catchment area, mean annual flow, and catchment yield of selected rivers and creeks to the Adelaide coastline (data for March 2001 to April 2003).

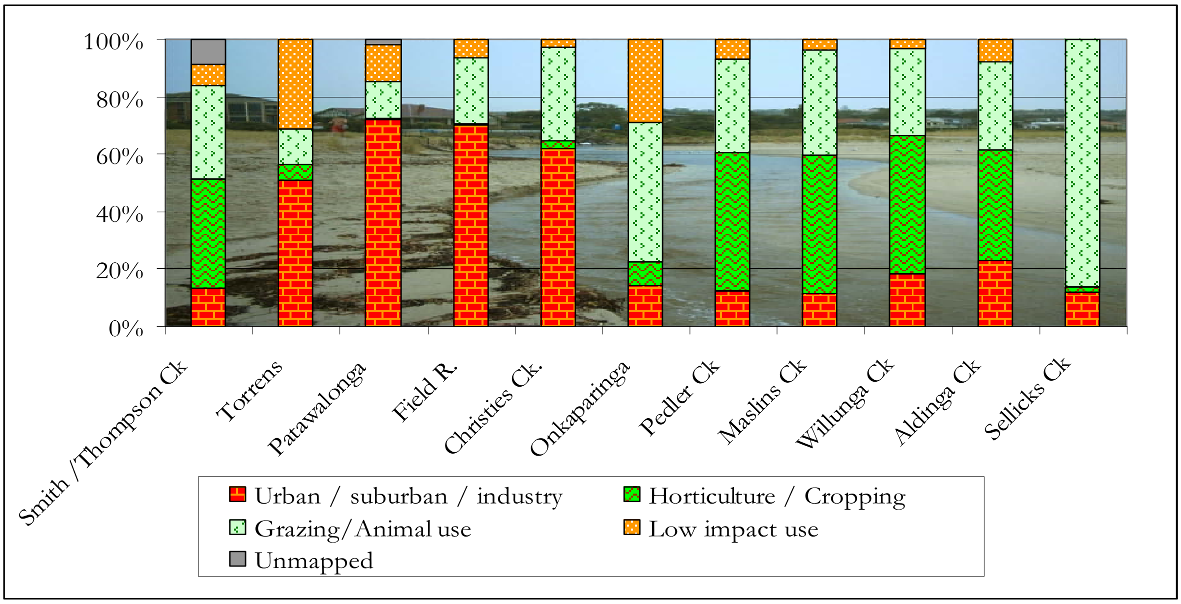


Figure 10. Graphical summary of the relative proportions of the general landuse groups in each ACWS area catchment.

Table 13. Generalised landuse groupings in the catchments of the ACWS area.

Land Classification (Ha)	Low impact use	Grazing/Animal use	Horticulture / Cropping	Urban / suburban / industry	Unmapped	Total
Smith Creek	1482	6708.	7818	2718	1833	**20560**
%	7	**33**	**38**	13	9	
Lower Torrens	6856	2692	1218	11083	0	**21849**
%	31	12	6	**51**	0	
Patawalonga	2742	2770	118	15252	358	**21239**
%	12	13	0.6	**72**	2	
Field River	238	821	21	2534	0	**3614**
%	6	23	0.6	**70**	0	
Christie Creek	105	1228	101	2346	0	**3780**
%	2	33	3	**62**	0	
L. Onkaparinga	4955	8348	1421	2465	0	**17188**
%	**28**	**49**	8	14	0	
Pedler Creek	717	3529	514	1339	8	**10739**
%	6	**33**	**48**	13	0.1	
Maslins Creek	123	1247	1634	390	0	**3393**
%	3	**37**	**48**	12	0	
Willunga Creek	93	922	1460	554	0	**3028**
%	3	**30.4**	**48**	18	0	
Aldinga Creek	391	1515	1890	1124	0	**4920**
%	8	**31**	**38**	23	0	
Sellicks Creek	0	563	14	78	0	**654**
%	0	**86**	2	12	0	

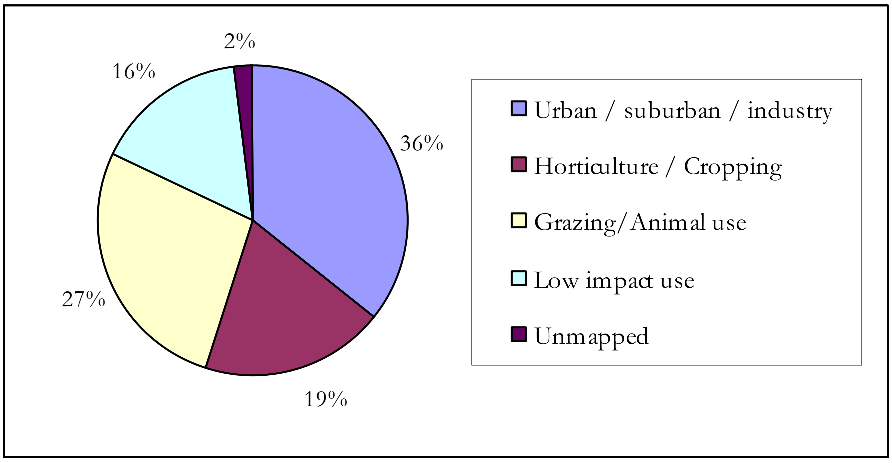


Figure 11. Summary of overall distribution of landuse groups in the ACWS area.

Figure 12 breaks down the annual yield figures into monthly intervals demonstrating seasonal variation in runoff. The urbanised catchments are the ones with high yield and produce runoff all year round. The rural catchments, such as Pedler Creek and the Gawler River, are the ones that generally only produce winter runoff and have a low yield.

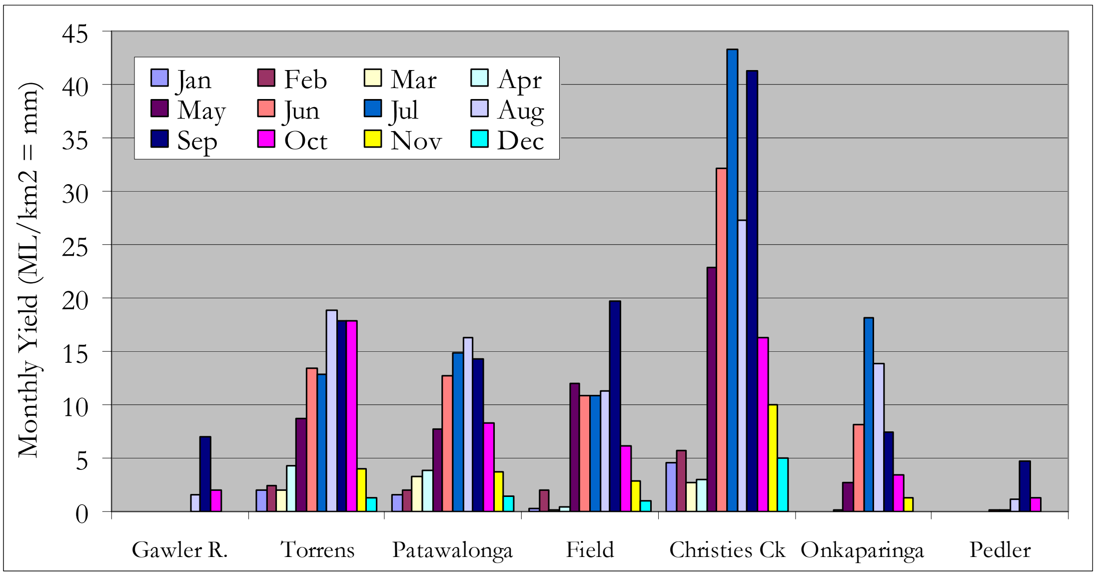


Figure 12. Unit area runoff by month from selected catchments in the ACWS area.

The annual and monthly yield from Christie Creek is greater than that of the other catchments (Figures 9 and 12). The summer yield from Christie Creek is of similar magnitude to that of the Torrens and Patawalonga, and in winter is significantly greater than the other creeks. Comparison of the daily flow series for Christie Creek with the Field River indicates that there is enhanced runoff during storm events as well as at lower rates of discharge. Examination of the base flow from Christie Creek indicates a consistent base flow of greater than 100 L/ha/d at times when the flow from the Field River is zero.

An examination of the annual flow volume, catchment area and annual yield of the various catchments with significant residential landuse (these include the Torrens, Patawalonga, Coastal catchment, Field River and Onkaparinga Estuary) shows that the mean of the annual yield estimates for these catchments was approximately 93 mm (ML/km^2) within a range of 77 mm and 108 mm. The yield from Christie Creek was 214 mm, slightly over twice as much as the other catchments. If Christie Creek were responding to rainfall with the average yield of 93 mm (for the period of estimation), the annual volume of run-off would have been 3.53 GL. The gauged flow indicates a discharge of 8.10 GL, suggesting that Christie Creek is producing around 4.57 GL of runoff more than might be expected for an urbanised catchment of 37.8 km^2 on the Gulf St Vincent coast. The 8.10 GL discharge is equivalent to the runoff that might be expected from an 86.7 km^2 catchment with a yield of 93 mm.

The cause of this elevated yield is not currently clear. One possible cause may be the interception of a groundwater body in the lower part of the catchment, although it is unlikely that this would cause the flow to be elevated to the extent indicated. Another potential cause might be the rating for the stage discharge control structure where flow is measured at Galloway Road, this issue is under investigation and the findings will be reported in the final input studies report.

6. Field and Laboratory Program

6.1 Field sampling program

The basis of the proposed sampling strategy for stormwaters in the ACWS area is very simple:

1. The Torrens, Patawalonga, Field River and Christie Creek are well characterised by the existing flow proportional monitoring carried out in those catchments. Thus it is proposed that any sampling in those catchments be limited to the occasional high flow sample (if at all).
2. The Holdfast Shores storm drains are very flashy in their hydrological response and can be guaranteed to flow on a regular basis. These outlets were last sampled more than 20 years ago. It would be valuable to assess any improvement or deterioration in the quality of runoff from these drains, given likely changes in rates of development in their catchments. It is proposed to sample up to 20 storm events from the main 5 drains sampled in the 1970s (Broadway, Harrow Rd, Wattle Ave, Edwards St. and Young St.).
3. The Gawler River and Smith Creek at the northern end of the study area are poorly characterised. It may be possible to retrieve the sample data for the 14 samples from the Gawler River if these still exist on the AWQC computer archives, in order to reference the results to the hydrograph phase. It is proposed that new samples be collected from the Gawler River. It is anticipated that only grab sampling will be carried out in the Smith Creek.
4. The creeks south of the Onkaparinga are predominantly in farming land with low urbanisation. The flow record for Pedler Creek indicates that these creeks are unlikely to produce significant runoff outside of the wettest central to late winter period, i.e. August, September and October. The Onkaparinga CWMB currently undertakes ambient monthly sampling of the southern creeks. In order to better characterise the period of greatest runoff it would be appropriate to undertake additional storm-response grab sampling.
5. There are currently two composite flow proportional samplers available for field use. Given the short duration of the field study and the high potential for vandalism, it has been decided that these samplers will be deployed in a responsive manner as indicated in Table 14. Pipework has already been installed in the Harrow Road and Young Street storm drains in preparation for composite sampling and additional composite sampling of the River Torrens outlets has been requested as part of a broader plume tracking marine oceanographic investigation within ACWS.
6. There are excellent web facilities for interrogating current and recent rainfall and river responses. The current weather map can be used to warn of incoming weather systems (http://www.bom.gov.au/weather/national/charts/synoptic.shtml). The current radar rainfall intensity image indicates the location and intensity of actual rainfall over Metropolitan Adelaide (http://mirror.bom.gov.au/products/IDR463.shtml). Actual rainfall totals at various time intervals and at numerous locations throughout Metro Adelaide can be used to decide where to focus field activities, since rainfall across the metropolitan area can be very heterogeneous (http://www.bom.gov.au/hydro/flood/sa/adelaide_clickable.shtml). River height gauges are also logged real-time by the Bureau of Meteorology and can indicate whether a river is responding to flow (http://www.bom.gov.au/cgi-bin/wrap_fwo.pl?IDS60151.html). This latter capacity is of particular use for the Gawler River which is at least 50 km north of Flinders University (the base level of the gauge is 1.2 m at Heaslip Bridge (Angle Vale Bridge: Map 31 UBD).

Table 14: Timetable and plan for stormwater sampling during the winter 2004 field monitoring period.

December 2003 to September 2004	Storm event sampling of Coastal catchment. • Attempt to capture rise of flow event. • Make use of composite sampler pipework in Young and Harrow drains • Reduce priority and intensity of sampling program from end July – focus on daytime flow rise episodes in the working week
May 2004 to end September 2004	Very targeted additional hydrograph rise sampling of Christie Creek and Field River (Use radar early warning)
June 2004 to end October 2004	Targeted high flow, rising flow, monitoring of Onkaparinga u/s Old Noarlunga and at estuary mouth footbridge • Note tidal situation • Use rain gauge data network to assist in decision making (Rainfalls in excess of 13 mm in the immediate vicinity of the Onka system should result in significant response)
July 2004 to end October 2004	Composite sampling of Torrens Outlet at Military Road – **only in response to request via Peter Fairweather or Simon Bryars (SARDI)** [use time based sampling]
July 2004 to end October 2004	Torrens, Patawalonga, Christie Creek, Field River • In consultation with H Fallowfield – additional sampling for Faecal Sterols and Faecal Indicator Bacteria (refer to Emily Fearnly)
August, September, October 2004	**Gawler River and Smith Creek** • Check BOM rain gauge network and interrogate BOM Heaslip Bridge level gauge (1.2 m is the base level of the gauge), check for rainfall in excess of 25 mm • Liaise with Kevin Taylor at Penrice 8409 9515 for local advice on Buckland Park Lake condition (i.e. is it empty, filling or full?) • Flows in these channels will be rare events and worthwhile to sample
August, September, October 2004	**Southern Creeks** • Pedler, Maslin, Willunga, Aldinga, Sellicks and South Sellicks Creeks • Check for rain in excess of 20 mm • **Give HIGHEST priority during August, September and October 2004** • Aim to capture rising flows and peak flows, expect 3 to 4 hour lag time to rainfall runoff response at outlets

6.2 Overview of protocol for sampling of stormwaters

Objectives

- To characterise loads of nutrients and suspended material entering the ocean from various stormwater outlets
- To determine the load of heavy metals in urban stormwater sources

Sampling Procedure

- A combination of grab sampling and flow proportional auto sampling is to be used. The auto-samplers are rotated between sites in order to characterise full events for each site
- Every storm outlet (in the chosen program) will be grab sampled at least once during the course of each event

Equipment Preparation

- Sampling tubes are installed in each outlet, such that the sampler may be connected up at the onset of each event
- Predetermined constants will be used to program the samplers at each site to ensure operation appropriate to that site
- Sample tubes are acid washed and reloaded as soon as practicable after each rainfall event
- The enclosure interior is regularly checked for dust and cleaned down with ethanol and deionised water as required

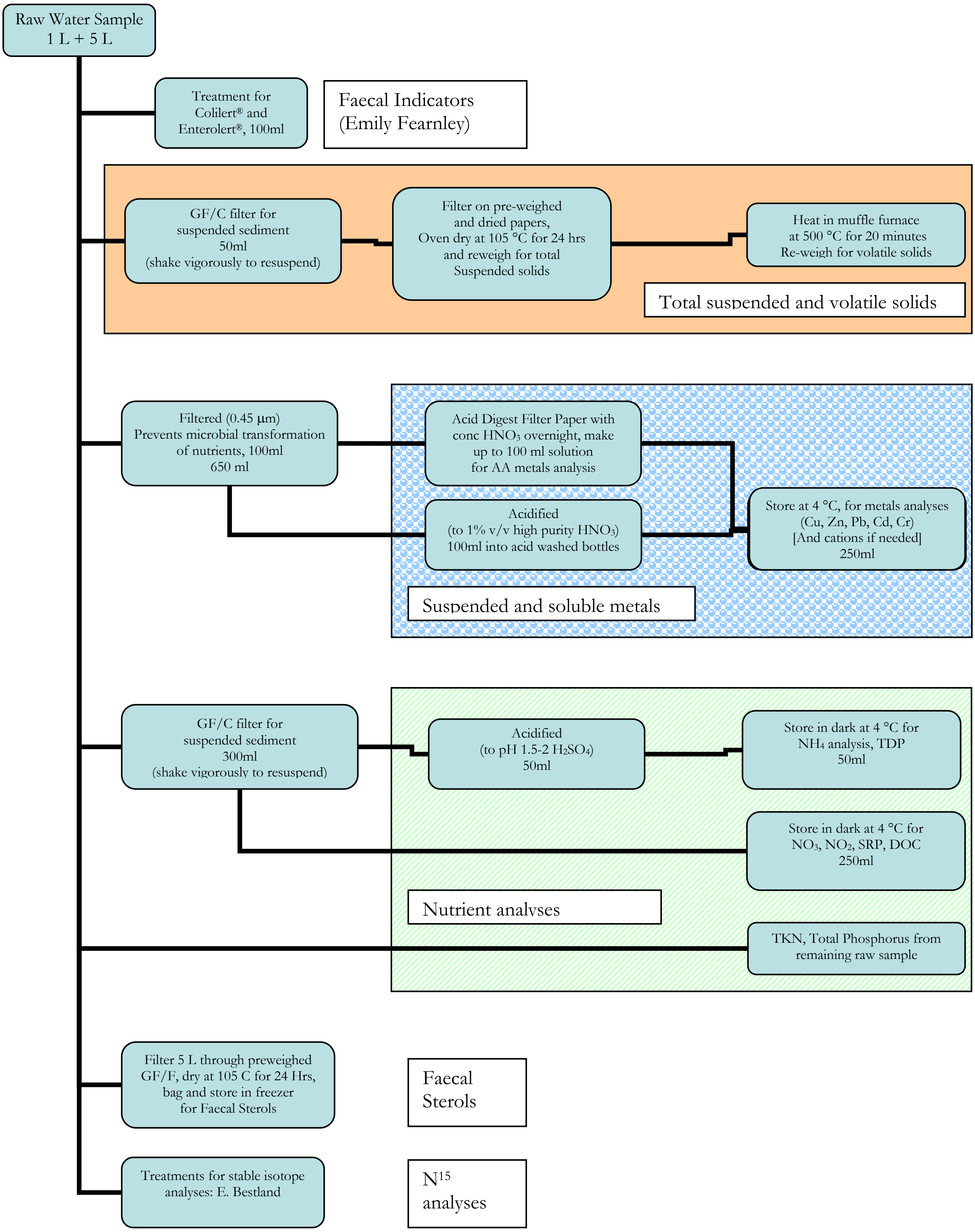
Sample Treatment and Storage

- Samples are divided into two sub-samples
- Sub-sample 1 is acidified to 1% vv high purity HNO_3 and stored in 10% nitric acid washed LDPE bottles and refrigerated at 4°C in the dark
- Sub-sample 2 is stored at 4°C in the dark prior to analysis
- An additional 1 litre raw sample is filtered on pre-weighed 47 mm GFC filter papers, these are oven dried overnight at 80°C and reweighed on a four-figure balance

Sample Analysis (see Flow Chart Below)

- Total nitrogen and total phosphorus by UV absorbance
- Major cations by atomic absorption Spectrometry of the acidified sub-sample (Na, K, Ca, Mg)
- pH, conductivity, suspended solids

Figure 13: Stormwater sample pre-treatment and analysis flowchart



7. Conclusions and Recommendations

The degree to which the quality and quantity of stormwater runoff from catchments and drainage systems in the ACWS area has been characterised varies greatly. There are 23 major and minor catchments in the ACWS study area ranging from the Gawler River in the north to the South Sellicks catchment. Of the 23, six are minor coastal areas in the southern area which have little or no surface drainage. The Barker Inlet receives runoff from 4 of these catchments and is the subject of a study by EPA, further meetings with EPA are being sought in order to discuss complementary areas of the two projects. It is not anticipated that ACWS will sample the Barker Inlet, although additional water may be requested from EPA for analyses that EPA are not undertaking. The Metropolitan Adelaide water supply network operated by SA Water has a major impact on the natural flows of a number of the catchments, in particular the Torrens and Onkaparinga. Where water supply management operations and infrastructure effectively split the catchments, only those areas downstream of the water supply systems have been considered as stormwater contributing areas and for the purpose of catchment area and landuse characterisation.

The Gawler River and Smith / Thompson Creek drain into the northern zone of the coast, which southern limit is Barker Inlet mouth. South of Barker Inlet to Port Stanvac are the Torrens and Patawalonga systems and the Patawalonga Coastal catchment which is drained by 10 storm drains of varying size. The southern central zone receives runoff from the Field River, Christie Creek and the Onkaparinga River. South of the Onkaparinga Estuary there are 4 catchments of greater than 3000 Ha., Pedler, Maslin, Willunga and Aldinga Creeks, these are predominantly in agricultural and horticultural use and only produce runoff to sea during the wettest months of August, September and October.

Downstream of the Port Wakefield Road the Gawler River spills out of its banks at flows in excess of 864 MLD. The river terminates in Buckland Park Lake (ca. 750 ML), a significant seasonal wetland. When full Buckland Park Lake spills over a causeway into the coastal mangroves. These within shore losses reduce the total annual discharge to sea from between 18 to 35 %.

The Torrens and Patawalonga are heavily urbanised. Rainfall events of 6 mm or greater in the Sturt catchment produce a storm runoff response within 20 minutes. In 1996 81% of suspended solids, 50 % of nitrogen and 67 % of phosphorus annual load from the Torrens was discharged within the period of two weeks. Formerly the Patawalonga Lake provided settlement for solids transported by the creek, removing an estimated 43 % of the load. The Barcoo Outlet now bypasses the Patawalonga Lake. Certain stormwater mitigation initiatives, some of which were proposed in 1974, have been implemented. Discharge of treated wastewater from Heathfield WWTP into the Upper Sturt River has risen from 55 ML in 1981 to around 1300 ML in recent years, the nitrogen load has risen from 1.5 to around 30 tons/year. Recent upgrades are expected to reduce this to around 13 tons N/year.

The Torrens and Patawalonga have composite samplers and hydrometric stations which provide a continuous record of water quality and quantity since 1996 and 1997, respectively. Weekly composite samples are analysed for a broad suite of determinants including nutrients, metals and suspended material. The Field River and Christie Creek are monitored in the same way as the Torrens and Patawalonga with flow proportional samplers. Monitoring commenced in 2001, therefore only three years of record are available for these sites. Additional ambient grab sampling is carried-out on a monthly basis. The Field River and Christie Creek are heavily urbanised and produce runoff in response to storms throughout the year. There have been a small number of analyses for pesticides in ACWS stormwaters, these suggest that this potential impact on the coastal ecosystem is not a high priority for further investigation. The authors have requested and are awaiting recent data for pesticides in the OCWMB streams.

Christie Creek presents an anomaly when compared to the other creeks with catchments with a large proportion residential landuse. The catchment discharges, annually, around 4.5 GL more water than would be expected from a catchment of that size with that degree of urban development. That's 130% more flow, or put another way, the current discharge is 2.3 times greater than might be expected. The actual flow volume is equivalent to what might be expected from and catchment of 87 km^2 rather than 37 km^2.

Of the southern creeks, south of and including the Onkaparinga River, only Pedler Creek has hydrometry. All of these sites are grab sampled monthly and analysis for metals, nutrients and suspended materials is carried-out. The Onkaparinga and Gawler Rivers had hydrometry near their outlets (or tidal limit) from the early 1970s to 1988. Flow gauging on the Gawler River was reinstated in 2001. The gauging site in the Onkaparinga has not been reinstated. Both catchments have a very minor urban component and only flow significantly in the winter from June to October.

The Onkaparinga Estuary receives storm runoff from 8 storm drains which service the suburbs of the Noarlunga area, as well as, runoff from the main Onkaparinga river channel. Observations of the Onkaparinga Estuary advection time and tidal transport indicate that during periods of minimal discharge from the main river system, the transit time downstream is slow and that only contaminants derived in the lower few km of the estuary will exit to sea. This finding suggests that locally derived stormwater from short duration storms occurring in the period when the upper catchment is not sufficiently wet (and when Mt Bold reservoir is in deficit) are likely to remain within the estuary affording settlement of solids and uptake of nutrients. At times of enhanced discharge from the upper river system there may be a combination of enhanced transport downstream and resuspension of settled material stored within the estuarine channel. It is worth noting here that similar observations of the Heathfield WWTP might be expected, i.e. maximum attenuation of nutrient loads during dry weather with the only appreciable long distance transport within the Sturt River during high flows.

There is a body of historical data from the early 1970s to early 1980s. The majority of this data was generated from the Gulf St Vincent Water Pollution Studies of the EWS Department of the SA Government. The data focuses on storm runoff from the Central Metropolitan zone; the Torrens, Patawalonga and Holdfast Shores' storm drains. The results are focussed on nutrients, suspended and dissolved contaminant loads. Additional summaries of data for the Onkaparinga and Gawler Rivers for 1978 to 1983 exists. These data offer some limited potential for comparing historical and contemporary water quality from a number of the major stormwater systems in the ACWS area.

The stormflow season is heavily affected by landuse. Those catchments with heavy urbanisation respond to rainfall all year round. The predominantly rural catchments have extreme soil moisture deficit and only produce significant runoff from July to October. The key period for stormwater discharges is August and September when around 40 % of the mean annual stormwater discharge to sea occurs. A further 40 % of the typical annual stormwater discharge occurs in June, July and October.

Of typical annual flows from the major stormwater sources, the Torrens contributes 23 % of the runoff, the Patawalonga 20 %, the Gawler River 10 %, Smith Creek 5 % and Onkaparinga River produces 15 % of the annual runoff. Christie Creek produced 8 % of the annual runoff from only 1.6 % of the total land area. The ACWS stormwater sampling strategy concentrates on characterising those discharges which are currently under-represented in the data or are not being investigated by other studies. On this basis the focus of the IS1 SP1 field effort will be on characterising the northern streams; Gawler River and Smith Creek, the five major Holdfast Shores storm drains, and the high flow discharges from the Onkaparinga and those creeks south of the Onkaparinga. Additional grab samples may be collected on selected storms from the existing composite flow proportionally monitored sites. There are two additional composite samplers available to ACWS IS1, these will be deployed on an event response basis in the Coastal catchment and the Torrens River.

A general point to be raised is that of the wind-wave resuspension of sea-floor fine sediments and the consequent reduction in light availability. The material from terrestrial sources that has accumulated in the coastal system since land disturbance commenced and the opening of direct transport pathways to the coastal zone needs to be quantified. In addition, if possible, it is necessary to establish the mass-balance of this reservoir. Is net accumulation still occurring, and to what extent, if any, do tidal currents disperse resuspended fines from the system. It is possible that the size of the fine sediment reservoir is so great that the inputs to the system have a negligible impact over short timescales. By investigating the wind record for the Adelaide coastline it should be possible to predict periods of wind activated turbidity and investigate the duration of these events and the total turbid time during each year. The turbid event period could then be related to typical information regarding sea-grass rhizome energy reserves and whether these events have a critical impact in weakening the plants.

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Appendix I – Listing of all identified storm drain outlets from Largs Bay to Seacliff (Courtesy of S. Bryars, SARDI)

	Grid Datum	UTM WGS84										
Waypoint	Date			Easting	Northing	location	Beach or Dune	Pipe type	approx. diam.(cm)	SA Water No.	Category	Comment
5	12/09/02	54	H	270509	6146503	Sth end Nth Haven	Dune	Unk	unk		2	Large manhole cover and Power possibly pump, behind sand
6	12/09/02	54	H	270539	6146141	Moldavia walk	Dune	Cement	30	3697	2	
7	12/09/02	54	H	270517	6145772	Gedville Tce	Dune	Stainless+trap	60	3695	1	signs of flow
8	12/09/02	54	H	270509	6145650	Paringa St (nth side)	Dune	Cement	30	3694	2	signs of flow
9	12/09/02	54	H	270501	6145156	Largs Academy	Dune	Cement	20	3654	2	signs of flow
12	12/09/02	54	H	270386	6144120	Afric St	Dune	Cement	20		2	below roads edge
13	12/09/02	54	H	270494	6144610	Charnock St	Dune	Cement	20		2	below roads edge
14	12/09/02	54	H	270483	6144499	Kybunga Tce	Dune	Unk	unk		2	Potentially a pipe (manholes and drains on road consistent with previous pipes
15	12/09/02	54	H	270443	6144282	Magarey St	Dune	Unk	unk		2	Potentially a pipe (manholes and drains on road consistent with previous pipes
16	12/09/02	54	H	270294	6143906	Walcot St??	Dune	Cement	30	3681	2	Possibly wrong on last digit of pipe no.
17	12/09/02	54	H	270257	6143837	Roslyn St	Dune	Cement		3680	2	
18	12/09/02	54	H	270201	6143720	Largs Sailing Club (Nth)	Dune	Cement	30		2	
19	12/09/02	54	H	270180	6143704	Largs Sailing Club (Nth)	Dune	Stainless+trap	100	3693	1	
20	12/09/02	54	H	270169	6143667	Largs Sailing Club (Nth)	Dune	Stainless+trap	60	3692	1	
21	12/09/02	54	H	270133	6143589	Largs Sailing Club (Sth)	Dune	Stainless+trap	60	3691	1	
22	12/09/02	54	H	270094	6143502	Largs Jetty Nth	Dune	Stainless+trap	60	3677	1	
23	12/09/02	54	H	270071	6143429	Largs Jetty Sth	Dune	Unk	Unk	3676	2	Small poly pipe visible but signs of larger waterflow
24	12/09/02	54	H	270038	6143363		Dune	Unk	unk		2	signs of flow
25	12/09/02	54	H	269997	6143274		Dune	Unk	unk	3675	2	Manhole visible but not pipe, assume closer to beach
26	12/09/02	54	H	269974	6143183	Anthony St	Dune	Stainless+trap	60	3690	1	
27	12/09/02	54	H	269935	6143082	Ralston St	Dune	Unk	unk		2	Potentially a pipe (manholes and drains on road consistent with previous pipes
28	12/09/02	54	H	269891	6143001	Kalgoolie Rd	Dune	Black Poly	30		2	Also Square manhole
29	12/09/02	54	H	269891	6143001	Hannay St	Dune	Black Poly	30		2	Also Square manhole

	Grid Datum	UTM										
		WGS84										
Waypoint	Date			Easting	Northing	location	Beach or Dune	Pipe type	approx. diam.(cm)	SA Water No.	Category	Comment
30	12/09/02	54	H	269847	6142867		Dune	Unk	unk		2	no notes
31	12/09/02	54	H	269789	6142673		Dune	Unk	unk		2	Manhole visible but not pipe
32	12/09/02	54	H	269763	6142602		Dune	Unk	unk	3667	2	Manhole visible but not pipe
33	12/09/02	54	H	269713	6142479		Dune	Stainless+trap	60	3689	1	
34	12/09/02	54	H	269650	6142329		Dune	Stainless+trap	60	3688	1	
35	12/09/02	54	H	269589	6142188		Dune	Unk	unk		2	No pipe visible but signs of water flow
36	12/09/02	54	H	269525	6142043		Dune	cement and trap	60	3652	1	
37	12/09/02	54	H	269504	6141995	Semaphore Rd	Dune	cement	30	3673	2	
38	12/09/02	54	H	269489	6141930		Dune	Stainless+trap	60	3687	1	
39	12/09/02	54	H	269482	6141847		Dune	Stainless+trap	60	3686	1	
40	12/09/02	54	H	269482	6141810		Dune	Stainless+trap	60	3699	1	
41	12/09/02	54	H	269472	6141747		Dune	cement	30	3672	2	
42	12/09/02	54	H	269465	6141714	Sth Tce	Dune	Stainless+trap	60	3684	1	
43	12/09/02	54	H	269443	6141615	Park	Dune	Stainless+trap	60	3685	1	
44	12/09/02	54	H	269429	6141555	Park	Dune	Stainless+trap	60	3684	1	
45	12/09/02	54	H	269400	6141435	Park	Dune	Stainless+trap	60	3682	1	
46	12/09/02	54	H	269390	6141388	Park	Dune	cement	20		2	
47	12/09/02	54	H	269328	6141142	Park	Dune	cement	30	3676	2	
48	12/09/02	54	H	269295	6140964		Dune	cement	30		2	
49	12/09/02	54	H	269368	6139678	Third Ave	Dune	Unk	unk		2	signs of flow
50	12/09/02	54	H	270128	6136600	Mirani Ct	Beach	Unk	unk		2	signs of large flow
51	12/09/02	54	H	270571	6134890	Grange Jetty	Beach	cement	30		2	
52	12/09/02	54	H	270643	6134581	Beach St	Dune	cement	60		1	Three pipes, 2 x 20, 1 x 30
53	12/09/02	54	H	270706	6134308	Grange Rd	Dune	Stainless+trap	60		1	
54	12/09/02	54	H	270788	6133981		Dune	Unk	unk		2	Cement pillar with manhole, assume pipe in greenery
55	12/09/02	54	H	270989	6133161	Henley Square Nth	Dune	Unk	unk		2	flow signs from rocks
56	12/09/02	54	H	271003	6133069	Henley Jetty Nth	Beach	poly	20		2	onto beach
57	12/09/02	54	H	271007	6133052	Henley Jetty Nth	Beach	poly	20		2	onto beach

	Grid Datum	UTM WGS84										
Waypoint	Date			Easting	Northing	location	Beach or Dune	Pipe type	approx. diam.(cm)	SA Water No.	Category	Comment
58	12/09/02	54	H	271015	6132999	Henley Jetty Nth	Beach	cement	20		2	onto beach
59	12/09/02	54	H	271023	6132979	Henley Jetty Sth	Beach	cement	20		2	onto beach
60	12/09/02	54	H	271031	6132953	Henley Jetty Sth	Beach	cement	20		2	onto beach
61	12/09/02	54	H	271037	6132934	Henley Jetty Sth	Beach	cement	20		2	onto beach
62	12/09/02	54	H	271050	6132826		Beach	cement	60		1	two pipes, 1 x 20 and 1 x 30
63	12/09/02	54	H	271065	6132790		Beach	cement	20		2	
64	12/09/02	54	H	271075	6132757		Beach	cement	20		2	
65	12/09/02	54	H	271094	6132706		Beach	cement	30		2	
66	12/09/02	54	H	271105	6132672		Beach	Unk	unk		2	Pipe not visible but signs of water, assume same as previous
67	12/09/02	54	H	271138	6132559		Beach	cement	30		2	
68	12/09/02	54	H	271157	6132488		Beach	Cement	30		2	
69	12/09/02	54	H	271190	6132314	Henley Beach Rd	Beach	cement	100		1	two pipes, 1x 100 and 1 x 20
70	12/09/02	54	H	271376	6131710	Lexington Rd	Beach	cement	30		2	
71	12/09/02	54	H	271664	6130650		Beach	Unk	unk		2	No pipe visible but signs of flow
72	12/09/02	54	H	271714	6130483	Cavendish St	Beach	Unk	unk		2	No pipe visible but signs of flow
73	12/09/02	54	H	271783	6130191	Cottesloe St	Beach	cement	60		1	Two pipes, both 30cm
369	12/07/02	54	H	272538	6128062	WB-Glen	Beach	cement	30		2	top of rock bund
370	12/07/02	54	H	272610	6127864	WB-Glen	Beach	cement	30		2	top of rock bund
371	12/07/02	54	H	272679	6127623	WB-Glen	Beach	cement	30		2	top of rock bund
372	12/07/02	54	H	272762	6127196	WB-Glen	Beach	cement	30		2	top of rock bund broken pipe
373	12/07/02	54	H	272770	6126484	Magic mtn	Beach	Rubber inner, cement	60		1	cement pipe with rubber inner at ground level
374	12/07/02	54	H	272738	6126280	Glen. Jetty	Beach	Rubber inner, cement	60		1	cement pipe with rubber inner at ground level + possibly one more buried 10m Nth, both just under Glenelg jetty
375	12/07/02	54	H	272754	6126210		Beach	Unk	unk		2	No notes ???
376	12/07/02	54	H	272791	6126010		Beach	Buried, Rubber inner	60		1	High sand with mark on wall similar to other outlets.
377	12/07/02	54	H	272772	6125909		Beach	cement	30		2	
378	12/07/02	54	H	272750	6125870		Beach	Rubber inner, cement	60		1	signs of significant flow

	Grid Datum	UTM WGS84										
Waypoint	**Date**			**Easting**	**Northing**	**location**	**Beach or Dune**	**Pipe type**	**approx. diam.(cm)**	**SA Water No.**	**Category**	**Comment**
379	12/07/02	54	H	272748	6125736	Pier St, Glenelg	Beach	Major drain 1	100		1	Buried but almost certain it's a large drain because top is similar to others, also confirmed by R Sandercock
380	12/07/02	54	H	272667	6125390	Broadway	Beach	Rubber inner, cement	60		1	sth of kiosk
381	12/07/02	54	H	272673	6125250	Farrel St	Beach	Unk	unk		2	Buried. Mark on rocks and signs of water flow.
382	12/07/02	54	H	272752	6124918	Marine St	Beach	Major drain 1	100		1	1m pipe mostly buried
383	12/07/02	54	H	272859	6124055	Harrow Rd	Beach	Major Drain 2	300		1	Large drain two pipes cement (150)
384	12/07/02	54	H	272886	6123849	Repton St	Beach	Polypipe	30		2	small pipe high on bund
385	12/07/02	54	H	272958	6123262	Downing - Hulbert St	Beach	cement	60		1	
386	12/07/02	54	H	272993	6123078		Beach	Polypipe	30		2	
387	12/07/02	54	H	273019	6122940	Wattle Ave	Beach	Major drain 3	200		1	Major drain, Large square outlet with rubbish trap
388	12/07/02	54	H	273037	6122840		Beach	Polypipe	30		2	
389	12/07/02	54	H	273040	6122800		Beach	Polypipe	30		2	
390	12/07/02	54	H	273064	6122718		Beach	Polypipe	30		2	signs of flow
391	12/07/02	54	H	273077	6122686	Smith Ave	Beach	Polypipe	30		2	signs of flow from under rocks
392	12/07/02	54	H	273081	6122660		Beach	Polypipe	30		2	signs of flow
393	12/07/02	54	H	273100	6122582	King St	Beach	Unk	unk		2	signs of significant flow from under rocks
394	12/07/02	54	H	273119	6122528		Beach	Polypipe	30		2	signs of significant flow from under rocks
395	12/07/02	54	H	273129	6122456		Beach	Unk	unk		2	signs of flow from under rocks
396	12/07/02	54	H	273146	6122406		Beach	Unk	unk		2	signs of flow from under rocks
397	12/07/02	54	H	273165	6122350	Dunluce Ave	Beach	cement	60		1	flow
398	12/07/02	54	H	273281	6121961	Brighton Jetty	Dune	cement	100		1	
399	12/07/02	54	H	273281	6121961	Beach Rd	Dune	cement	60		1	Large flow
400	12/07/02	54	H	273379	6121699		Dune	Unk	unk		2	Large flow from a low point in the road
401	12/07/02	54	H	273410	6121584	Edward St	Dune	Major drain 3	200		1	Large square one, plenty of water
402	12/07/02	54	H	273456	6121342		Dune	Unk	unk		2	Not sure this is a drain, cement structure and plenty of sign of water around but no flow.
403	12/07/02	54	H	273506	6121122	Young St	Dune	Major drain 3	200		1	
404	12/07/02	54	H	273515	6121057	Angus Neil Reserve	Dune	Unk	unk		2	Cant see pipe but signs of significant flow into the dunes

	Grid Datum	UTM WGS84										
Waypoint	Date			Easting	Northing	location	Beach or Dune	Pipe type	approx. diam.(cm)	SA Water No.	Category	Comment
405	12/07/02	54	H	273525	6120637	Seacliffe	Beach	cement	100		1	Two pipes both around 50cm, signs of flow
406	12/07/02	54	H	273523	6120569	Seacliffe	Beach	cement	60		1	flowing
407	12/07/02	54	H	273459	6120166	Seacliffe Yacht club and SLSC	Beach	cement	60		1	signs of significant flow
408	12/07/02	54	H	273370	6119901	Kingston Pk	Beach	cement	30		2	
409	12/07/02	54	H	273346	6119859	Beginning of rocks	Beach	cement	60		1	flowing

Appendix II: Maps of catchments, with sampling and hydrometry locations.

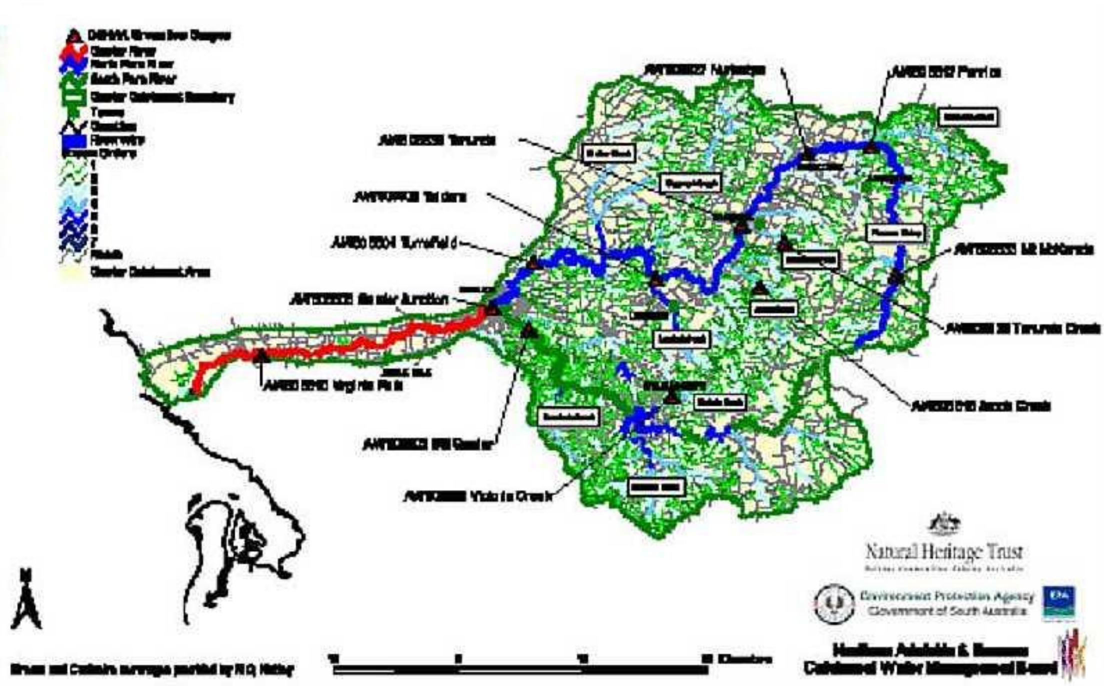

Figure AII.1 Catchment map of Gawler River (source NABCWMB)

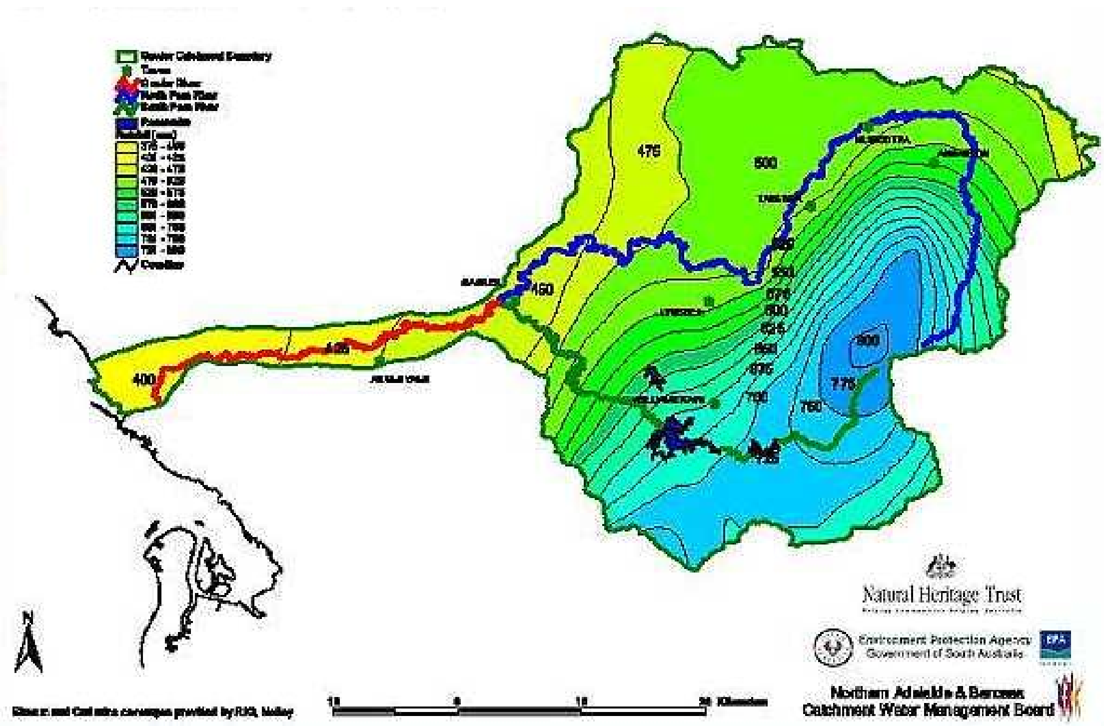

Figure AII.2 Rainfall distribution over the Gawler catchment (source NABCWMB)

Figure AII.3 Section of water balance schematic for the Gawler River and Smith Creek (From the NABCWMB Plan 2001-6). The inset shows Buckland Park Lake.

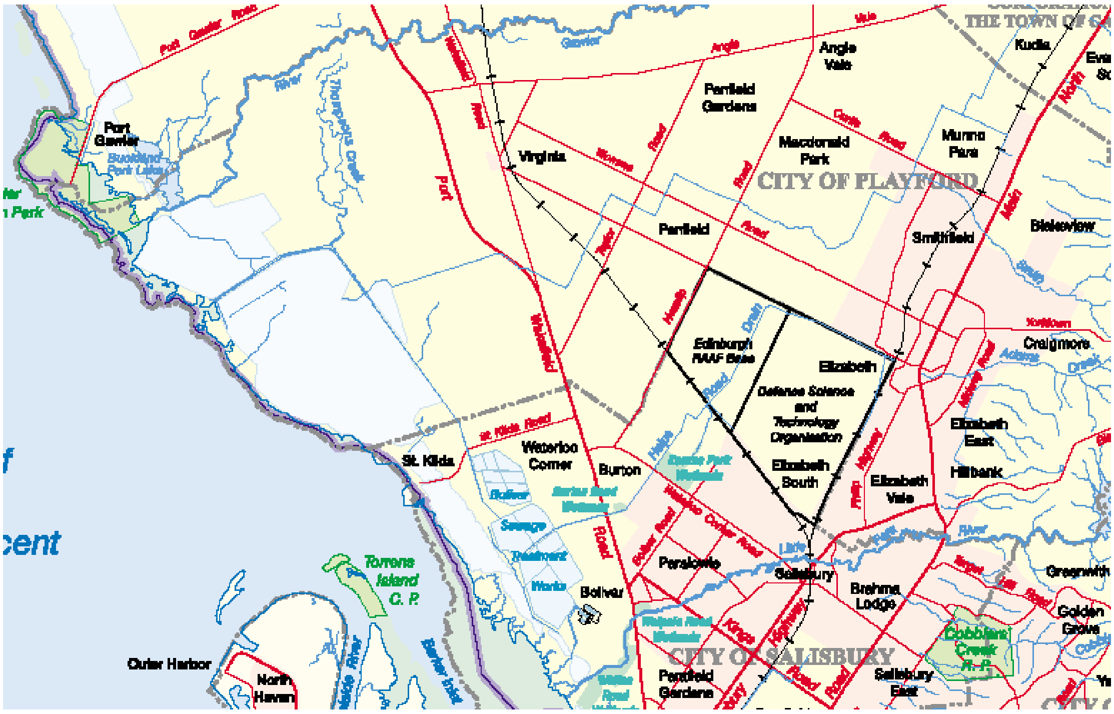

Figure AII.4 Location of the Smith / Thompson Creek system and Buckland Park Lake on the Gawler River outlet (From the NABCWMB Plan 2001-6)

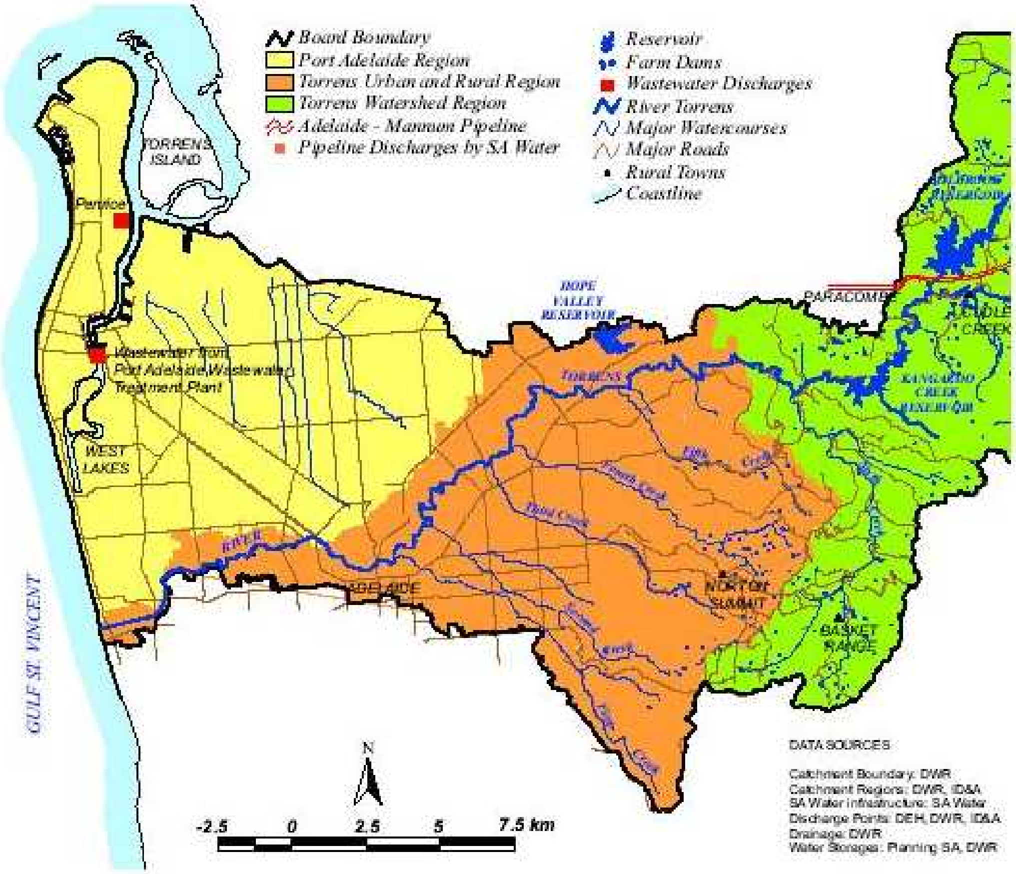

Figure AII.5 The Torrens urban catchment (from TCWMB Management Plan 2002-2007)

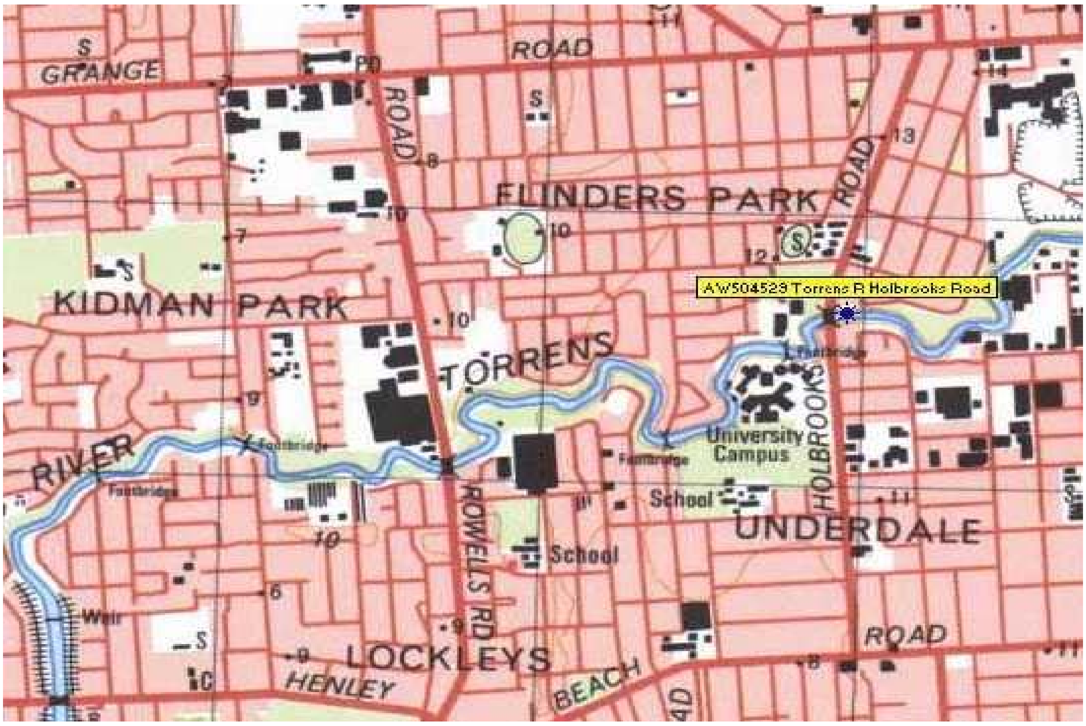

Figure AII.6 Location of the Holbrooks Road hydrometric and composite monitoring station on the Torrens

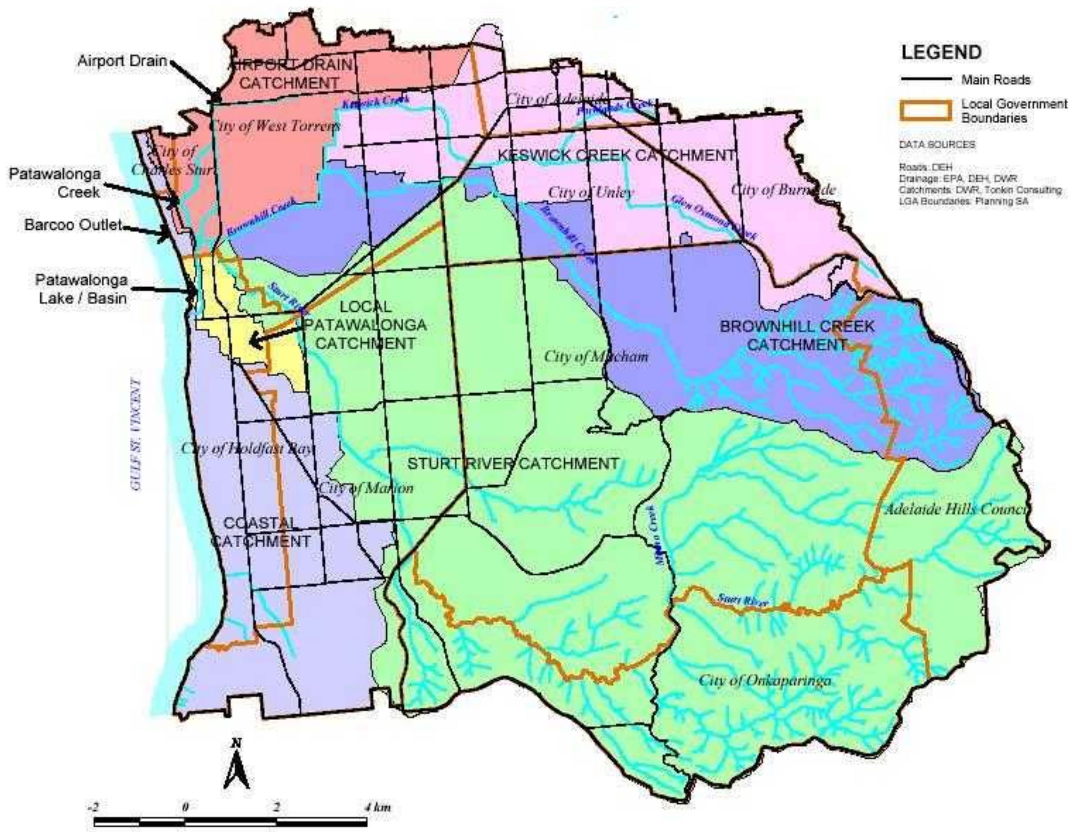

Figure AII.7 The Patawalonga Catchment (from PCWMB Management Plan, 2002-2007)

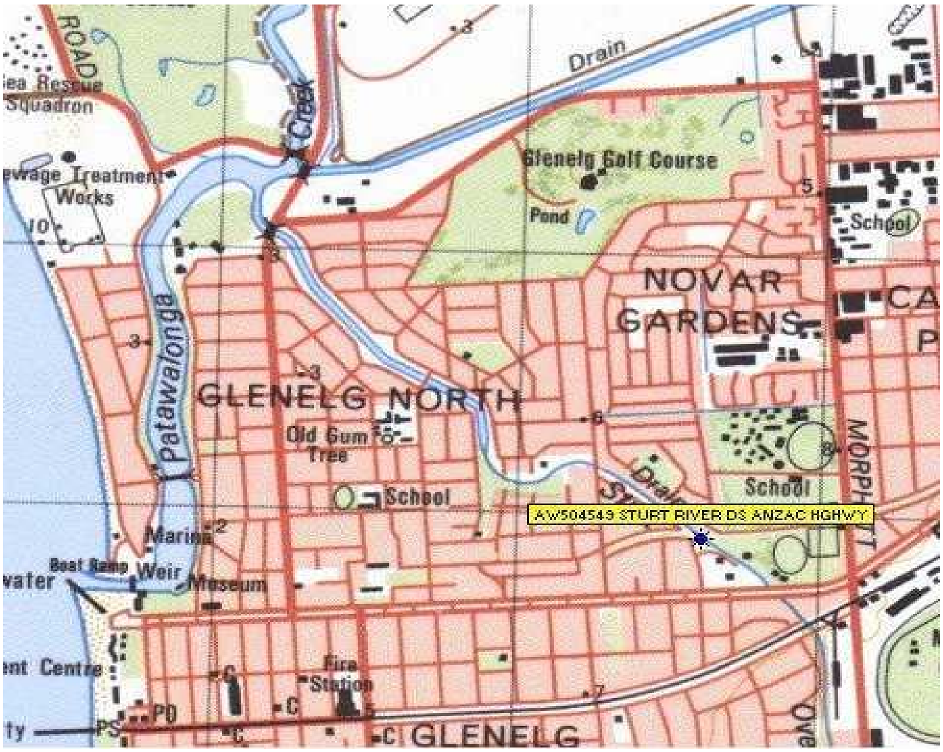

Figure AII.8 Location of the Anzac Highway hydrometric and composite monitoring station on the Sturt River.

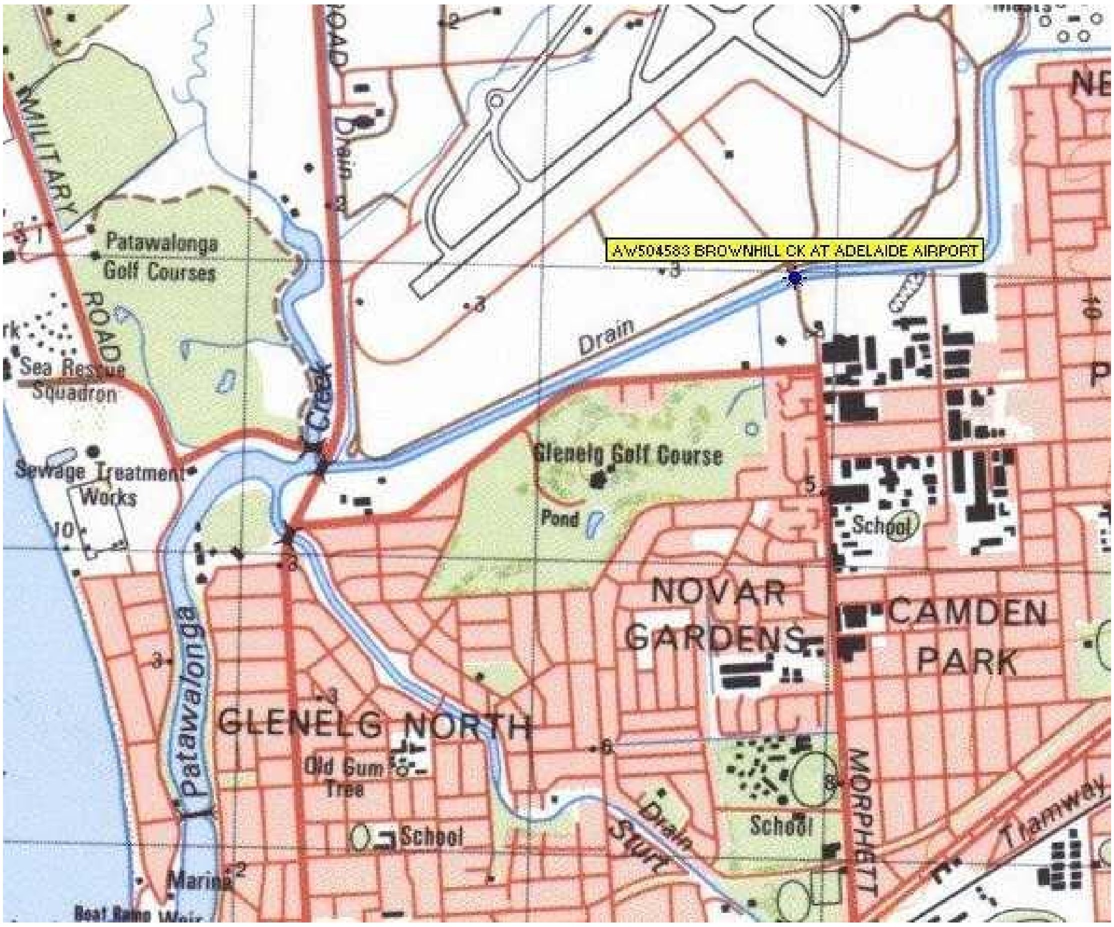

Figure AII.9 Location of the Adelaide Airport hydrometric and composite monitoring station on the Sturt River.

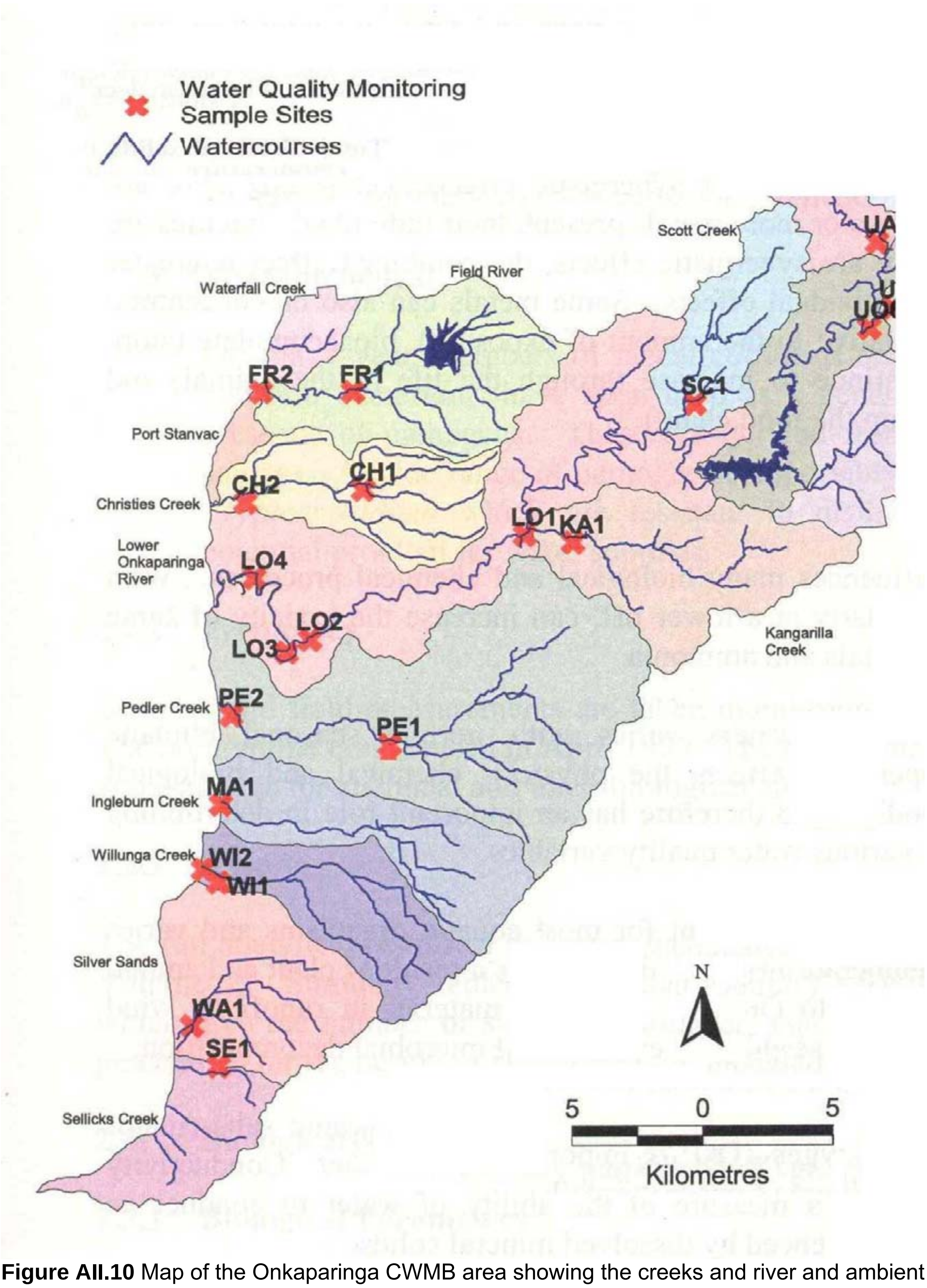

Figure AII.10 Map of the Onkaparinga CWMB area showing the creeks and river and ambient water quality monitoring locations (source: S Gatti OCWMB)

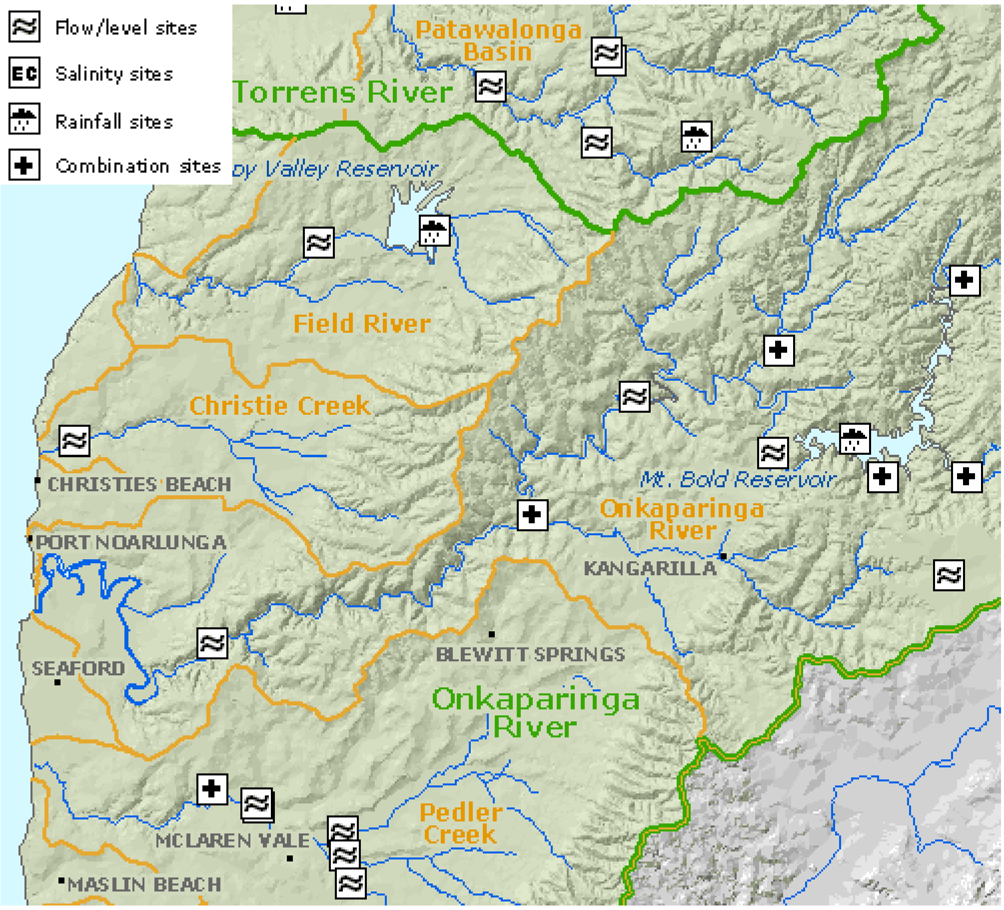

Figure AII.11 Location of hydrometric stations in the southern catchments of the ACWS area (source DLWBC, Surface Water Archive)

Appendix III: Key Water Quality Findings of the 2002-2007 Patawalonga Catchment Water Management Plan

General

- Water quality in both the rural and urban catchment areas is extremely variable due to the nature of runoff events and seasonal factors. Many of the water quality trigger valves in ANZECC, 2000 are exceed for the catchment's aquatic ecosystems which range from highly to slightly disturbed ecosystems. Water quality objectives suitable for the catchment and its receiving waters need to take account of habitat condition and the assimilative capacity of those systems. This will require further detailed assessment such as the current Adelaide Coastal Waters Study. At this stage, the urban and coastal systems have been moderately to highly disturbed and measures of riparian habitat, macroinvertebrate health and ambient water quality have been made. A detailed risk based decision framework to tailor water quality guidelines for specific Patawalonga catchment conditions will need to be progressively implemented through the next planning period.
- Water quality variability in terms of loads is also of interest. Data have shown that the bulk of pollutants (particularly suspended solids, nutrients) is exported during large events over very short periods (AWQC, 2000). This has significant implications for source control management, available treatment options and impacts on receiving waters.
- The majority of the pollutants in the catchment come from diffuse sources, with the exception of nutrients in the discharge from the Heathfield Waste Water Treatment Plant (WWTP) which is a major point source.

Urban Catchment

- Urban stormwater quality in the catchment is similar to that in other cities throughout Australia, although Adelaide's sewerage system ensures that the occurrence of sewer overflows is very limited.
- Most of the heavy metals from the urban catchment appear to come from road runoff and represent loads from motor vehicles, road surfaces and vehicle wear materials. Heavy metals are also associated with industrial areas.
- The source of microbiological contamination from the urban catchment appears to be birds, dogs, cats and wildlife in the catchment. Research on faecal steroids by Flinders University has confirmed this (Ralph et al, 1998).
- Urban stormwater will never be able to meet current ANZECC primary or secondary contact trigger guideline valves all the time because of the extensive and endemic sources of faecal coliforms throughout the catchment. Sources include native and exotic birds (including ducks), dogs and other animals. Dispersion, die-off or dilution in receiving water bodies will reduce these levels, however this can take time.
- Microbiological contamination in urban stormwater is unlikely to be sourced from sewerage system leakages and therefore the risks associated with accidental primary/secondary contact are likely to be very low (WHO, 1999).
- Urban stormwater quality is quite acceptable for irrigation and most industrial supplies. These uses make up the bulk of metropolitan Adelaide's water supply needs which are annually serviced by SA Water.
- Gross pollution, debris, turbidity and unsightly algae growths remain the primary community perception of poor water quality. The inability to use the Patawalonga Basin for recreation has generated a perception of poor water quality.
- Community awareness and education is needed regarding what are realistically achievable water quality targets in the urban environment.

Patawalonga Lake/Marine Waters

- The man-made Patawalonga Lake has acted as a sedimentation basin, on average capturing approximately 42% of suspended solids load from the catchment. As a result of high numbers of faecal coliforms following stormwater events, the Lake has been unsuitable for primary or secondary contact recreation for many years. In addition, the accumulation of pollutants in the sediment has been a source of contamination due to their remobilisation in a bioavailable form. As a result of this accumulation and the development of black anaerobic sediments, each time the flood gates were opened in storm events, to flush the Lake or to move the near shore sand bar, an extensive black plume was produced which resulted in the closure of beaches. Because of its unsightly nature and extent, it was easy for the general public to associate it with damage to marine ecosystems, such as the seagrass beds. It is now believed the principal factor in seagrass decline has been the offshore discharge of sewage sludge (which ceased in 1993) and sewage effluent.
- The recent dredging of the Basin as part of the clean up of the Patawalonga has removed a potential source of contamination and the plume.
- With the Patawalonga Basin seawater circulation system and stormwater outlet (Barcoo Outlet) in place, a significant improvement in lake water quality will occur. The discharge point has been located offshore in an attempt to reduce the risk of adversely affecting beach amenity and recreational use.
- The construction of the Barcoo stormwater outlet and the completion of the previous Catchment Plan strategies have resulted in less pollutant load discharging into the Gulf despite the loss of the sedimentation basin function of the Patawalonga. The previous 'sedimentation' function of the Patawalonga was not sustainable because it could not be readily de-silted so as to prevent the remobilisation of pollutants. Despite some community perception that the Barcoo Outlet has increased pollutant load to the marine environment, in the Board's view, catchment water quality modelling and assessments have indicated that the level of load will decrease.

Data Requirements

- As outlined in ANZECC (2000), the development of local water quality objectives is not a simple process. More detailed ambient water and biological monitoring data is required before locally appropriate Water Quality objectives are adopted – rather than reliance on the ANZECC (1992-2000) trigger levels and draft EPP Water Quality (EPA, 2001). Also more local research on the impacts of stormwater on ecosystems and receiving waters is needed.

The Adelaide Coastal Waters Study will assist in setting appropriate objective levels

Appendix IV – Detailed breakdown of landuse in main ACWS catchments (landuse data provided by PIRSA)

Landuse class	Area of cover Ha.	Description of class	Smith Ck	Torrens	Patawalonga	Field R.	Christies Ck	Onkaparinga	Pedler Ck	Maslins Ck	Willunga Ck	Aldinga Ck	Sellicks Ck
1	7833.5	Natural feature protection	1	2601.5	1274.25	76.75	5.75	2370	181.5			266.5	
3	448.75	Other conserved area			179.5		3.5	67.25	75	25.5		42.75	
4	162.25	Landscape	93							17			
6	66.25	Other minimal use						6.75	4				
8	32.25	Rehabilitation							1.75		18.75		
9	17419.25	Grazing natural vegetation	142.5	4067.75	1217.75	151.25	94.75	1825.25	410.25	39.5	50		
10	3357.75	Plantation forestry	10.25	165	40.75	3.5	1	554.75	44.5	24.5	8.25	68	
29	3213.25	Open water features	1235.5	21.5	29.5	6.25		77.25			15.75	13.5	
30	53.75	River						53.75					
31	16	Marsh/wetland								16			
		Low impact use	1482	6856	2742	238	105	4955	717	123	93	391	0
11	71495.75	Grazing modified pastures	5935	2668.6	2743.75	821.25	1215.25	7731.75	3523.25	1228	921.75	1515	562.5
15	8698.75	Irrigated modified pastures	773.75	23.5	26.5		12.25	611	0.75	17.25			
20	11.5	Intensive animal production						4.75	5.25	1.5			
		Grazing/Animal use	6708.75	2692.1	2770.25	821.25	1227.5	8347.5	3529.25	1246.75	921.75	1515	562.5
12	4955	Cropping	2904.25	18			8.75	159.5	158.75	135	109	363.75	
13	39.75	Perennial horticulture							35.5	4.25			
14	3.5	Irrigated plantation forestry							3.5				
16	720.5	Irrigated cropping		61.5				18.5					
17	19701.25	Irrigated perennial horticulture	1730.75	1101.5	116.5	20.75	92.25	1239.25	4947.5	1494.25	1335.25	1518.75	13.75
18	4666.25	Irrigated seasonal horticulture	3183.25	37	1			3.75			7.75	6.25	
19	9.5	Intensive horticulture									7.5	1.5	
		Horticulture / Cropping	7818.25	1218	117.5	20.75	101	1421	5145.25	1633.5	1459.5	1890.25	13.75
21	612	Manufacturing & industrial	34	4.25	63.5	27	313.5	56.5	18	0.75	1.75		
22	22773	Residential	1849.5	966	3468.25	1388	1345.25	1311.5	632	183	343	675.25	15.75
23	4881.5	Services	713	27.75	700	537.75	283.5	287	156.75	72.75	36.5	121.75	0.25
24	0.25	Utilities							0.25				
26	775	Mining	16.5	203.75	41.75	26.5	3.25	93.25	12.5				33.75
27	153.25	Waste treatment & disposal			1		24	30.5	70.5				
34		Urban areas not on map	105	9881	10977.5	554.5	376.5	685.75	448.75	133.25	172.25	326.5	28
		High impact landuse	2718	11082.75	15252	2533.75	2346	2464.5	1338.75	389.75	553.5	1123.5	77.75
32	2393.5	**Unmapped**	1832.75	0	357.5	0	0	0	8.25	0	0	0	0
		Totals	20560	21849	21239	3614	3780	17188	10739	3393	3028	4920	654

Appendix V – Summary of estimated loads of nutrients and suspended solids delivered to the central metropolitan area 1978 to 1981 (data from Steffensen, 1985).

	1978		1979		1980		1981	
	Tonnes/ year	% of total	Tonnes/ year	% of total	Tonnes/ year	% of total	Tonnes/ year	% of total
(a) Phosphorus								
Edwards Street Drain	0.10	<1	0.20	<1	0.06	<1	0.13	<1
Young Street Drain	0.30	<1	0.40	<1	0.20	<1	0.30	<1
Patawalonga Creek	4.3	3	5.8	4	3.9	3	6.3	4.0
River Torrens	3.6	2.5	6.6	4.5	3.0	2.5	12.5	8.0
Glenelg STW effluent	135	94.0	125	91	125	95	140	88
(b) Nitrogen								
Edwards Street Drain	0.6	<1	0.8	<1	0.3	<1	0.7	<1
Young Street Drain	10	1	12	1.5	6	1	10	1
Patawalonga Creek	70	8	95	12	64	8	104	9
River Torrens	74	9	136	17	62	8	257	23
Glenelg STW effluent	700	81	540	69	650	83	740	67
(c) Suspended Solids								
Edwards Street Drain	90	1	120	1	45	<1	100	<1
Young Street Drain	510	6	640	5	300	4	550	3
Patawalonga Creek	5650	66	7680	62	5[illegible]30	69	8360	50
River Torrens	2210	26	4050	32	1840	25	7640	46
Glenelg STW effluent	120	1	130	1	120	2	130	1

Appendix VI – Flow proportional composite sampling and water quality variable codes

Composite Sampling Method

Water is sampled from the stream using the volume proportional composite sampling method. The method requires that an accurate predetermined calibration of the river flow versus height relationship is available. This relationship is programmed into the data logger. The logger continuously calculated the cumulative flow passing the sampling location from the continuous measure of water level. Programmed into the logger is a predetermined volume increment (e.g. 0.2 ML). Each time the volume increment is reached the logger triggers a sampler. The sampler then: -

- Purges the sample line by forcing air out to the river.
- The pump then reverses and flushes the sampling line by extracting water from the river over a preset time.
- After flushing, a 500ml aliquot of water is extracted and delivered into an 80 litre high quality PET plastic tub.

The flow volume increment for triggering the collection of each sample was selected to ensure that a maximum number of samples were taken without overtopping the container into which the individual samples were discharged. The increment was changed as necessary based on current flow conditions so as to attempt to achieve the maximum number of samples. Because the actual flow could never be predicted the increment was chosen so as to provide a safety margin to ensure that the tub does not overflow. A logbook was kept on-site documenting the volume increment and the number of aliquots taken between sample collection visits. The number of individual aliquots varied from 0 to 160, depending upon the flow and the volume increment. Each week, usually Wednesday, the station was visited and the composite tub was stirred vigorously and one representative sample set removed (1 @ 500ml, 1 @ 1.25 litre PET bottles). The tub was then emptied and cleaned. The determinant sample result represents the mean flow-weighted concentration of the flow during the sample period (usually 1 week). By multiplying the mean concentration value by the total flow volume for the sampling period produces a reliable estimate of load for the sample period.

For more detailed information on the composite sampling method, including effects of storage on the determinant concentrations refer to the report 'Nutrient Loads in the Onkaparinga River System' (Nicholson B.L., Clark R.D. 1992)

Sample Delivery and Analysis

Sample analysis was done by the Australian Water Quality Centre (AWQC), which is NATA accredited for chemical testing and has Quality Certification ISO 9001. The AWQC provided 'run sheets' and bar coded labels for each sample bottle and site location. The bar code provided the AWQC with the site details and the type of water analysis required for the site. When the sample was collected WDS would write the date, time and operator name onto the label. When the sample run was completed each bar code was scanned. The sample bottles were delivered to the AWQC on the same day that they were collected and the scanned information uploaded to the AWQC computer. The bar code then provided the AWQC with trace-ability throughout the processing stages of the sample.

TDS was determined by the direct measurement method for the period 1988 to November 1996. From 1996 TDS was then calculated from EC. The reason for this change is not known. For this report the results from both methods were combined to form the one data set 1988 to 2002.

Analysis for suspended solids commenced in 1996 rather than at the commencement of the program. The reason for this is not documented and not known Nicholson and Clark (1992) found that Nox deteriorated over the period of on-site storage (1 week) and TKN increased. The change in Total Nitrogen (TKN + Nox) was shown to be less than 4% for the period of on-site storage (Nicholson and Clark, 1992). Therefore, Total Nitrogen, rather than TKN and Nox, was used for the purpose of this report. TKN and Nox concentrations for each sample were added together to produce Total Nitrogen (TN).

Analyte	Units	Method	Reference	Limit	Instrument
Total Dissolved Solids (TDS)	mg/L	Direct measurement up to Nov 1996 Derived from conductivity after 1996	ALPHA 2520 B	1	WTW auto ranging with temperature correction
Suspended Solids (SS)	mg/L	Total suspended solids dried at 103 – 105 °C	ALPHA 2540 D	2	Drying Oven
Electrical Conductivity (EC) (at 25 °C)	uS/cm	Electrical conductivity	ALPHA 2520 B	1	WTW auto ranging with temperature correction
Phosphorus – total (TP)	mg/L	$H_2SO_4/K_2SO_4/HgO$ digestion followed by automated ascorbic acid colorimetric method	Technicon Method 376-75W, Technicon Method 155-71W, in-house modifications	0.005	Skalar segmented flow analyzer
Nitrogen + Nitrate as N (Nox)	mg/L	Automated colorimetric cadmium reduction method	ALPHA 4500	0.005	Skalar segmented flow analyzer
Nitrogen – total Kjeldahl (TKN)	mg/L	Kjeldahl digestion followed by automated colorimetric method	Based on Technician method 376-75W	0.1	Skalar segmented flow analyzer

Variable Description Report
Variable Name Units Precision
800 Total Dissolved Solids (by EC) mg/L 0.001000
801 Total Dissolved Solids (Measured) mg/L 0.001000
802 Suspended Solids mg/L 0.001000
803 Turbidity (Un-corrected) NTU 0.001000
804 Turbidity (Corrected) NTU 0.001000
805 Colour - True (456nm) HU 0.100000
806 pH units 0.100000
816 Uncorrected Conductivity MicroSeimens/cm 1.000000
820 Uncorrected Conductivity MilliSeimens/m 1.000000
821 Conductivity (Corrected) MicroSeimens/cm @25C 1.000000
822 Nitrate as nitrogen mg/L 0.010000
823 Nitrite as nitrogen mg/L 0.010000
824 Phosphorus - Total as P mg/L 0.001000
825 Phosphorus - Soluble as P mg/L 0.001000
826 TKN as N mg/L 0.001000
827 Nitrate + Nitrite as N mg/L 0.001000
828 Filtered Reactive Phosphorus as P mg/L 0.001000
829 Total N mg/L 0.001000
830 Calcium mg/L 0.100000
831 Magnesium mg/L 0.100000
832 Potassium mg/L 0.100000
833 Sodium mg/L 0.100000
834 Bicarbonate mg/L 0.100000
835 Carbonate mg/L 0.100000
836 Chloride mg/L 0.100000
837 Sulphate mg/L 0.100000
840 Asenic - Total mg/L 0.000100
841 Cadmium - Total mg/L 0.000100
842 Chromium - Total mg/L 0.000100
843 Copper - Total mg/L 0.000100
844 Lead - Total mg/L 0.000100
845 Mercury - Total mg/L 0.000100
846 Zinc - Total mg/L 0.000100
847 Iron - Total mg/L 0.000100
848 Nickel - Total mg/L 0.000100
849 Aluminium - Total mg/L 0.000100
850 Boron mg/L 0.001000
851 Manganese mg/L 0.000100
860 Ethyl Benzine ug/L 0.010000
861 O-Xylene ug/L 0.010000
862 M,P-Xylene ug/L 0.010000
863 Toluene ug/L 0.010000
864 Benzene ug/L 0.010000
865 Hydrocarbons C06 - C09 mg/L 0.001000
866 Hydrocarbons C10-C14 mg/L 0.001000
867 Hydrocarbons C15-C28 mg/L 0.001000
868 Hydrocarbons C29-C40 mg/L 0.001000
869 Total Aromatic Hydrocarbons mg/L 0.100000
870 Grease and Oil mg/L 0.001000
871 Simazine ug/L 0.001000
872 Atrazine ug/L 0.001000

Appendix VII: A Simple Hydrological Model for ACWS Stormwaters

The model used in this study, is ***based-on*** the IHACRES model, and is a lumped conceptual rainfall-runoff model, based on unit hydrograph principles. IHACRES means ‘Identification of unit Hydrographs and Component flows from Rainfalls, Evaporation and Streamflow data’.

The IHACRES rainfall-streamflow modelling methodology is the result of collaboration between the Institute of Hydrology, Wallingford, UK and the Australian National University, Canberra (Jakeman *et al*. 1990; Littlewood and Jakeman, 1993, 1994). In principle, the methodology can be applied at any data timestep. There are published accounts of analyses ranging from using 6-minute interval data on catchments less than 1 ha (0.01km^2) to monthly data on a catchment of about 10000 km^2. The methodology has been successfully applied to many catchments at a daily data timestep.

The only input data required are:

- unbroken time series of rainfall (and streamflow for calibration);
- corresponding air temperature (as an indicator of seasonal changes in evaporative demand);
- catchment size (km^2).

The outputs are:

- modelled streamflow time series;
- modelled catchment wetness index time series;
- unit hydrographs (only with the package, not used in this study);
- hydrograph separation (in many cases) into dominant quick and slow flow components;
- indicative uncertainties associated with the unit hydrograph parameters (only with the package).

A three pathway manually optimised model based on IHACRES has been applied in the ACWS study. The standard model consists of two modules, a non-linear loss module to convert rainfall to effective rainfall, and a linear module to convert effective rainfall to streamflow (Jakeman and Hornberger, 1993). Effective rainfall is that rainfall which is not lost to evapotranspiration and which therefore eventually becomes streamflow. Figure 1 is a schematic diagram showing the structure of the model in graphical form. In the formulation used by ACWS there are three flow pathways one for rapid runoff that might be associated with surface runoff from residential or developed areas with a high proportion of impervious surfaces, the other two pathways are for slower travelling water to provide the hydrograph recession and sustain baseflow during dry weather (where this occurs). Further physical interpretation of these flow components is avoided because it would be over-simplistic to attempt to represent the many spatial and temporal processes and factors that result in a flow time-series at a given location. Indeed, it is not the purpose of such a model to represent a physical analogy of the complex hydrological system. The purpose is to provide a reliable and robust estimate of discharge at a point of interest.

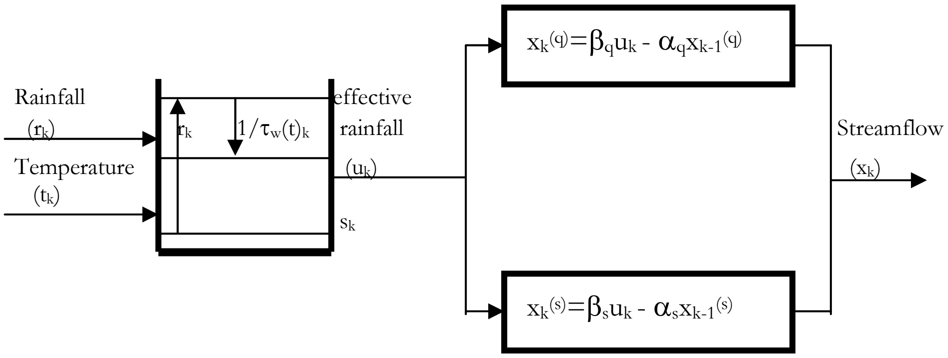

Figure 1: Commonly identified basic model structure of the "IHACRES" model as described by Littlewood and Jakeman, (1993).

In the non-linear module, a catchment storage index s_k is calculated at each time step. This indicates the potential of the catchment to produce streamflow from precipitation (Jakeman *et al*, 1990). The most commonly identified structure in the linear module (used here) is two flow pathways in parallel, corresponding to quick and slow flow (Figure 1). The model equations are as follows.

Effective rainfall,

$$r_k^* = 1 - \left(\frac{T}{T_{\max}} \right) r_k$$

where r_k is the measured rainfall, r^*_k is rainfall minus evapotranspiration, and T is air temperature. The catchment storage index is represented by

$$s_k = \left(\frac{\tau_w^{-1}}{1-(1-\tau_w^{-1})z^{-1}} \right) r_k^*$$

where τ_w is the time constant of the soil moisture store. The model is presented in the finite difference backwards approximation (see Young and Wallis, 1993). In the discrete time form, z^n is the "z-operator" and is a mathematical convenience to aid notation and to help simplify equations. For example, if the rainfall at time t, $r_t = r_k$ and the sampling interval is given by Δt, then the rainfall at $t + \Delta t$ is r_{k+1}, which is $z^1 r_k$, similarly $z^{-1} r_k = r_{k-1}$, i.e. the previous value of rainfall. Finally, the effective runoff volume, u_k, is the product of effective rainfall (m) and catchment area (m^2);

$$u_k = A \frac{s_k}{s_{\max}} r_k^*$$

where s_{max} is used to scale soil moisture storage between 1 and 0. In the IHACRES model where the output runoff volume is known, a scaling constant is used to adjust the effective rainfall volume to the observed discharge volume (Littlewood and Jakeman, 1994). In the current application the effective catchment area is varied to match the model and measured run-off volumes.

The effective run-off volume, is routed (typically) through the two-box transfer function model to produce a resultant flow with a quick and slow flow component given by

$$Q_{ik} = \frac{b_s}{1-a_s z^{-1}} + \frac{b_q}{1-a_q z^{-1}} u_k ,$$

the model differs only slightly from the IHACRES model in that the user decides the separation between fast and slow flow and the time constant, T. The parameter relationships are, $a_q = e^{-\Delta t.\alpha_q}$,

$b_q = (1 - a_q)\psi$ and $a_s = e^{-\Delta t.\alpha_s}$ $b_s = (1 - a_s)(1 - \psi)$, where, $\alpha = 1 / T$, ψ, is the quick-flow / slow-flow ratio for the separation of the effective discharge volume, u_k, and has a value of between 1 and 0. For certain sites a third streamflow component is required, this is where there is a very slow baseflow, a very rapid quickflow component and an intermediate component. These might be considered to be infiltration excess plus shallow soil drainage and deep soil system drainage.

In the current application the model is applied in an excel spreadsheet version, the model is calibrated manually and three measures of model fit are used.

Rt^2 is a statistic of goodness of fit used in time-series modelling (see Young and Benner, 1991, Price *et al.*, 2000);

$$Rt^2 = 1 - \frac{\sigma(y_k - \hat{y}_k)^2}{\sigma(y_k)^2}$$

where, $\sigma(y_k - \hat{y}_k)^2$ is the variance of the squared model errors and $\sigma(y_k)^2$ is the variance of the squared observed values. When the model errors are small Rt^2 tends to 1.

The R^2 coefficient of determination is similar to Rt^2;

$$R^2 = 1 - \frac{\Sigma(y_k - \hat{y}_k)^2}{\Sigma(y_k - \bar{y}_k)^2}$$

where, $\Sigma(y_k - \hat{y}_k)^2$ is the sum of the squared model errors and $\Sigma(y_k - \bar{y}_k)^2$ is a measure of the variation of the observed values from the mean. When the model errors are small R^2 tends to 1.

The third measure of fit is specifically intended for the improvement of the fit of the recession limb of the modelled flows (Jakeman et al. 1993), this is the relative mean absolute error RMAE and is given by;

$$RMAE = \frac{1}{n}\sum\left|\frac{y_k - \hat{y}_k}{y_k}\right|$$

IHACRES rainfall-runoff model in the version of Littlewood and Jakeman (1994)												r2 = 1	rt2 = 1	rmae > 0
Tot. rain (mm)	541.814	T_max		τ_wet		τ_1 hrs	τ_2 dy	τ_3 dy	Sepn. Ratios = 1		Model	*R^2*	Rt^2	RMAE
Rain vol. ML	75149.5	16 °C		25 days		72	15	15	Ψ1	0.8	Scores	0.103	0.113	1.23
Catchment Area		138.7 km^2		Infiltration excess	0.03921	0.717	0.936	0.936	Ψ2	0.2		Model		Observed
		Volume	13558.4	40	13199.1	0.227	0.013	0.0000	Ψ3	0	9672.872	8834.3	vol. ML	7301.1
		35 % loss	82.0	0.232	0.804 max			0.000	Total	1		88.2	% loss	90.3
Date, time	Rainfall Temp	R-star		Soil_ moist	U_k	Q_1	Q_2	Q_3			Q2+ Q3	Model Q		Obs. Q
					0		31	0.000						

Figure 2. Header section for the model of the Onkaparinga River between Clarendon Weir and Old Noarlunga township.

In the current study, flow modelling gives an indication of the variation in bedform at the control site where stage and hence discharge is measured. The nature of the field locations and the relatively short duration of the studies meant that it was not feasible to build fixed channel control structures. The consequence of this is that frequently after flood flows the bedform may have changed and hence the stage discharge relationship is altered. By fitting the model to the period of observed flows when gauging was most recently carried-out it is possible, by virtue of the modelling approach, to correct for these medium term changes in bedform at the gauging location.