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Catchments and Waterways

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CHAPTER 3

Catchments and Waterways

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Introduction

The major part of the Adelaide occupies the alluvial lowlands between Gulf St Vincent and the Mount Lofty Ranges. The landscape rises to the east and south along the lines of the faults that underlie Adelaide (Figure 3.1). The vast majority of the streams that traverse the plains originate in the ranges, as illustrated in Figure 1.1. There is a marked asymmetry of the River Torrens across the plains, where it is dominated by left bank tributaries. Relatively high precipitation in the ranges feeds the streams of the lower country. The original streams rarely reached the coast but petered out on the plains or formed wetlands dammed back by the dune barriers that flank the shoreline.

Figure 3.1: Faults of Adelaide

Faults of Adelaide

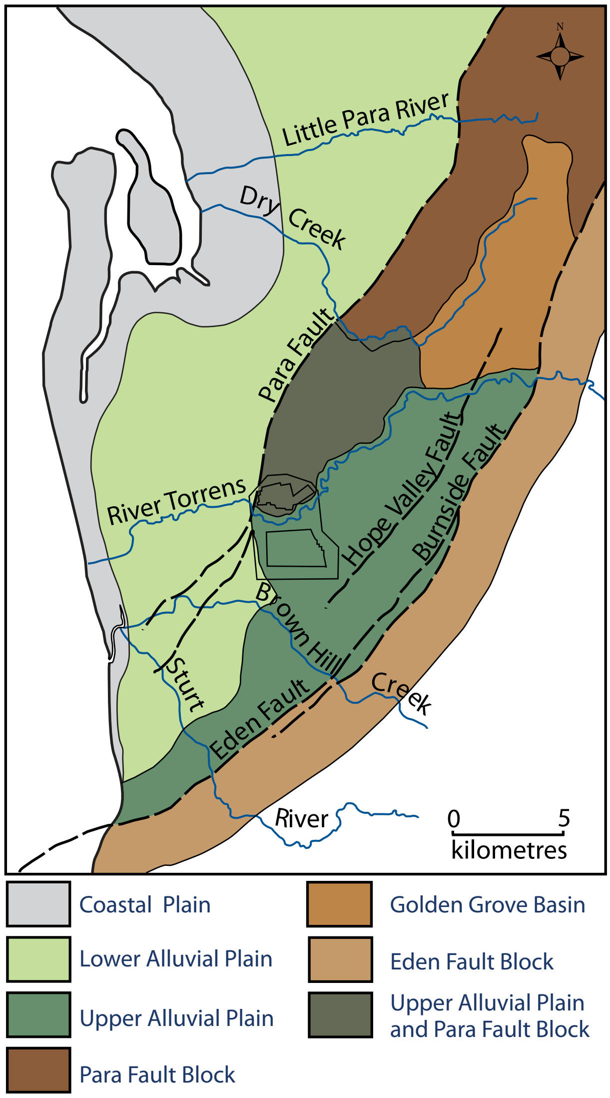

Figure 3.1 Major faults and geomorphic zones of the Adelaide area
Source: Sheard M.J. and Bowman G.M. (1996) : Soils, stratigraphy and engineering geology of near surface material of the Adelaide Plains. Mines and Energy South Australia, Report Book, 94 /9

Catchments of the Adelaide region

There are four major catchments occurring in the metropolitan region: the Northern Adelaide and Barossa, the Torrens, the Patawalonga, and the Onkaparinga. A drainage basin or catchment may be defined as '*… an area of land that collects water, which drains to the lowest point in the area which could be either a lake, a dam, or the sea. Rain falling on the land will make its way to this lowest point, via creeks, rivers and stormwater systems. As well as rivers, creeks, lakes and dams, a catchment also includes groundwater, stormwater, wastewater, and water-related infrastructure*'[1].

The Patawalonga catchment comprises 230 km^2 and encompasses a large part of metropolitan Adelaide. It includes Brownhill Creek, Keswick Creek, the Sturt River and the Airport Drain which flow into the Patawalonga Basin at Glenelg. The comparatively larger catchment area of Northern Adelaide and Barossa covers almost 2,000 km^2 and includes the Gawler River, which forms the northern boundary of the Adelaide Metropolitan Region, the South Para and North Para Rivers, Little Para River and Dry Creek. The Onkaparinga catchment comprises approximately 920 km^2 and includes the Onkaparinga and Field Rivers, Christie Creek, Pedler Creek and the Washpool Lagoon, '*one of the last remaining coastal lagoons in metropolitan Adelaide*'[2]. The catchment of the River Torrens comprises 620 km^2 with the upper part of the catchment arising at Mt Pleasant, beyond the Adelaide metropolitan area. In the lower part of the catchment the Torrens has five major tributaries flowing from the hills, First, Second, Third, Fourth and Fifth Creeks. It is significant to note that the River Torrens was one of the major reasons for Colonel Light's selection of the location of Adelaide[3].

Channel and floodplain modifications and management

Human impact varies between the different catchments. Before discussing the four major catchments within the region it is worth noting impacts on the Gawler River at the northern boundary. This river forms an administrative boundary between two councils but unilateral flood protection works by either council may have major flood impacts on the adjoining council. This highlights the need to manage flood issues on a catchment basis rather than on administrative boundaries. The two northern catchments within the Adelaide planning region are quite different with the Little Para being predominantly rural whereas the Dry Creek catchment has been significantly altered by industrial and urban development. The sedimentation in the Dry Creek catchment has led to management problems such as the accumulation of 1.5 kt of sediment at the Walkleys Road culvert in 1993 and another 0.7 kt in 1994[4]. Elsewhere, there have been attempts to improve the quality of the catchment such as by the construction of the Salisbury Greenfields wetlands in the 1980s.

To the south, the Torrens catchment has been heavily modified. While the catchment has a higher conservation value in the upper reaches this becomes patchy downstream and many lower sections no longer have any conservation value because of extensive modification. The Torrens used to discharge into a low lying marsh area called the 'Reedbeds' landward of the West Beach dunes. In times of high flow, the water drained both to the north through the Port River

The Biodiversity of Buckland Park

BOX 10

Buckland Park Lake is located approximately 30km north of Adelaide on the floodplain of the Gawler River. The area consists of low, flat alluvial plains with widely spaced stream channels feeding a number of shallow terminal lakes. The damming of several of the stream channels of the Gawler River in around 1920 is thought to have created the Buckland Park Lake[1]. Although the hydrology of the mouth of the Gawler River has been altered, Buckland Park Lake is one of the few remaining semi-natural places where rivers meet the sea on the northern Adelaide plains. The Draft Estuaries Policy & Action Plan for South Australia[2] listed Buckland Park Lake as one of only four recognised estuaries north of Adelaide in the Gulf St Vincent (others included the nearby Salt Creek to the north and the Port River Barker Inlet System to the south).

The area surrounding Buckland Park Lake is dominated by complex and diverse ecological characters which includes coastal dune systems, estuarine and inter-tidal environments, river floodplains, seasonal river-channel flows, open fresh water-bodies, mudflats and diverse vegetation including significant mangrove communities, samphire/saltmarshes, lignum shrublands and redgum woodlands. Few other places near Adelaide support such a diverse range of habitats within such a small area.

At the landscape scale, the area has natural links with protected areas including the Pt Gawler Conservation Park and the Dolphin Sanctuary to the west. There is also a variety of freshwater and brackish areas such as Thompson Creek, the Bolivar Sewage Treatment Works and Middle Beach, which contain significant vegetation (*Gahnia filum* sedgeland) and potential habitat for the Yellowish Sedge Skipper butterfly (*Hesperilla flavescens flavia*)[3]. Extensive salt evaporation pans occur to the south and to the north and east the land use is dominated by agriculture with highly cleared and fragmented native vegetation. A few small remnants near Buckland Park Lake indicate that these agricultural areas would have once supported extensive mallee box (*Eucalyptus porosa*) low woodland.

The area surrounding Buckland Park Lake is relatively diverse in both the plant communities and the plant species that it supports. The vegetation at Buckland Park Lake is dominated by saltbush (or saltmarsh) and samphire communities which surround the lakes and form a link between the coastal and terrestrial vegetation communities. On the low sand ridges coastal dune vegetation dominates the landscape, along the Gawler River Chanel riparian woodlands are found and significant mangrove (*Avicennia marina ssp. marina*) forests are present at the shoreline.

One of the most notable features of the Buckland Park Lake area is its importance for waterbirds. In 1991 Buckland Park Lake was the single most important breeding habitat for a range of waterfowl within the Adelaide region[1]. During 1989 and 1990 over 60 species of waterbirds were recorded using the Buckland Park Lake and surrounding habitat. This included many species which are rarely encountered in the Adelaide region and 9 species which were recorded as breeding at the location (the report also cited a further 12 species which were reported to have bred at the lake in previous years)[1]. It is thought that the habitat is most suitable for waterbirds due to the large influx of freshwater that reaches the system which then remains in the area of lignum, bulrush (*Typha domingensis*) and samphire which floods each year.

Within the Buckland Park Lake area there is over 120 ha of lignum shrubland, which excludes the river redgum woodland along the Gawler River where it is also present. This represents 96% of the currently mapped remnant lignum shrubland in the Southern Mount Lofty Region[4]. The importance this places on Buckland Park Lake's role in biodiversity conservation cannot be under estimated. These shrublands, combined with the flooding regime, contribute significantly to the protection of waterbird habitat and breeding cycles.

Buckland Park Lake must be considered an important biodiversity asset at both a site level and at the landscape scale. It is a valuable link between the freshwater riparian system on the Gawler River and the inter-tidal saltmarsh and mangrove communities at the coast and beyond to the marine ecosystem. Preserving the integrity of the Buckland Park Lake habitat contributes to the protection of bird species which may move between Buckland Park Lake, the Port River Barker Inlet wetlands and the Coorong and Lower Lakes.

Kate Smith

estuary and also to the south through the Patawalonga outlet. However, in 1937 an artificial sea outlet was constructed for the Torrens at West Beach diverting freshwater flow from the Patawalonga and Port River estuaries. Given the lack of flow from the Torrens to the Port River, that area was subsequently modified because of pressure for urban growth. This area was originally a mangrove swamp with tidal drainage but the mangrove and samphire vegetation was cleared in the mid 1970s to make way for the construction of the West Lakes waterfront residential development. Although extensive soft sediment (mud, sand and seagrass detritus) was removed this did not entirely prevent building problems. At times there have also been water quality problems with issues such as marine weed outbreaks related to storm water inflows and capacity of the marine flushing system.

The section of the Torrens closest to Adelaide CBD has been modified by the construction of a weir and creation of the artificial Torrens Lake. While this has very little conservation value it does have a high amenity value. Upstream from the lake, impacts include the O'Bahn transport system along the Torrens Linear Park and significant modification to all of five major tributaries flowing from the hills, First, Second, Third, Fourth and Fifth Creeks. Warburton[5] described in some detail the state of the five creeks in the mid-1970s. First Creek begins in the Cleland Conservation Park and works it way through Hazelwood Park and Marryatville but is constrained by urban development and in places has an engineered channel. It travels underground in a few sections as it approaches the CBD before disappearing under Prince Alfred College re-emerging in the Botanic Gardens before entering the River Torrens near Frome Road. Second Creek has suffered even greater modification. This creek starts in the hills to the north of Greenhill Road and travels through Stonyfell, Burnside and Leabrook before it largely disappears underground until it enters the Torrens at St Peters.

Third Creek has three main tributaries in the hills near Norton Summit. It travels toward Magill and Tranmere where there are sections of concrete channel. It travels underground as it enters the suburb of Firle before moving through a narrow drainage reserve or concrete channel until it joins the Torrens in Felixstow. Fourth Creek which has the largest catchment of the five creeks rises in the hills above Morialta Conservation Park before traversing the park with associated waterfalls before passing through Rostrevor. Fourth Creek still has a number of river gums and is discernible as a creek course although constrained in a many of places by urban development. Fifth Creek starts in the hills near Cherryville before traversing Black Hill Conservation Park beside Montacute Road and then turning northwest through Foxfield Reserve, Athelstone and Paradise. Although the creek is undergrounded at the Gorge Road and has some narrow creek reserve sections, it also benefits from a number of open spaces with river gums. This is not true in the final section of the Athelstone Recreation Reserve where native vegetation was non existent in the 1970s[5].

South of the Torrens is the Patawalonga catchment. In its upper reaches, in the vicinity of the Sturt River catchment are some sections of higher conservation value such as the Sturt Gorge Conservation Park but in the lower reaches the river is highly impacted to the extent that west of Marion Road it now resembles an open concrete drain. Closer to the hills, construction of the Warraparinga wetlands has provided an area of amenity value linked to indigenous heritage values in the area. A flood control dam was constructed in the Sturt Gorge and the lower section across the plain was set in a concrete channel to ameliorate flooding problems.

In the lower reaches of the Patawalonga catchment there has been significant human impact particularly with the creation and subsequent modifications to the airport drain which merges with the Sturt River, Brownhill Creek and the much smaller Patawalonga Creek to flow into the Patawalonga Lake, formerly a tidal estuary, created by the construction of lock gates at Glenelg. The Patawalonga Basin is important for ponding of stormwater. Enlarged in 1972 to store 450 ML, subsequent sediment accumulation reduced the storage volume to 300 ML[6]. The Patawalonga Basin thus acts as a storage sink for sediment and pollutants, with severe impacts on water quality. Some of the sediment is flushed out of the system under conditions of low tide or during flood events. Under these conditions the sea becomes stained with terrestrial materials, which drift northward along the coast and sometimes require closure of beaches.

Significant re-development projects at Glenelg near the mouth of the Patawalonga necessitated flood mitigation works for the Patawalonga Lake. The original Basin was formed by construction of a weir and lock system in the 1960, with the number of flood gates increased from 5 to 8 in the early 1970s following flood issues from storm water runoff. Later a weir was built at the northern end of the lake with a stormwater outlet system cut through to the sea to allow the regular flood events to bypass the Patawalonga outlet. The Barcoo Outlet comprising underground culverts was completed in 2001. In the first rains following its opening it was reported that a 'fine black waste' was deposited at West Beach[7] and warnings were made about undertaking 'recreational activities' at both West and Henley Beaches[8]. In addition to pollution, the issue of flooding came to the fore in February 2003 when the gates of the Barcoo Outlet did not open during heavy rains causing flooding in Glenelg North, and was partially responsible for flooding in West Beach[9]. In June 2003 severe flooding in Glenelg North with 'an estimated $20 million damage' bill occurred when the Patawalonga weir gate system reportedly failed[10].

Many of the human impacts have happened in a piecemeal manner and it was not until the 1990s that the State Government adopted a more integrated approach with the creation of four Catchment Water Management Boards in Metropolitan Adelaide. In 1995 Catchment Water Management Boards were created for the Patawalonga and the Torrens catchments. Two years later (1997) a board was created for the Northern Adelaide and Barossa catchment, and in 1998 a management board was created for the Onkaparinga catchment. These catchment boards were dissolved when the Federal Government introduced a natural resource management (NRM) system and separate legislation was introduced for the creation of NRM boards within South Australia. Most of the streams and rivers in the area now fall within the Adelaide and Mount Lofty Ranges

NRM Region.

Characteristics of Adelaide streams

In many other parts of the world channel capacities increase downstream with additional water contributed by inputs from tributaries. However, many Adelaide streams display a diminution in channel capacity downstream. This phenomenon is also reflected in Adelaide streams over thousands of years as fossil channels also display downstream diminution in channel size. Thus there is a tendency for channel capacities to be inadequate to contain the stream-flow with the response that natural levees in the lower stream sections are over-topped and the excess channel capacity of a flow is accommodated by flood-outs.

There are few perennial streams in the Adelaide area. Waterfall Gully, which is fed from water stored in high level swamps, such as Wilson Bog, is perennial for at least part of its course. However, the vast majority of streams are intermittent or ephemeral. Originally many streams did not have continuous channels but constituted "Chains of Ponds" that were only linked during flood events. Following European settlement, however, grazing and trampling by stock, and deliberate drainage works led to the erosion of continuous channels and the drainage of the ponds, with important impacts on stream hydrology.

A common feature of many Adelaide streams is that valley dimensions are largest near the junction of the hills and the plain. Streams are incised into alluvial deposits and are flanked by high level red-coloured river terraces and alluvial fans, with lower level grey coloured terraces and floodplains occupying valleys cut into the red alluvium. In the lower stream reaches there are further decreases in valley size; there are no terraces and the sediments that originally formed the low level terraces (grey alluvium) are washed out over the older red coloured alluvium, forming natural levee banks flanking the stream. In this way the stream channel can become perched above the general level of the plain so that if a levee is breached, widespread flooding can occur at lower levels even in areas remote from the actual channel. In some instances downstream channel capacity has been reduced by accelerated sedimentation following vegetation clearance and accelerated erosion on the valley slopes. It is uncommon on the Adelaide Plains for eroded sediments to be transported directly out to sea, but they are stored within the valley as sediment slugs and may be moved further down valley by successive flood events.

Originally, many of the streams of the Adelaide region did not reach the sea: the streams either simply ran out of water as they flowed across the plain, losing water by evaporation or seepage into the underlying aquifers (losing or influent streams), or because of low gradients ended in wetlands sometimes dammed back by coastal sand dunes (Figure 3.2). Occasionally some freshwater was delivered to the marine environment through streams such as the Gawler River, Smith Creek, and the Port River/Barker Inlet estuary system which originally comprised inflows from the Torrens River and several other smaller creeks. The Port River estuary has been constrained by the northward development of LeFevre Peninsula over the last 6-7,000 years[11]. Most coastal sediment here was derived from offshore sources during the rise in sea level following the last glacial maximum, and there is a significant biogenic contribution to Adelaide's coastal sediments. However, very little sediment was delivered to the coast by Adelaide streams.

Figure 3.2: Map of the Country between Adelaide and the Sea Coast, 1882. Image courtesy of The Bodleian Library, University of Oxford, reference I3:26 (3)

To the south the original extensive wetland of the Reedbeds in the western suburbs was formed by the blocking effect of coastal dunes. Most freshwater adjacent to Holdfast Bay, including the River Torrens, was initially caught in the Reedbeds[10, 11, 12, 13]. This water would have either, (1) recharged the below-ground aquifer, (2) seeped into the nearshore marine environment through the dunes, (3) evaporated, or (4) trickled into the Port River to the north or into the Patawalonga Creek to the south. Nevertheless, any freshwater flowing into the Port River would have been well mixed with seawater by the time it reached the open coast. Further south, the Sturt River flowed into the Patawalonga Creek which opened directly into Holdfast Bay at Glenelg[12] and was originally the only break in the sand dunes between Outer Harbor and Seacliff[13]. However, coastal inflows from the Patawalonga Creek would have been minimal.

The southernmost part of the Adelaide region would have historically received some direct freshwater run-off from several small creeks (Field River, Christies Creek , Pedler Creek, Maslin Creek, Willunga Creek, and Aldinga Creek), with the Onkaparinga River being the major source of freshwater inflow[14] into a significant estuary.

Evolution of the major relief features of the Adelaide area

The main relief features of the Adelaide region have resulted from faulting of resistant, ancient rocks of the Adelaide Geosyncline that caused uplift of the Mount Lofty Ranges and downfaulting of the Adelaide Plains and the Gulf of St Vincent. For example, the Croydon bore penetrates some 600 m below sea level before intersecting resistant Precambrian bedrock, which extends up to 700 m above sea level in the Mount Lofty Ranges suggesting differential offset in excess of 1000 m. Views from Mount Lofty over the Adelaide Plains give a dramatic impression of the extent of tectonic dislocation responsible for the geomorphic evolution of this landscape, which in turn has established the framework for water flow across the city of Adelaide.

Figure 3.1 shows the major faults affecting the topography of the Adelaide area. The arcuate faults trend broadly north-south and form relative lowlands such as the Willunga, Noarlunga and Adelaide-Golden Grove Embayments and the Adelaide Plains Sub-basin. The basic tectonic structure of the Mount Lofty Ranges existed prior to the Tertiary as fault scarps and valleys provided avenues for Tertiary marine incursions and influenced the deposition of terrestrial sediments. Faulting continued throughout the Tertiary

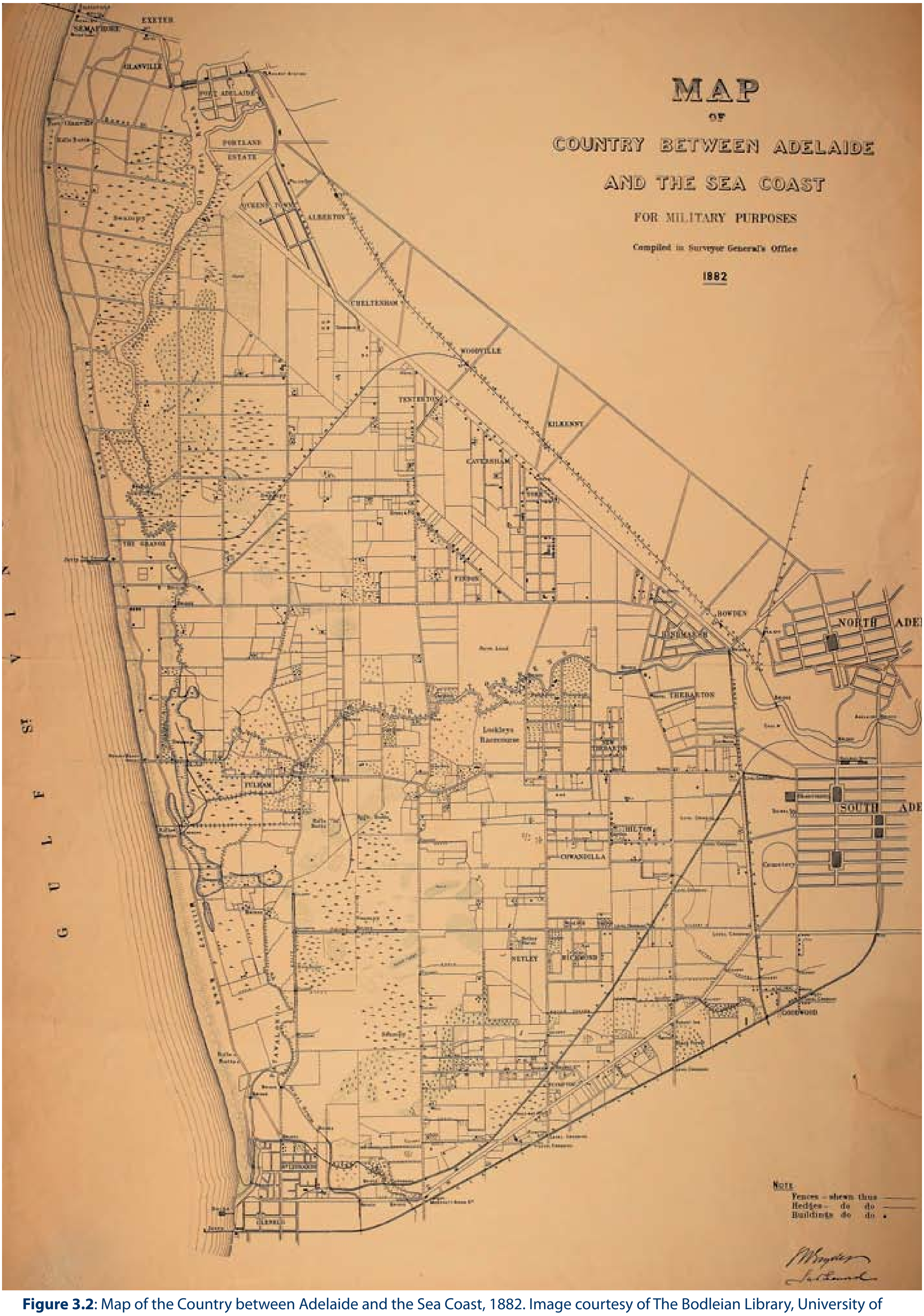

Figure 3.2: Map of the Country between Adelaide and the Sea Coast, 1882. Image courtesy of The Bodleian Library, University of Oxford, reference I3:26 (3)

and beyond as revealed by the differential dislocation of sediments, especially marine limestones, with the oldest rocks displaying the greatest offsets. The earth movements continue to today as demonstrated by ongoing minor tremors and more severe earthquakes such as that of March, 1954, which seriously damaged buildings near its epicentre at Darlington.

Originally co-joined to Antarctica as part of the super continent Gondwana, Australia had moved sufficiently north by the Eocene (55 Ma ago) to allow a seaway to develop along the southern margin of Australia. Basalt erupted on Kangaroo Island and in the Polda Basin of Eyre Peninsula about 165 Ma ago was possibly a stress precursor of the impending continental separation.

Geological background of the Adelaide area

The geological history of the Adelaide area is significant in explaining and understanding the evolution of Adelaide's drainage network and the ongoing geological changes that impact on it, which in turn, can influence management of the system. In addition the geological setting influences such things as the siting of dams, locations of aquifers and sources of building materials.

The Adelaide Geosyncline, which contains rocks of Precambrian and Cambrian ages, is now occupied by the upland areas of Kangaroo Island and the Mount Lofty and Flinders Ranges[15]. Extensive basaltic extrusions accompanied initial rifting and subsidence. A sedimentary sequence exceeding 24 km in thickness was deposited in a gradually subsiding geosynclinal depression. The succession consists largely of shallow water, marine and glacigenic sediments and was derived from higher surrounding areas.

During the Delamerian Orogeny of Late Cambrian and Early Ordovician age (480 - 500 Ma ago), the sediments of the geosyncline were subjected to compressive tectonic forces that resulted in folding, faulting, intrusion of granitic rocks (e.g. Encounter Bay Granites) and variable metamorphism. These forces culminated in the formation of a vast fold mountain range, the Delamerides[16], which probably extended into the then juxtaposed Antarctic continent.

For the next 220 Ma the geological record is sparse, and the area was probably subjected to prolonged erosion, during which the Delamerides were eroded to expose granites that had been emplaced at depths of 10 km[17]. The next major geological event was that of extensive glaciation during the Permian, some 280 Ma ago, and excellent evidence of which is preserved at Hallett Cove and on the Fleurieu Peninsula. The major direction of ice movement across southern South Australia was from the southeast towards the northwest, and striations on granite at Port Elliot demonstrate that the granite was exposed prior to or during the Permian ice advance.

During the Triassic and Jurassic the entire land mass of the State stood above sea level so that only fluviatile and lacustrine sediments were deposited and basalts of Jurassic age[18] on Kangaroo Island and in the Polda Trough[19] were possibly extruded in response to stresses related to the separation of Australia from Antarctica about 165 Ma ago.

As most of the southern part of the State remained above sea level throughout the Mesozoic, the landsurface was subjected to prolonged weathering and erosion[20]. Throughout the Tertiary, reactivated faults resulted in the further uplift of the denuded Delamerides to initiate the formation of the Mount Lofty-Flinders Ranges, a process which continues till today.

The succession of Tertiary sediments in the St Vincent Basin began with the deposition of terrestrial freshwater sediments (North Maslin Sand) in the Middle Eocene, and these were followed by the marginal marine South Maslin Sand and later marine sediments including the Port Willunga Formation of Late Eocene to Oligocene age. A marine transgression occurred during the Pliocene resulted in deposition of the Late Pliocene Hallett Cove Sandstone, which occurs at levels up to 30 m asl (above sea level) and underlies the Adelaide CBD.

The Tertiary was a period of considerable geological change as differential and episodic tectonism led to the broad scale development of uplands and plains. Weathered landsurfaces were uplifted, initiating dissection and the stripping of previously deposited sediments by streams, which cut gorges and deposited widespread channel and lake sediments throughout the Mount Lofty Ranges.

During the Pleistocene, extensions and retreats of glaciers, mainly in the Northern Hemisphere, were accompanied by world wide glacio-eustatic sea level fluctuations. The earliest Pleistocene marine deposit in the Adelaide area is the Burnham Limestone, which crops out at Marino, Port Willunga and Sellicks Beach. During the majority of the Pleistocene Period, shorelines stood below modern sea level. However, excursions of up to 6 m above the present shoreline occurred during Late Pleistocene interglacials. The marine Glanville Formation indicates the level of the sea during the Last Interglacial some 125 ka ago, when sea level was ~ 2 m higher and the climate was warmer and wetter than today. During the Last Glacial Maximum of about 20,000 years ago sea level stood as much as 120 m below present sea level, under which conditions there would have been a land link to Kangaroo Island. Gulf St Vincent was also dry land and engrafted streams from the Adelaide area would have continued across the exposed sea bed and may have linked with the River Murray.

The Geomorphic Units of the Immediate Adelaide Area

The immediate Adelaide area has been divided into six major geomorphic zones[21] (Figure 3.1). *The Coastal Zone* consists of the St Kilda Formation which includes both the white sand dunes that back the coastline as well as the estuarine and lagoonal mud facies landward of the dunes. Now much modified by human intervention the dunes were originally up to 15 m high and 400 m wide and began to form ~ 7,000 years ago when sea level rose and stabilised near its present level. The formation of the sand dunes and the northward drift of sand along the coast formed LeFevre Peninsula and formed the estuaries of the Port River and the Patawalonga

as well as the original Reedbeds wetlands which existed near West Beach up until the 1930s (see below).

Inland of the estuarine zone is an older line of distinctive red to yellow coloured sand dunes, the Fulham Sand on which many of the city's golf courses are built. These older dunes do not display the same linearity of the modern coastal dunes. They broadly parallel the coastline but also seem to have migrated inland from the coast. The age of the Fulham Sand has been determined as ~75,000 years[22] at which time sea level was possibly 80 m lower than today. Thus the Fulham Sand was probably blown from the exposed sea floor of the gulf and parts of it would have been reincorporated into the modern dunes as sea level rose to near its present position. Other smaller and older relics of dune deposits occur along the Para Fault near Kilburn and Gepps Cross.

The Lower Alluvial Plain occurs to the west of the Para Fault Zone and is underlain by Late Pleistocene alluvial sediments, dominantly those of the Pooraka Formation and younger deposits that include the Waldeila Formation and Post European Settlement sediments. These alluvial sediments variously grade to and overlie the marine Glanville Formation of last interglacial age (~125 ka). Originally marking a shoreline ~ 2 m higher than present, the Glanville Formation in the Adelaide area has undergone substantial tectonic depression, especially in the Port Adelaide area.

The Upper Alluvial Plain is also underlain by alluvial sediments of Pleistocene age west of the Eden-Burnside Fault and occupies part of the fault angle depression between the Burnside and Para Faults. Numerous streams draining from the uplifted ranges have deposited alluvium and debris avalanche deposits at the base of the scarp where the stream channels broaden and become less hydraulically efficient. The Pleistocene sediments of both the Lower and Upper Alluvial Plains are underlain by older Tertiary deposits such as the Eocene North and South Maslin Sand and the marine fossiliferous Pliocene Hallett Cove Sandstone.

The Eocene sand of the *Golden Grove Basin* is preserved in the northern extension of a fault angle depression between the Burnside and Para Faults. The Para Fault Block and the Eden Fault Block represent the uplifted, weathered and eroded ancient rocks of the Adelaide Geosyncline. At Anstey Hill, on the eastern margin of the Eden Escarpment a small bench cemented with iron oxides occurs about halfway up the scarp at an elevation of about 210 m. It is underlain by sands of Eocene age and is a small remnant (~5000 m^2) of a formerly far more extensive land surface. Major Edmunds, a cartographer and Boer War veteran, who saw its potential as a gun site, named it the 'Gun Emplacement' as it commands splendid views of the city and the coastline. However, it was never used for this purpose.

A series of alluvial fans fronts the major fault generated escarpments, particularly the Eden-Burnside Fault, the Para Fault and the Willunga Fault and river terraces flank the major streams flowing across the plains. Stream incision following uplift of the ranges has produced the waterfalls and gorges within the ranges, providing sites for water storages.

River Terraces of the Adelaide Area

The streams draining the Mount Lofty Ranges have deposited a series of alluvial sediments at the bases of the escarpments as alluvial fans and also form river terraces and natural levees flanking the modern streams. River terraces are former floodplains now situated above usual flood levels and have been stranded due to downcutting by the streams following tectonic uplift, a fall in sea level, a climatic change that leads to channel incision, or combinations of these factors. Direct

Table 3.1 Sediment Characteristics

Sediments	Characteristics
Post European Settlement Aggradation (PESA)	Presence of European artifacts
Waldeila Formation	Grey black alluvium of Mid Holocene age (4-6 ka)
Un-named minor alluvial fill unit	Light grey in colour (40-50 ka)
Pooraka or Christies Beach Formation	Red-brown of last interglacial age (125 ka)
Taringa Formation (Keswick Clay)	Columnar, green-grey clay containing angular clasts and calcium carbonate in the upper part of the sequence. In places it may be a mud flow deposit
Ochre Cove Formation (Hindmarsh Clay)	Red and orange mottled sandy sediment Middle Pleistocene. Contains Bruhnes/Matuyama geomagnetic reversal of 780 ka (Pillans and Bourman, 1995)
Kurrajong Formation (Hindmarsh Clay)	Lithified, resistant breccia that merges with the base of the Ochre Cove Formation (Middle Pleistocene)
Seaford Formation (Hindmarsh Clay)	Green grey clayey sand with weak orange mottles. Base interfingers with Burnham Limestone and is Early Pleistocene in age
Burnham Limestone	Fossils present suggest an Earliest Pleistocene age

Table 3.1 Alluvial / colluvial sediments, basic characteristics and ages

Riparian Revegetation: The Tulya Wodli Program

BOX 11

Location

This project encompasses a length of approximately 500 metres of the River Torrens and its banks in Tulya Wodli (Park 27), within Bonython Park. The site is 100 metres at its widest point and covers an area of approximately 4.5 hectares. UBD Reference 117 (N5).

Project Background and Objectives

Almost all native vegetation was cleared from the site during construction of the Torrens Weir in the 1860's. Since that time woody weeds and other planted exotics flourished, leaving only small patches of native sedges and rushes along the water's edge.

This project aims to improve habitat diversity by replacing weeds with local native trees, shrubs and sedges. Areas of the site are fairly inaccessible to the public which will help provide good refuge for fauna once fully restored.

All vegetation works are designed to require minimal ongoing maintenance, provide an attractive destination for residents and visitors, and contribute to the Adelaide City Council's commitment of planting 100,000 indigenous plants within the Park Lands through its partnership with the Million Trees Program.

On-ground works

Stage one of the project started in 2004 with the removal of woody weeds. The riparian zone was smoothed via earthworks and laid with biodegradable erosion matting prior to commencing planting.

Stage two in 2005/06 included planting the area with local indigenous seedlings and continuing weed control. These plantings included a diversity of local native trees, shrubs, groundcovers and grasses. Sedges were also used with erosion matting to help stabilise areas.

The final stage was conducted during the 2006/07 financial year with more plantings and weed control. Consideration is also being given to promoting the educational value of the site for schools and community groups.

Original Flora

Originally the site was part of a *Eucalyptus camaldulensis* (River Red Gum) and *Eucalyptus leucoxylon* (SA Blue Gum) riparian association, which would have transitioned into a *Eucalyptus porosa* (mallee Box) woodland on the upper banks of the river.

Fauna

Native water birds, aquatic reptiles, frogs and various common birds have been observed at the site. When completed, the project is expected to attract additional wildlife to the area.

Key issues

Bank Erosion

Due to its proximity to the Torrens Weir, the site is frequently inundated by high velocity flow after heavy rainfall events.

Woody Weeds

There were dense infestations of woody weeds as well as a number of deciduous exotic trees scattered across the site.

Indigenous Consultation

Consultation has taken place with the Kaurna Heritage Board for the preparation of Community Land Management Plans in the Park Lands.

Monitoring and Evaluation

Million Trees Program staff have established a series of photo points, which will be used to monitor plant survival. A frog census will be conducted at regular intervals while records of other fauna will be recorded opportunistically.

The site is also being considered as a bird monitoring site as part of a wider program to assess the habitat benefits of revegetation/restoration.

Project Partners

This project has been developed with the support of the SA Urban Forests – Million Trees Program, Adelaide City Council, Adelaide and Mount Lofty Ranges Natural Resources Management Board and Youth Conservation Corps for training.

Jock Conlon

and indirect impacts of human activity may also accelerate stream incision and lead to terrace formation. River terraces record past hydrological events and are very useful in explaining landscape evolution.

In the Adelaide region the river terraces are most commonly formed on alluvial fill and have evolved through alternating aggradation and erosion**.** For example, initially large valleys were excavated into pre-existing rocks and sediments following which they were variably infilled with red/brown coloured Pooraka Formation sediments. Subsequent erosion of the Pooraka Formation developed smaller valleys, which in turn were partially infilled with younger sediments of the grey/black cloured Waldeila Formation (see Table 3.1). In general the older terraces occupy the broader deeper palaeovalleys and successively younger alluvial fills are progressively smaller and infilled to lower levels, an indication that fluvial activity in the past was considerably greater than at present.

Table 3.1: Sediment Characteristics

High Red RiverTerraces

The Pooraka Formation is one of the most widespread alluvial units across the Adelaide Plains and comprises significant portions of the alluvial fan deposits and river terraces. The Pooraka Formation is a distinctive red to yellow coloured alluvial deposit often with a pronounced red brown soil underlain by a light coloured calcareous horizon. Commonly the highest river terraces of the Adelaide region are underlain by sediments of the Pooraka Formation, which Twidale[23] had also named the Klemzig Sand along the valley of the River Torrens. It forms the major terrace formations along the River Torrens (Diagram 3.1). Adelaide Oval, for example, is sited on a major terrace (Parklands Terrace) underlain by the Pooraka Formation. The deposition of the Pooraka Formation represents a major pluvial event and at this time the Adelaide

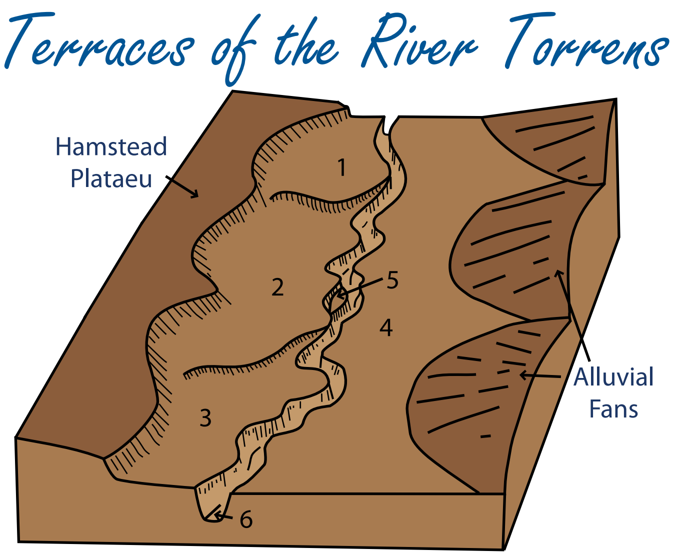

Diagram 3.1 Sketch block diagram of the terraces formed by lateral corrosion during slow incision:
1) Klemzig Terrace; 2) Walkerville Terrace; 3) Parklands Terrace; 4) Hackney - Felixstowe Terrace; 5) depositional Terrace remnant of Walkerville Sand; 6) present channel of the River Torrens. Source: Twidale C.R. (1968) Geomorphology (Melbourne: Thomas Nelson Aust Ltd) 406 p

Plains would have presented a picture of aggrading, well vegetated swamps grazed by now extinct mega-fauna such as the *Diprotodon*. Tate noted the occurrence of bones of the extinct giant marsupial in the sediments and described them in 1879 as the 'mammaliferous drift'[24]. The Pooraka Formation has been demonstrated to be of last interglacial age or 125 ka old[25] and formed when sea level was ~ 2 m higher than present and when the climate was considerably warmer and wetter than at present.

Diagram 3.1: Terraces of the River Torrens

Intermediate Terraces

Terraces at intermediate elevations between the highest and lowest terraces occur in many streams having been eroded into the Pooraka Formation sediments. For example, in the lower Torrens valley the Walkerville, Parklands and Hackney-Felixstow terraces are all formed on the Pooraka Formation but are at different elevations[23]. Erosion of the unpaired terraces occurred during stream rejuvenation, possibly due to tectonic uplift, but most likely a result of climatic change that favoured erosion of the alluvial deposits. Sporadic occurrences of a light grey coloured alluvium occur in valleys eroded into the Pooraka Formation. This younger unit has been dated at ~40-50 ka and represents a sub-pluvial event about this time.

Low Grey-Black Terraces

The next alluvial unit is grey-black in colour and forms a lower set of paired river terraces set within valleys carved out of the Pooraka Formation. In the lower reaches of many streams the grey-black alluvium also occurs in natural levees that overlap the older red alluvium. Named the Waldeila Formation in the Noarlunga and Willunga Basins by Ward[26] and the Walkerville Sand[23] in the Torrens valley, these grey-black sediments have been dated as of mid-Holocene age (4-6 ka) and reflect a warmer, wetter episode, a minor sub-pluvial event. There is widespread occurrence of terraces on the mid Holocene Waldeila Formation, both at the coast and well inland.

In some cases such as the lower Onkaparinga River, extensive terraces formed on this alluvial material are closely associated with a former slightly higher shoreline (1-2 m asl). When sea level stabilised ~7 ka years ago the lower reaches of the Onkaparinga valley comprised a broad, shallow, sheltered estuary as revealed by the presence of estuarine shells dated at ~ 4.6 ka and incorporated within the Waldeila Formation[27].

Relationship between the grey and red terraces

When the elevations of the grey and red terraces are traced downstream three main sets of relationships are revealed. Near uplands the red terrace is always highest and the low grey alluvium is set within a valley cut into the red alluvium. Where there is a large stream such as the Onkaparinga River, and the high country is reasonably close to the coast, the elevational distance between the two sets of terraces is maintained to the coastline. Characteristically the red terrace grades to the last interglacial shoreline and the grey terrace to the mid Holocene shore. Thus these terraces have probably formed by the influences of changing global sea level.

However, this simple pattern may have been interrupted by faulting in some localities.

In other situations, particularly where there is a long low gradient flow to the coast over a plain (e.g. Gawler River), or the stream only has a small drainage basin (e.g. Sellicks Creek) the terraces converge. Initially occupying a valley cut in the red alluvium the grey alluvium progressively fills in more and more of the valley, which also decreases in size downstream, and eventually spills out of the valley, forming natural levees that can completely blanket the red alluvium. In this manner a perched stream can form, increasing the flood risk to areas well away from the stream as the water flowing through the channel is well above the level of the surrounding floodplain. In some instances the location of a cross-over point may be influenced by faulting. For example, the abrupt western margin of the River Torrens terraces is coincident with the Para Fault where downfaulting to the west would have lowered the level of the red alluvium and initiated its burial by grey alluvium. Notwithstanding this observation, the formation of crossover terraces can occur simply by climatic change and variations in sediment availability and the stream's flow regime.

Converging terraces can also occur high up in the ranges grading to a local base level well above sea level. These terraces almost certainly reflect the influences of climatically-induced changes in bedload/discharge relationships that caused erosion or sedimentation with warmer, wetter pluvial events encouraging deposition in valleys, and colder, drier conditions favouring valley incision.

Terraces and sediments predating the Pooraka Formation

The alluvial sequences of the Adelaide area and their associated terraces are dominated by the Pooraka (~125 ka) and Waldeila Formations (4-6 ka). Rocks and sediments that underlie the Pooraka Formation are of Pleistocene, Tertiary, Permian or older ages. Table 3.1 lists the major Pleistocene fluvial sediments and their possible ages as recorded in the Noarlunga and Willunga embayments. Although occasional relicts of sediments and terraces occur older than those associated with the Pooraka Formation the vast majority of older, terrace -forming Pleistocene sediments have been removed by erosion.

Human Impact on rivers and streams

Human impact has affected streams in a number of ways such as vegetation clearance in the catchment causing localised erosion, gullying and accelerated sedimentation in downstream sections. In areas of intensive urban development such as the Torrens, Brownhill and Patawalonga catchments, many of the streams have been channelised, re-directed or even piped underground. Dams and reservoirs have altered flow regimes and together with artificial levee banks, such as the construction of the Torrens sea outlet, have altered flood patterns and frequency. While many of the earlier modifications were piecemeal, more recent human impacts have been planned or controlled either through catchment or natural resource management authorities.

Gully evolution and management

Pre-European episodes of erosion and sedimentation were triggered by factors such as climate change, tectonic dislocation and global movements in sea level. However, a new and dramatic episode of landscape change was precipitated by the impact of European settlers. The most obvious manifestations of these dramatic changes are erosion in stream channels and accelerated sedimentation in downstream sections of river valleys. Erosion and sedimentation since European settlement are marked by the burial of European artefacts such as fence posts, wire, metallic objects, bullock wagon chains, cattle bones, horse bones, pottery, bottles, other household items, bridges, building materials and even building structures.

Spectacular examples of human induced gullying occur in the Sellicks Creek drainage basin where prominent gullies up to 10 m deep have formed since the arrival of Europeans[28]. The erosion gullies are a consequence of widespread landscape modification in an area of easily erodible alluvial and colluvial sediments that were initially associated with swamps and wetlands. The incision of the gullies has drained the swamps, lowered groundwater levels and dramatically altered the local hydrology. The upper part of the Sellicks Creek drainage basin lies within the Mount Lofty Ranges and extends up to 300 m asl. A break in slope between the ranges and the piedmont alluvial fan zone occurs at ~ 120 m asl. Base level controls have been extremely important in limiting the impacts of gullying in Sellicks Creek. Downward erosion of colluvium in the upper part of the basin is limited by outcrops of resistant bedrock and quartz veins. In the alluvial lower drainage basin resistant silicified Quaternary sediments also limit stream incision as do artificial base levels where bridges and drains have been constructed across the creek.

Gully development does not seem to be simply related to vegetation clearance within the catchment but requires some direct or indirect form of channel disturbance. Moreover, not all gullies within a drainage basin need form at the same time. In Sellicks Creek several different mechanisms for gully development have occurred at different times. For example in the upper part of the basin well vegetated and stable swamps and wetlands were disturbed with burial by sediment washed down from the valley sides following land clearance. The loss of stabilising channel vegetation together with slightly steepened slopes lead to channel incision some time in the late 1850s. Further downstream at the Main South Road erosion was precipitated by changed channel and streamflow characteristics where pipes constricted flow under the roadway. Channel disturbance by stock trampling and grazing also fostered erosion here. Further downstream at Justs Road a bridge with a severely restricted sluiceway accelerated spectacular erosion downstream. The bridge was built in the 1920s and erosion began shortly after that. The lowest section of about 1 km was rapidly eroded into a box like canyon up to 8 m deep in 1911 when a local landowner diverted ponded water from his land onto the roadway. It is in this section of the creek where artificial wetlands have recently been constructed.

The following generalised model of gully development has been reported by Bourman and Harvey[29] and Bourman and

BOX 12 Challenges to Environmental Flows

IMPACT OF SMALL DAMS

The impact of farm dams on stream baseflow is severe and increasing. The current dam permit system limits the volume farm dams in a sub-catchment can capture to 50% of the median annual rainfall runoff. This means that streams also get flow but only after all upstream dams are filled. The result of this is a significant change to the period of zero flow in streams in summer and autumn. The length of this zero flow time is increasing as the autumn date of the start to flow in streams is progressively delayed. This places stress, on native fishes, macroinvertebrates, instream vegetation and riparian vegetation. For example the gauging station records at Mount Pleasant on the upper River Torrens show that the average period of summer zero flow in the first decade of records, 1974-1983, was 74.2 days (10.6 weeks), while for the most recent decade, 1998 – 2007 this has almost doubled to 137.3 days or (19.6 weeks) (Figure 1).

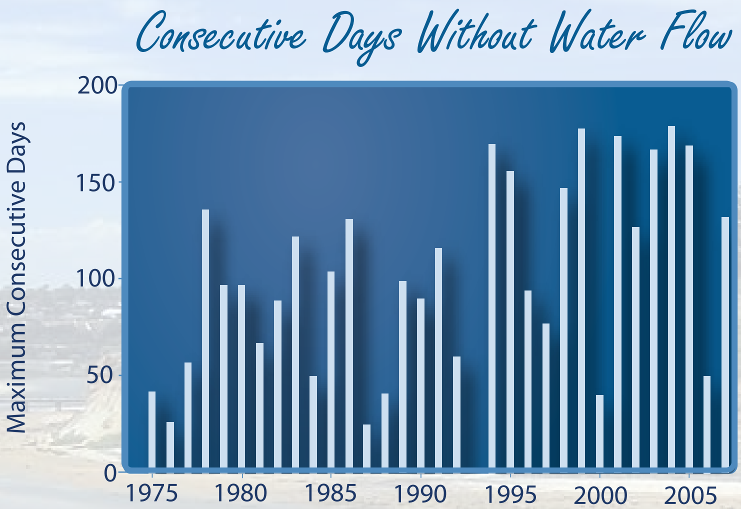

Figure 1. Consecutive days with zero flow at Mount Pleasant Flow Gauging Station, from Summer to Autumn 1974 - 2007

The main Onkaparinga River has had to survive on groundwater and for just a few days in Spring in five of these ten years the river has natural flows.

The loss of small flows in summer threatens biodiversity as refuge pools dry. The loss of medium to large flushing flows is altering the river sediment composition, river geomorphology, instream and riparian vegetation. Important breeding cues for native fish are missed favouring introduced generalist species like European carp, redfin and trout.

IMPACT OF LARGE STORAGES

A second major impact occurs downstream of the major water harvesting storages. Our early South Australian Governments in the 19th and early 20th century, with great wisdom, invested in small diversion weirs on the two main rivers that capture and divert water to much larger off-stream storages. The first on the River Torrens, the Gorge Weir completed in 1860, diverted water to Thorndon Park and later Hope Valley Reservoirs. Clarendon Weir on the Onkaparinga River, completed in 1896, diverts water to Happy Valley Reservoir. In 1918 the Gumeracha Weir began diverting River Torrens water to Millbrook Reservoir. The diversion pipes or aquifers have quite large capacities. Hence downstream of these three diversion weirs all the water from small and medium flows is harvested and none flows downstream. Only rare truncated flows from major rain events still pass downstream when the stream flow exceeds the capacity of the diversion pipes, but these are rare events. The hydrograph for the flows downstream of the Clarendon Weir for the years 1997 - 2007 show this clearly (Figure 2) when compared with the hydrograph for Scotts Creek, a naturally flowing stream only eight km distant (Figure 3).

The flow changes wrought by the three large on-stream storages, Warren Reservoir (1917) on the South Para River, Mount Bold Reservoir (1937) on the Onkaparinga River and the Kangaroo Creek Reservoir (1967) on the River Torrens are different. As with the diversion weirs they restrict rain passing downstream. However, they are used to deliver water to downstream diversion weirs in summer. This creates a reserve pattern to the natural river flow. Instead of the natural climatic pattern of low summer flows and high winter flows, that the native fauna and flora have evolved with, we now have zero or low winter flows and unseasonably high summer flows in

the reaches downstream of these reservoirs. Downstream of the South Para Reservoir there is zero flow unless the storage is full which is a rare occurrence.

A similar situation exists in the reaches downstream of the terminus of the Murray Bridge – Onkaparinga Pipeline at Hahndorf and the dissipaters at Mount Pleasant and Angus Creek that feed Mannum - Adelaide Pipeline water into the River Torrens. Again we have high and very variable summer flows in these reaches of the rivers used as aquifers to transmit and treat River Murray water to off-stream storages.

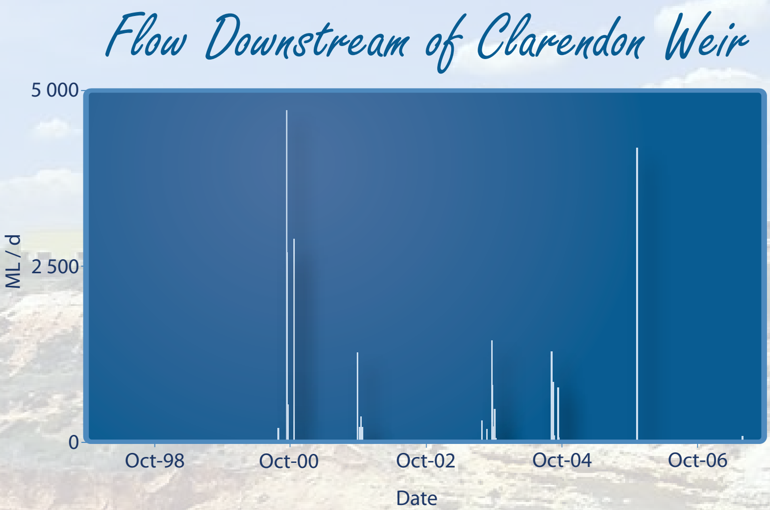

Figure 2. Gauged flows downstream of the Clarendon Diversion Weir from 1996 to 2006. ML/d = megalitres per day

ENVIRONMENTAL FLOW SOLUTIONS FOR SMALL STORAGES

The change caused by farm dams in base stream flow threatens both biodiversity and river ecosystem function. Environmental flows could alleviate the impact but for most of the streams in the Mount Lofty Ranges there are no stored water sources to supply environmental flow releases. The only practical method to alleviate the impact of this critical lack of flow is to allow some flows to bypass on-stream farm dams and the off takes to off-stream farm dams. This can be achieved by either a bypass option or returning a set percentage of all flows downstream. Simple bypass mechanisms exist that pass all flows below a set threshold around a dam. Investigations are needed to find the most cost effective way to allow flow to start in the small headwater streams and tributaries of the main rivers as soon as the rain begins to fall. Then streams will begin to flow when rain falls and the dams will fill during larger rainfall events reversing the current situation where dams must fill first. The only impact on farms will be a delay of a few weeks in the time taken to fill.

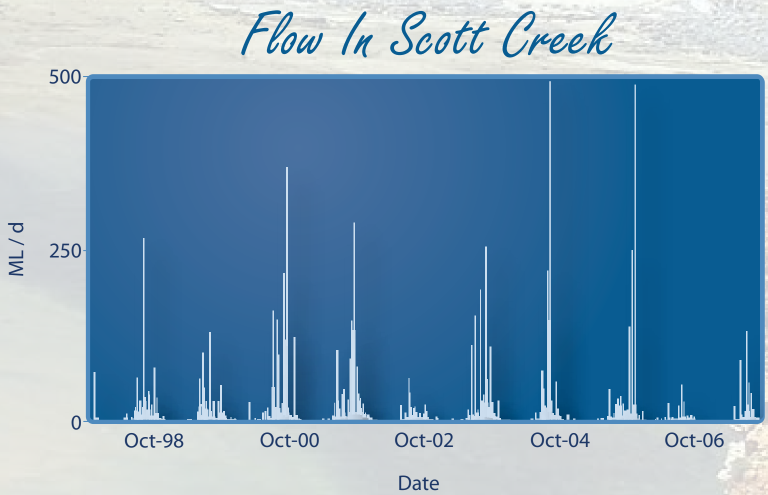

Figure 3. Gauged flows in Scott Creek from 1996 to 2006 ML/d = megalitres per day

FOR LARGER STORAGES

A trial of environmental flow releases downstream of these weirs is planned to commence soon in the Western Mount Lofty Ranges. At each stream a variety of base flows, freshets and flushing flows is planned. An associated monitoring program is underway monitoring the predicted changes to stream morphology, vegetation, productivity and biodiversity.

Peter Shultz

James[28]:

1. Gully development is related to landscape modifications such as vegetation clearance, destruction of ground cover, cultivation and engineering works, thereby increasing the susceptibility of the landscape to erode.
2. A lag time ensues between the initial disturbance and an erosional response until the optimum conditions for gullying are achieved. e.g. very wet years, storm events, time for plant roots to decay.
3. Sudden and dramatic gully initiation is possibly related to the occurrence of intense, drought-breaking rains[30].
4. Rapid gully development can occur with some gullies forming in response to individual storm events or forming over short time periods.
5. Slowing down of erosion slows as adjustments to the new conditions are established. Erosion proceeds but at a much reduced rate.
6. Under a new regime, some gullies gradually stabilised and some may actually start to heal, especially where stock are they are excluded and the channel floor become vegetated. Successive aerial photographs (1949 to present) of Sellicks Creek reveal only minor changes in the gully system and that a new quasi-equilibrium condition is being approached.

The main cause of gullying at Sellicks Creek appears to be related to channel vegetation disturbance and agricultural activities, though various other factors, such as road, culvert and bridge structures, which impact on stream flow, are locally significant. Disturbance of the valley floor vegetation is the dominant cause of gully development in the Sellicks Creek catchment. Without disturbance of the channel vegetation catchment clearance on its own will probably not initiate erosion. Consequently, an effective mechanism for stabilising gullies appears to be by reducing stream velocity by planting to increase channel roughness. The alluvial sediments forming alluvial fans at the foot of the Mount Lofty Ranges are very susceptible to erosion and great care need to be taken in managing water flow across them. Within the last decade a new gully was initiated north of the Sellicks Creek drainage basin by inappropriate diversion of water from the Main South Road, resulting in the formation of a long V-shaped gully up to 6 m in depth that prevented access to a large area of a property.

Post European Settlement Aggradation (PESA)

Prior to recent landscaping, a spectacular example of Post European Settlement Aggradation occurred along Dry Creek at Mawson Lakes, about a kilometre downstream of the Main North Road. Accelerated erosion had cut a vertical channel some 6 m deep through alluvial deposits that included at 2-3 m of PESA sediments which overlay Pooraka Formation deposits. Dry Creek appears to be relatively insignificant but it actually drains an area of 109 km^2 or some 40% of Adelaide's suburban area. Originally Dry Creek dissipated into the alluvial deposits of the plains, rarely reaching the sea. Today the creek is discharged via artificial drains through samphire flats and mangroves into Barker Inlet.

Sedimentation in this section of Dry Creek followed land clearance for agricultural purposes in the few decades after European settlement, which began in 1836. Large amount of charcoal occur in the PESA sediments and a tree trunk, dated at about 400 years before present could suggest that the charcoal was a product of Aboriginal burning practices. However, the presence of a glass bottle, a European artefact of the 1850s, also at the base of the PESA deposits, indicates that European agricultural activities were responsible for the accelerated erosion and deposition. Following deposition of the PESA sediments, largely as levees flanking the stream channel, Dry Creek incised into its own flood plain, cutting a deep and steep sided channel. Various factors may have influenced this erosion phase: the initial deposition of sediments would have buried and killed riparian vegetation, which is so important in maintaining channel stability, and thereby initiating erosion. Alternatively, as suggested by Schumm[31], following a reduction in the delivery of sediments to the stream channel as erosion slows down on the valley sides of the catchment, with enhanced run off from the hillsides, the stream is likely to cut back down through its own recently deposited sediments. In many other instances across the Adelaide Plains PESA deposits are perched at the top of the present stream channels after having completely infilled, choked and overtopped pre-existing channels.

In Dry Creek there have been several events of PESA marked by different vintages of European artefacts, the most recent episode involving plastic materials. The Dry Creek drainage basin is now intensively urbanised which has increased discharges, reduced immediate stream loads, exacerbated erosion downstream and caused accelerated erosion even further downstream. Artificial structures across stream invariably have unwanted impacts. Concrete drains under roads for example often lead to erosion immediately downstream, and that eroded material is dumped further downstream.

Changes in water flow to the coast

Today the channelisation of streams, the impermeable nature of much of the urban development, the discharge of storm water to sea and the cutting of an artificial outlet for the River Torrens from Breakout Creek directly to the sea at West Beach has vastly increased water flow to the sea. The increased fresh water flows containing pollutants and nutrients, along with discharge of treated sewage, has had detrimental impacts on the stabilising sea grass meadows. Loss of sea grasses increases the impacts of waves which erode sand from the surf zone and beaches. In addition, the urbanisation has created impermeable surfaces such that many storm drains discharge directly into the sea across sandy beaches.

Coastal inflows can be grouped into three broad geographic zones: Port Gawler to Outer Harbor, Holdfast Bay (defined here as Outer Harbor to Seacliff), and Seacliff to Sellicks Beach. Much of the information here is sourced from recent work completed by the Task IS1 researchers from the Adelaide Coastal Waters Study[14, 32, 33, 34].

The Flood of 1931

BOX 13

It is better to describe the impact and scope of the 'great' River Torrens Flood of 1931 in the words of a reporter for The Chronicle at the time, as published on 10 September 1931:

HUNDREDS OF HOUSES FLOODED

Sweeping down from the hills, stormwaters, fed by torrential rain in the Mount Lofty Ranges … devastated wide areas in the eastern, southern and western suburbs causing damage estimated at over £30,000. Hundreds of people were rendered homeless through the flooding of their houses, many square miles of country between Adelaide and the sea were inundated, scores of market gardeners irretrievably ruined, and miles of road placed under water or blocked by landslides.

Overflowing its banks, First Creek, swept in two streams through Marryatville, Norwood and Hackney, flooding 30 or 40 houses a foot deep in King William and Rundle Streets, Kent Town …

Transformed by the swollen waters of Third, Fourth, Fifth and Sixth Creeks, and by innumerable freshets which grew into steams overnight, the Torrens swept down chains wide. It broke its banks in many places, cutting off road and tram traffic to Henley and flooding 150 houses.

In most places the stormwater passed away quickly; but, owing to the immense quantity flowing down the Torrens, which was 60 or 70 yards [54-64m] wide at the back of the Zoo, the low lying country near Henley Beach will be inundated for many days. There the flood was worse than that of 1917, for a count last night showed that at least 150 houses were flooded …

David Jones

Image courtesy of the State Library of South Australia.
SLSA: B 5995 Floods at George Street, Norwood, 1931

Coastal inflows from the Gawler River have been modified significantly with the total volume greatly reduced by construction of South Para Reservoir[14]. There are now only occasional inflows during major rainfall events or when the reservoir overflows. Due to diversion of the Torrens River directly to Holdfast Bay (see below), the construction of evaporation ponds, effluent treatment ponds and artificial wetlands, the Port River/Barker Inlet estuary now receives very little freshwater. For 70 years from 1935 to 2005, the Port Adelaide wastewater treatment plant (WWTP) discharged treated effluent into the Port River near Ethelton. The Port Adelaide WWTP no longer discharges to the Port River but is instead re-directed to Bolivar WWTP (see below).

One of the most ecologically significant changes to coastal freshwater inflows in the Port Gawler-Outer Harbour zone was the opening of the Bolivar WWTP outfall north of St Kilda in 1967. This outfall currently delivers 35.3 GL/yr of treated effluent directly to the marine environment (= average volume for period 1995-2005[34]). Reuse of effluent for irrigation from Bolivar did reduce flows to the sea for a while, but redirection of effluent from the Port Adelaide WWTP has maintained flows from Bolivar at recent volumes.

Direct freshwater inflows to Holdfast Bay have increased dramatically since European settlement, especially since the 1930s. Significant "events" in the Holdfast Bay zone include:

- Opening of three treated effluent outfalls from Glenelg WWTP in 1943, 1958 and 1973. The Glenelg WWTP now delivers 17.3 GL/yr of treated effluent to the nearshore marine environment at West Beach (average volume for period 1995-200534).
- Operation of the Glenelg WWTP sludge outfalls several kilometres offshore from Glenelg between 1961-1993.
- Operation of the Port Adelaide WWTP sludge outfall ~4.5 km offshore from Semaphore from 1978-1993.
- Diversion of the Torrens River away from the Reedbeds and through the sand dunes directly to the sea to form "Breakout Creek" during the 1930s.
- Construction of concrete stormwater drains and an efficient stormwater system from Adelaide into Holdfast Bay (since the 1950s).
- Construction of a weir at Patawalonga Creek outlet in 1890 which allowed some regulation of freshwater inflows to the sea.

Collectively these events have resulted in the most dramatic changes to freshwater inflows along the entire Adelaide coast, with an average of 114.9 GL entering the marine environment as stormwater, and an additional 62.0 GL per year from WWTPs during 1995-2005[34] in an area where historical inflows were minimal.

Direct flows from the Onkaparinga River have been dramatically reduced and flow regimes altered since construction of Mount Bold reservoir[14]. The smaller creeks flow to the sea intermittently with relatively small annual volumes[14], but when they do it is often with slugs of highly turbid water during major rainfall events. The opening of the Christies Beach WWTP treated effluent outfall off Christies Beach in the 1970s[33] marked a significant new source of freshwater to the Seacliff-Sellicks Beach zone; it delivered 9.4 GL per annum for the period 1995-2005[34].

From the above it can be seen that the nature of freshwater flows to Adelaide's coastal waters has changed dramatically since European settlement in the 1800s. For the period 1995-2005, the total freshwater inflow per annum to the marine environment between Port Gawler and Sellicks Beach averaged 177 GL, containing 2,357 tonnes of nitrogen and 8,428 tonnes of suspended solids[34]. Much of this freshwater discharge is from sources that did not exist prior to European settlement. For example, the 83.4 GL of freshwater that is discharged each year directly to the sea from Bolivar, Glenelg, Christies WWTPs and the Torrens River is completely unnatural (average for period 1995-2005[34]. However, in some cases, such as the Gawler and Onkaparinga Rivers, it is likely that the volume of natural catchment flows has been decreased[32].

Coastal impact of stream and river flow

Stormwater and wastewater discharges contain various pollutants, including nutrients (viz. nitrogen and phosphorus), suspended solids, colour-dissolved organic matter (CDOM), and toxicants such as heavy metals. Stormwater is often highly turbid (suspended sediments and/or CDOM), while treated wastewater is clearer but with much higher nutrient concentrations. Digested sludge, which is no longer discharged but was mostly suspended solids rather than freshwater, was high in nutrients and also highly turbid. Toxicants such as pesticides are detected intermittently and/or at generally low levels in stormwater[14, 35].

Elevated levels of nutrients have been regularly detected in Holdfast Bay since at least the 1970s; these are caused by WWTP and industrial outfalls (and to a much lesser extent by stormwater[35]. While dissolved nutrients can be difficult to detect in marine waters, a survey of nitrogen stable isotopes in seagrass tissue indicates that seagrasses along the entire coast from Port Gawler to Port Noarlunga are receiving nitrogen from the three local WWTPs and other industrial sources[35]. Highly turbid coastal waters in Holdfast Bay caused by pulsed stormwater events have been observed since the 1930s[34]. Indeed, photosynthetically active radiation levels have recently been measured at zero on the seabed off Henley Beach during some stormwater events[36] (e.g. Figure 3.3). Significantly, any discharges into Adelaide's nearshore coastal waters are trapped nearshore by prevailing winds and moved up and down the coast by tides[37]. Elevated levels of heavy metals in sediments of the Port River near Ethelton are due to decades of discharges from the Port Adelaide WWTP.

Figure 3.3: Stormwater from the Torrens River discharging to the sea, October 2005. Photographer: S. Bryars.

Alteration to freshwater inflows to Adelaide's coastal waters, in terms of both the quantity and quality of water, have had an impact on the local marine habitats. There are three main subtidal benthic habitats off Adelaide's coast in depths of <20 m: seagrass meadows (dominated by *Amphibolis* and *Posidonia*), reefs, and sand[38, 39]. Seagrass habitat is dominant

Figure 3.3: Stormwater from the Torrens River discharging to the sea, October 2005. Photographer: S. Bryars.

in the north from Port Gawler to Seacliff, with reefs and sand dominant in the south from Seacliff to Sellicks Beach[39]. Sand is also now common in some parts of the north due to several localised zones of seagrass loss. North of Outer Harbor intertidal habitats consist of extensive tidal mud/sand flats (vegetated with seagrasses or unvegetated), tidal creeks, mangrove forests (*Avicennia marina*), and saltmarshes[38]. South of Outer Harbor, the main intertidal habitats are sandy beaches and rocky shores[38]. There are also several natural estuaries along Adelaide's coast including the Gawler River, the Port River/Barker Inlet estuary, the Patawalonga Creek, and the Onkaparinga River[38]. The pelagic habitat (or overlying water column) may also be classified as a habitat in its own right.

Freshwater discharges can potentially be detrimental to marine habitats in a number of ways: freshwater *per se* (i.e. causing a decrease in salinity), nutrients (viz. nitrogen and phosphorus), sediments (causing a decrease in water clarity and/or sedimentation), colour-dissolved organic matter (causing a decrease in water clarity), and toxicants (e.g. pesticides, heavy metals). With changes to freshwater inflows, sediment and nutrient levels in Adelaide's marine waters have increased dramatically. Recent experimental work has clearly shown the detrimental effects of elevated nutrient levels on *Amphibolis* and *Posidonia*, even at very low concentrations[40]. It is believed that the nutrients stimulate epiphyte growth on the seagrasses which eventually cause the seagrasses to die. It is also apparent that *Amphibolis* is more sensitive than *Posidonia* to elevated nutrients[39, 41], which explains some of the patterns of selective seagrass loss. It is thought that increased nutrient levels have mainly affected local seagrasses, rather than factors such as reduced water clarity, reduced salinity, or exposure to toxicants[41]. Experimental work has also shown a link between the degradation of temperate reefs and the addition of nutrients and/or sediments[42, 43, 44]. Indeed, the degradation of Adelaide's reefs is thought to have been caused by increased nutrients and increased sedimentation[45].

Besides seagrasses and reefs, some other marine habitats can also be affected by increased nutrients. For example, increased nutrient levels can stimulate growth of the macroalga, *Ulva*, which can then degrade intertidal mangroves (*Avicennia marina*) by smothering both juvenile plants and the aerial roots of adult plants. Increased nutrient levels can also cause phytoplankton blooms in the water column, including those comprised of toxic dinoflagellates.

The loss of seagrasses off Adelaide since the 1930s is well documented[35, 46, 47]. An estimated ~9,000 ha of seagrass loss has occurred off Adelaide[46], with much of this loss linked to freshwater discharges from wastewater treatment plant outfalls and stormwater outlets[47]. As with seagrass meadows, reefs off Adelaide have also suffered from the effects of freshwater discharges, but the decline of reefs is less well documented than for seagrasses. Nonetheless, it is evident that over the past few decades many of Adelaide's reefs have become degraded, most notably with a significant reduction in the cover of large canopy-forming macroalgae[45]. The sections below explore specific cases of habitat degradation in more detail.

- The discharge of treated effluent and digested sludge from wastewater treatment plants (WWTPs) is linked with habitat degradation in every location where it has occurred along Adelaide's coast:
- Bolivar WWTP effluent outfall – caused complete loss of 900 ha of intertidal and subtidal seagrasses46; selective loss of Amphibolis further offshore39; loss of intertidal mangroves46.
- Port Adelaide WWTP effluent outfall – linked to toxic algal blooms in the Port River46.
- Port Adelaide WWTP sludge outfall – caused complete loss of 365 ha of seagrasses and selective loss of 1100 ha of Amphibolis39, 46.
- Glenelg WWTP effluent outfalls – linked to complete loss of 2800 ha of seagrasses in nearshore zone from Semaphore to Seacliff 46.
- Glenelg WWTP sludge outfalls – caused small area of complete seagrass loss48, but a much larger area of selective loss of Amphibolis39; reefs in the area that are degraded (e.g. Broken Bottom, Seacliff Reef45, could also have been affected.
- Christies Beach WWTP effluent outfall – seagrass is not a dominant habitat in this area but there may have been some small losses35; degradation of nearby Horseshoe and Port Noarlunga Reefs has occurred (e.g. loss of canopy-forming macroalgae) and this may be linked to the effluent discharge45; impacts on benthic infauna of sand habitat have been documented.

Due to vegetation clearance, the proliferation of impervious surfaces, and a network of stormwater drains, freshwater flows now generally occur as major pulses of turbid water. Nonetheless, while the Torrens River and the Patawalonga outlet have been linked to the nearshore seagrass loss in Holdfast Bay, they are unlikely to have been the major cause of nearshore loss[41]. In contrast, the Torrens River and other stormwater sources are thought to have had a major impact on coastal reefs through increased sedimentation[45]. While reefs further south such as Port Noarlunga Reef would historically have been exposed to some freshwater flows from the Onkaparinga River, the nature and quality of the flows would have changed dramatically with the construction of Mount Bold reservoir, clearance of the catchment, and the input of turbid freshwater from the River Murray into the Onkaparinga River system. There is also speculation that turbid discharges from Christies Creek are having a detrimental impact on Horseshoe and Port Noarlunga Reefs.

Apart from impacts on marine habitats, stormwater causes other issues for Adelaide's coastal waters such as increased turbidity and rubbish (an amenity issue, i.e., it looks terrible) and increased levels of faecal bacteria (a public health issue). Changes to the nature and extent of freshwater inflows can also affect estuarine fish that rely on the marine-freshwater interface for part of their life-cycle (e.g. congolli); an issue that is not explored further in this chapter but which is probably significant. In this respect, it is worth noting that in estuarine locations where freshwater inflows were a natural occurrence, then some level of freshwater input is still required. In contrast, in locations where freshwater inflows are an unnatural occurrence, inflows should be ceased or have nutrient and sediment levels within them drastically reduced.

While freshwater inflows have caused or been linked to the majority of degradation to Adelaide's seagrasses and reefs, some degradation is due to other processes. For example, dredge spoil dumping off Outer Harbour ("Spoil ground") has smothered many hectares of seagrasses; increased sedimentation in Largs Bay since construction of the Outer Harbour break walls has caused the loss of many ha of seagrasses[46]; increased erosion and expansion of blowouts due to erosional processes continues to cause seagrass loss in southern Holdfast Bay[47], although the initial and ongoing link with freshwater discharges and seagrass degradation in this process is unclear); and reef degradation in the Port Noarlunga area has been linked to increased sedimentation caused by sand dredging operations off Port Stanvac[45].

The significant degradation that has occurred to Adelaide's marine habitats as a result of freshwater inflows has many ecological and management consequences. For example, the loss of seagrass and macroalgal cover will mean a loss of habitat for many species (including commercially and recreationally important fish species), a loss of primary production (i.e. photosynthetic services), and in the case of seagrasses, loss of an important sediment binder. Indeed, the loss of seagrasses in the nearshore of Holdfast Bay has exacerbated the longshore drift of sand in the area, which is a major management problem in itself. A further problem with seagrass loss (viz. *Amphibolis* and *Posidonia*) is that recovery is a very slow process, if it occurs at all. For example, while some recovery of *Posidonia* is occurring at the disused sludge outfall sites, recovery to original coverage at the Port Adelaide WWTP sludge outfall will take many decades[48, 49]. On the positive side, it also means that if discharges are ceased then seagrass recovery may be possible. Nonetheless, it is apparent that natural recovery of *Amphibolis* is not occurring at either of the sludge outfalls[39], and attempts at artificial rehabilitation of *Amphibolis* are currently underway in Holdfast Bay[48].

Unnatural freshwater inflows containing elevated nutrients and sediments have had a devastating impact on Adelaide's marine habitats, and yet we continue to discharge many gigalitres of freshwater into the marine environment that could otherwise be reused on land. If we are to have any chance of natural recovery or rehabilitation of our seagrasses and reefs, then all unnatural freshwater flows (and the pollutants they carry) need to be reduced dramatically; a move that would appear obvious given the major damage they have caused and that freshwater is such a precious commodity for Adelaide.

Conclusion

There has been a marked change in attitude towards water flow across the plains from the hills over the past decade. Prior to that time Adelaide's water supply seemed assured from the reservoirs in the hills and pumping from the River Murray. Rainwater tanks were deemed to be unnecessary or even a health risk. Drainage schemes were developed to evacuate storm water from the suburbs to the sea as rapidly

Why Conserve the Field River?

BOX 14

Urban ecosystems are usually defined as areas "in which people live at high densities (equal to or greater than 186 people per km²), or where the built infrastructure covers a large proportion of the land surface". Currently, slightly less than half the world's population live in dense urban areas, particularly cities. In industrialised countries this percentage is closer to 80%. The situation in Australia is particularly significant, as nearly 85% of Australians live in towns with 1000 or more inhabitants while two thirds of the Australian population live in the eight capital cities. Two of the principal concerns for promoting biological diversity within urban environments are: 1) the maximisation of biodiversity within the city and 2) the management of problem species (such as introduced and native weeds). In addition, as the world's population increasingly includes people with an urban lifestyle, it is predominantly in this urban environment that they will gather their views on nature.

These issues are particularly marked in Adelaide. Adelaide is a unique city. Adelaide is best described as a garden city with relatively few parks and even fewer natural remnants (Table 1) . Historically, the Adelaide region has supported a diverse range of natural habitats. Before 1836, the Adelaide Plains supported approximately 1130 species of native plants and around 285 native species of bird (including migratory and nomadic species). The Adelaide area has now lost many of its native plant, bird, mammal and reptile species over the last 166 years, because the area was not managed to protect biological diversity. Now, less than 3% of the natural vegetation remains on the Adelaide plains .The larger patches of remnant vegetation are situated within the National, Conservation and Recreation parks located throughout the Adelaide area and a few degraded regions such as the Field river (Table 1)

Presently, the major threat to local biodiversity is the limited space. In locations such as the Field river where the space is available, uncontrolled recreational activities, inappropriate management and rubbish dumping are also threatening activities to the continued survival of this ecosystem. It is now vital that the importance of appropriate land management strategies be highlighted in order to combat and mitigate the harmful and long-lasting effects of these particular practices. Development will continue, but, as stressed by the National Conservation Strategy of Australia, development needs to be within the sustainable capacity of the natural environment. The four objectives of the National Strategy include preserving genetic diversity, ensuring the sustainable use of species and ecosystems, preserving essential ecological processes and life-support systems, and sustaining and enhancing environmental qualities, thus improving quality of life. Conservation leading to the sustainability of the few remaining open spaces such as the Field River is now becoming a priority for councils and communities, with management of the remaining species and habitat types the main priority. Maintenance and develoment of the Field river could be a world first –the retention of a natural system inside a city, to highlight the importance of and need to conserve biodiversity.

Park Type	Park Name	Park Area (ha)
National Park	Belair	816
	Onkaparinga River	1490
Conservation Park	Cleland	993
	Horsnell Gully	245
	The Knoll	1.7
	Torrens Island	79
	Morialta	540
	Port Gawler	433
	Montacute	201
	Black Hill	701
	Fort Glanville	5
	Ferguson	8
	Hallett Cove	50.2
	Eurilla	7.5
	Angove Scrub	5.19
	Kenneth Stirling	253
	Mount George	66.7
	Mark Oliphant	181
	Mylor	45.7
	Scott Creek	706
	Marino	30
	Moana Sands	21.4
	Aldinga Scrub	265
Recreation Park*	Onkaparinga Estuary	290
	Para Wirra	1426
	Brownhill Creek	51
	Greenhill	27
	Shepherds Hill	88
	Sturt Gorge	178
	Cobbler Creek	288
	Anstey Hill	307
	O'Halloran Hill	289

Table 1. Summary of the size of the National, Conservation and major Recreation Parks in the Adelaide Metropolitan Area.

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as possible to ameliorate the flood risk, a risk exacerbated by the very development of paved roads and houses. Water in the suburbs was seen as a nuisance and pollutants associated with the runoff made storage of the water an undesirable activity.

Under pre-European conditions flooding occurred but the majority of floodwaters were probably retained on the land, forming swamps and wetlands and recharging aquifers. Some freshwater did reach the sea and ecosystems had become established in balance with variable salinities experienced in different parts of the estuaries and near shore waters.

The long-term geological view reveals that past stream discharges were considerably greater than at present, and that there has been an general diminution in water flow since 125 ka when wet and warm conditions favoured the deposition of vast alluvial deposits (the Pooraka Formation) across the Adelaide region. Sea level at this time was some 2 m higher than present. The general drying trend was punctuated by minor pluvial events about 40 ka and 4-6 ka ago. Colder episodes were associated with drier and windier conditions. These severe conditions culminated about 20 ka ago when sea level was up to 150 m lower than now. We are currently experiencing mild interglacial conditions that have favoured human activities.

Today there is a move towards returning the hydrological regime of the Adelaide region more back to that of pre-European times. Even though extensive areas of the city of Adelaide are covered with hard surfaces, water is being retained on the land by increasing numbers of rainwater tanks and there have been some highly successful wetland developments with associated aquifer recharge schemes developed such as those at Parafield Airport. We are concerned about discharging sediment and pollution-laden waters into the gulf where past events have severely impacted on the nearshore ecology. Care needs to be taken in planning to avoid flood prone areas and to maintain any surviving wetland environments, which provide an amenity for humans, a habitat for wildlife and preservation of biodiversity.

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