THE RELATIONSHIP BETWEEN SEDIMENTATION ON ALDINGA REEF, AND WASHPOOL CREEK AND SELLICKS CREEK CATCHMENTS, WILLUNGA BASIN

by

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ABSTRACT

This study assesses the relationship between sediment accumulation on Aldinga Reef in Gulf St. Vincent, and sediment discharges from two neighbouring rural catchments, Washpool Creek and Sellicks Creek, in the Willunga Basin, South Australia. Since European settlement, extensive woodland clearance, the introduction of plant species, and intensive agricultural activities have been major features of the Basin's environment. As a result erosion and gullying have been prevalent in the two catchments. The study compares patterns of erosion as noted from field observations, with analysis of a sediment core from a lagoon in Washpool Creek catchment. The palaeoecological approach was undertaken to investigate changes in vegetation, erosion and sedimentation associated with European land use practices on the rural catchment. Field observations indicated that erosion and gullying was greatest in Sellicks Creek catchment. Lead-210 dating of Washpool Lagoon sediments indicated that the rate of sedimentation was not as great as was expected from a catchment experiencing such severe erosion and gullying. The calculated ^{210}Pb flux indicated that sediment discharges from Washpool Creek catchment to the Gulf of St. Vincent were only negligible.

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

> 'The landscape of the earth has been greatly influenced by the processes of soil erosion and sedimentation. When uninfluenced by the activities of humans, these processes often produce picturesque landscapes . . . and other places of natural beauty. However, when the landscape is subjected to human activities with no consideration for conservation, the result is all too often a rather grotesque picture of fields riddled with gullies and muddy streams whose channels are filled with sediment.' (Haan *et al.*, 1994: 238)

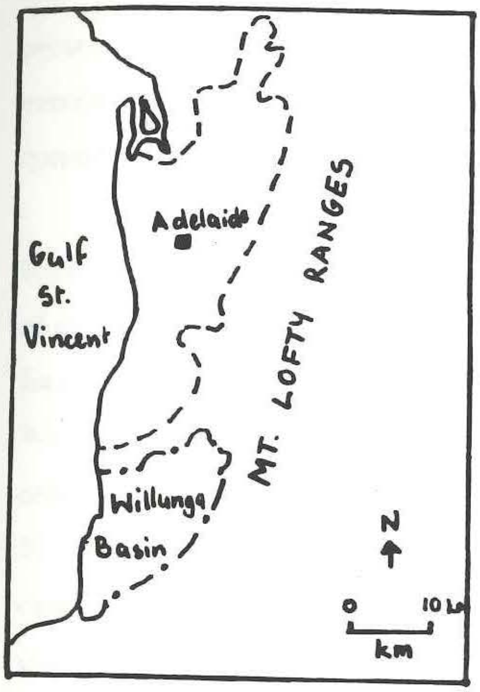
In Australia the impact of European occupation on the environment has resulted in dramatic changes to the landscape. These changes have arisen through activities such as land clearance and the conversion of much of the Australian landscape to agricultural production -- both major contributors to the serious problem of soil erosion and gullying. Yet the problem of erosion and sedimentation is not contained in the terrestrial environment alone. Throughout Australia and the world, the devastating effects of sedimentation are being recognised on our marine environments, which have too often become the ultimate basin for terrestrial discharges.

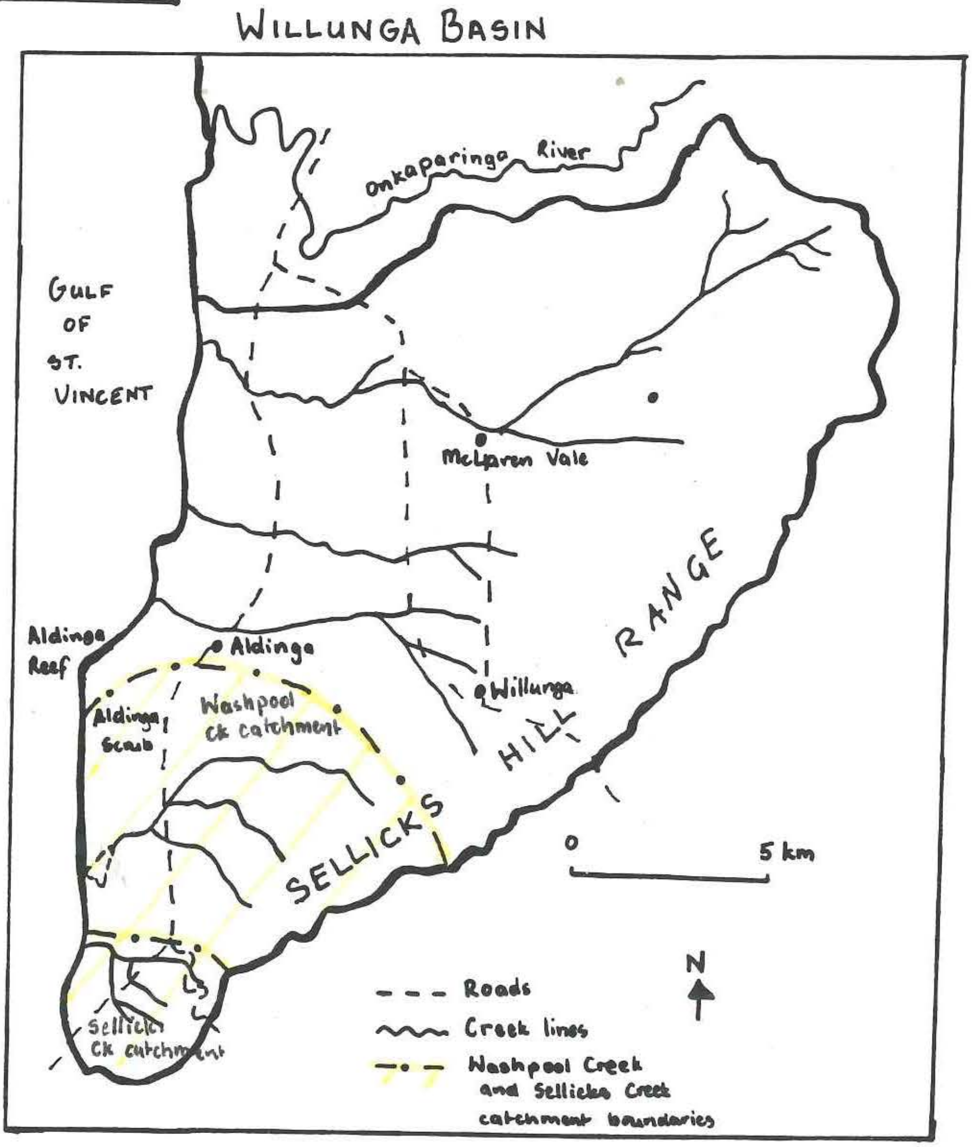
An aim of this thesis is to examine two catchments (Washpool Creek and Sellicks Creek) on the Fleurieu Peninsula, South Australia. Both relate very well to the criteria described above: the catchments are severely eroded and riddled with gullies, and their discharges have the potential to impact on the marine ecosystem, in this case Aldinga Reef in the local offshore region of Gulf St. Vincent (Figure 1).

Prior to this research, two studies were carried out by Kinhill Engineers of Adelaide which examined the state of the marine environment of Aldinga Reef (Kinhill Engineers, 1987), and the sources of sediments and the quality of water entering the reef (Kinhill Engineers, 1988). Kinhill Engineers were initially engaged by the District Council of Willunga in 1986 to investigate siltation sources to Aldinga Reef following reports from the SCUBA Divers Association of apparent increases in siltation on the reef.

The purpose of the first study (Kinhill Engineers, 1987) was to assess whether degradation, through siltation, was occurring to plant and animal communities on the reef. The main method used by Kinhill Engineers to assess whether siltation was a problem on the reef was the

Figure 1: The location of Washpool Creek and Sellicks Creek catchments in the Willunga Basin relative to Adelaide.





placement of nine sediment traps on, and in the vicinity of, Aldinga Reef. Sediment from the traps was collected at monthly intervals and analysed for particle size. Sand was found to be present in all samples due to the resuspension of coastal sands caused by wave-generated currents. However, in the June and July samples, silt was found to be the dominant sediment component in the samples. It was inferred that these sediments were terrigenous.

High volumes of silt deposits on the reef in June and July 1986 coincided with the observation of sediment plumes from catchment runoff along the coastal zone near Aldinga Reef. Kinhill Engineers (1987) found that creeks provided 98% of fine sediment to the reef area, with Willunga Creek, Maslin Creek, Sellicks Creek and Cactus Canyon being the major sources of sediment. It was also noted that Silver Sands Creek lagoon (referred to in this thesis as Washpool Lagoon) normally acted as a retaining basin for most of the sediment in that catchment, but when the lagoon overflowed a discharge of turbid water flowed from that catchment.

In addition to an assessment of both the presence and nature of sedimentation on the reef, Kinhill Engineers (1987) also used radio-isotope analysis of corals and fixed photo-quadrats of invertebrate reef communities to assess whether degradation was occurring to reef organisms. Analysis of fixed photo-quadrats indicated that there was a definite sediment coating on reef organisms on Aldinga Reef. This was particularly evident on the lower reef. Sediment deposition was much greater on Aldinga Reef than at Ochre Point, only six kilometres to its north in an area distant from the effects of terrigenous sedimentation. Despite these observations, the radium isotope signatures for coral on the reef did not indicate that any significant land-based runoff had affected the growth rates of coral on the reef.

Sedimentation on the reef was found to be moderate to severe. While no clear assessment was made of degradation to the reef community it was suggested that community composition may have shifted to more sediment tolerant species or growth forms. However, there was no conclusive evidence for this. The final conclusions for the report were that silt fractions in sediment traps were from land based runoff, caused by soil erosion from human activity in the respective catchments.

The second Kinhill study (Kinhill Engineers, 1988), carried out in 1987, was concerned with the quality of water entering the Gulf of St. Vincent near Aldinga Reef. Water samples were taken from three urban drains in Aldinga Beach and the six nearby creeks (Pedlar, Maslin, Willunga, Washpool, Sellicks and Cactus Canyon) to test for total suspended sediment (TSS), nutrients, bacteria and pesticides. Northward-moving sediment plumes were noted along the coastline. These occurred in July, corresponding with observations made by Kinhill Engineers the previous year.

Results from the water sampling showed that suspended sediment concentrations, dominated by silt, were greatest in July. Sediment discharge was greatest from the creeks as opposed to the stormwater drains. The creeks generated approximately 6,800 tonnes per annum or 99.5% of total sediments discharged into the reef. While the urban stormwater drains were found to be the major source of nutrients to the reef, once the nutrients were discharged to the ocean the high concentrations became diluted and only background concentrations were detected. It was inferred that the effects of nutrients on the reef from the stormwater drains were negligible. This report concluded that any biological deterioration of Aldinga Reef was caused by sedimentation coming from the nearby rural catchments rather than urban stormwater runoff.

As a response to these reports, an aim of this thesis is to examine the relationship between sedimentation on Aldinga Reef and sediment supply from Washpool Creek and Sellicks Creek catchments. According to Kinhill Engineers (1988: 4) annual sediment contribution from Washpool Creek and Sellicks Creek catchments is 18.9% and 13.0% respectively of the total sediment supply to the reef from the creeks and drains, and their July contributions, when runoff appears to be greatest, is 19.7% and 15.6%. The contribution of sediment from these two catchments to the Gulf of St. Vincent is thought to be greater than neighbouring catchments.

The main objectives of this thesis are to:

* ascertain spatial and temporal variation in soil erosion and deposition in the two catchments;
* determine whether sedimentation from the rural catchments has increased since European settlement.

1.2 Literature review

1.2.1 The effects of fluvial discharges on coastal environments

Land-based discharges into coastal waters come from various sources. Discharges are usually point sources, such as sewerage outfalls, or non-point or diffuse sources, such as surface runoff from urban and agricultural areas. Focus will be given in this section to discharges from fluvial sources. With respect to the well being of marine littoral zones, the nature of such fluvial discharges is a key issue, as they contribute nutrients and sediments to that zone. In 1995, the Federal Government of Australia released the *State of the Marine Environment Report for Australia* which addressed these key issues and other issues concerning the welfare of Australia's marine environment (Zann, 1995).

'The transport of [sediments and] plant nutrients from soil to waterbodies by ... surface runoff is a natural consequence of the hydrological cycle and is essential for the maintenance of aquatic ecosystems' (Gabric & Bell, 1993: 262). However, the export of sediments and nutrients from fluvial discharges has been accelerated by anthropogenic activities (Gabric & Bell, 1993). Activities such as deforestation, agriculture, surface mining and urbanisation have been the most prominent anthropogenic causes for accelerated rates of sediment and nutrient discharges to the marine environment (GESAMP, 1994; Gabric & Bell, 1993; Brodie, 1995; Zann, 1995).

Soil erosion, as a result of land clearance associated with agriculture, deforestation and surface mining, is the main cause for increases in the sediment loads of rivers, and ultimately, the coastal zone (GESAMP, 1994). The application of fertilisers to pastures and crops increases the concentrations of nutrients in surface runoff, particularly nitrogen and phosphorous (Gabric & Bell, 1993).

High volumes of sediments and nutrients can have quite significant impacts on the ecosystem of the coastal zone. One significant effect of high sediment and nutrient loads on the coastal zones is that it reduces the penetration of light to marine plant life (Drew, 1983; Keough & Butler, 1995; Rogers, 1990). Light is the source of energy for plant photosynthesis. The attenuation of light through water with depth usually influences the distribution of marine plants (Drew, 1983), but this distribution can also be affected by factors such as turbidity (Keough & Butler, 1995). Turbidity of coastal waters is often a consequence of human activities on the land which lead to increased sediment loads in fluvial discharges. Turbidity leads to a reduction in light availability, thereby favouring the growth of shade-tolerant species and non-phototrophic organisms (Keough & Butler, 1995). Plant communities need then to become adapted to limited light and also different spectral compositions. Changes in light penetration may have profound effects on plant distributions, and hence other organisms (Keough & Butler, 1995).

The growth of algae, for example, is dependent on light penetration. Green and brown algae usually colonise closer to the surface water because of their spectral preference, with red algae colonising at lower depths. In dimly lit places, or places with turbid water, green and brown algae become rare. This is particularly important because brown algae, such as kelp, provides an important habitat for other smaller marine organisms. The decline of brown algae is, therefore, likely to have dramatic effects on species that depend on the structure provided by these habitat-formers (Keough & Butler, 1995).

The penetration of light through the water surface can also be affected by factors relating to elevated nutrient levels from fluvial discharges. Australian waters are generally low in nutrients and therefore have a relatively low biological productivity (Zann, 1995). So there is considerable potential for increases in nutrient discharges to have a dramatic effect on coastal waters (Gabric & Bell, 1993). The nutrients found most responsible for any changes along the coastal zone are phosphorous and nitrogen (Gabric & Bell, 1993; Brodie, 1995). These nutrients are responsible for the eutrophication of coastal waters. While plants require nutrients to grow, they have specific nutrient requirements (Brodie, 1995). Increased concentrations of nitrogen and phosphorous tend to enhance plant growth. This is particularly so for phytoplankton, the food base of the oceans (Gabric & Bell, 1993; Zann, 1994). Excess algae growth can reduce light penetration and smother other organisms, such as seagrasses, which decline in response (Zann, 1995; Brodie, 1995).

Seagrass beds are ecologically important because of their high productivity, as a habitat, and because of their ability to trap and stabilise sediments (Zann, 1995). Their die-back has been associated with increases in nitrogen loadings from runoff which encourages the growth of canopy-forming plants, and reduces ambient light reaching the leaf surfaces of seagrasses (Brodie, 1995). In Australia the decline of temperate seagrass beds is of particular concern to the long-term state of temperate marine environments. In South Australia, 5000 hectares of seagrass beds in the metropolitan region of Gulf St Vincent have been lost to sedimentation and eutrophication, with greatest losses for the genus *Amphibolis* (Edyvane, in press (a)).

Fluvial discharges can have implications for the marine environment other than lowering irradiance. While there are no convincing data on the damaging effects of sedimentation in Australian waters (Keough & Butler, 1995), excessive sedimentation can be lethal to marine organisms. Most research into the effect of sedimentation of coastal environments has focused on the effects on corals in tropical systems (Rogers, 1990; Stafford-Smith & Ormond, 1992). Corals have natural mechanisms for coping with, and rejecting sediments which include the use of their tentacles and cilia (Rogers, 1990). However, suspended and overlying sediments disturb the energy budget of corals by reducing the light availability, which in turn interferes with their capacity to capture food. This increases the energy demand for sediment rejection (Stafford-Smith & Ormond, 1992) and results in reductions in growth and calcification rates. Layers of sediment on the substrate may also inhibit the settlement of juvenile corals and, therefore, recruitment (Stafford-Smith & Ormond, 1992). Not all coral species have the same ability to actively reject sediments. Excessive sedimentation can smother and bury corals which generally results in their death (Rogers. 1990). In such cases, sponges, which serve as food and habitat for fish, can also be killed by sedimentation (GESAMP, 1994). Excessive sedimentation therefore alters the interactions between organisms and their habitats (Rogers, 1990).

While some evidence exists on the effects of fluvial discharges on coastal waters, the 1995 *State of the Marine Environment Report for Australia* indicated that very little is known of the effects of human activities on temperate reefs in Australia and that such reefs are inadequately studied scientifically (Zann, 1995). Fairweather and Quinn (1995) also acknowledge the lack of experimental studies of the effects of human impacts on Australia's shoreline biota. An urgent need therefore exists for research on the population ecology of common algae and other biota susceptible to human disturbance (Underwood & Kennelly, 1990; Fairweather & Quinn, 1995).

1.2.2 Assessing the impacts of European settlement through sediment core analysis

Suspended sediments will settle once the energy of a stream dissipates. This often occurs in its lower reaches where reduced slopes produce lower stream velocities. It is particularly so in lakes where the sediments readily settle from impounded waters. In such a way the lagoon in Washpool Creek catchment, located close to Gulf St. Vincent, has the potential to trap fluvial sediments and stop them from entering the Gulf and from impacting on the coastal environment. Therefore, Washpool Lagoon is an ideal site at which sediment core analysis might assess European impacts.

Little baseline data exist on the impact of humans on the Australian environment (Boon & Dodson, 1992; Dodson *et al.*, 1994b). Chappell (1985) and Clark (1990) argue that successful management of Australia's ecosystems requires knowledge of their history. Recent studies by Australian palaeoecologists have therefore concentrated on reconstructing past environments of Australia in order to assess the impact of humans, both Aboriginal and European, on these environments.

The most common approach to investigating past environments is to use sedimentary records. Sediment records yield integrated histories of past changes and can represent the interaction of climate, ecology, and cultural and technological changes on land and water systems (Boon & Dodson, 1992). One of the great advantages of sediment-based studies is that they can be completed in a relatively short period of time and provide information on the environment that spans tens of thousands of years (Boon & Dodson, 1992).

Sedimentary records are usually taken from lakes because lakes and their ecosystems continually accumulate sediments providing uninterrupted evidence of environmental processes (Meybeck *et al.*, 1989; Dodson *et al.*, 1994a). Ephemeral lakes are generally not considered suitable for sedimentary analysis of pollen because their dry nature is not conducive to long-term pollen preservation (Kershaw *et al.*, 1994). However, Rutherfurd and Kenyon (submitted) have found sedimentary records from seasonally dry floodplains on the Murray River to be useful and have investigated floodplain vegetation history.

Climatic change and human activity can alter biological and physical processes in the environment (Dodson *et al.*, 1994a). While aboriginals have impacted on the Australian environment, particularly through the use of fire (Kershaw *et al.*, 1994), the most dramatic changes induced by humans on the Australian environment have occurred since the time of first European settlement. Changes to the environment in the historic period (since European settlement) have been related to European land use activities such as land clearance and grazing (Boon & Dodson, 1992; Dodson *et al.*, 1993; Dodson *et al.*, 1994b). The impact which Europeans have had on vegetation and sedimentation can be identified through core analysis.

In recent years, the reconstruction of vegetation history has moved away from reconstructing past climatic conditions to address the questions related to human history on the environment (Head, 1988). Research has shown that the most profound vegetation changes have been wrought by Europeans (Head, 1988). Major changes in vegetation during the historic period have resulted in reduced stability and persistence in vegetation (Dodson *et al.*, 1994b; Kershaw *et al.*, 1994). Changes in the response of vegetation to the environment have been brought about by replacement of native vegetation with exotic species, the clearance of land for agriculture, and changes in fire regime due to changes in human influence on the environment (Gell *et al.*, 1993). Evidence suggests that changes in vegetation, as seen through sedimentary records, are a direct result of European activities on the environment (Kershaw & Strickland, 1988).

Comparisons of prehistoric (pre-European) and historic sediments, as identified from dating of sediment cores, have also shown that sedimentation rates and erosion have been greatest since European occupation (Boon & Dodson, 1992; Dodson *et al.*, 1993; Dodson *et al.*, 1994a; Dodson *et al.*, 1994b), and in some cases nearly ten times greater (Dodson *et al.*, 1994a). While the most likely reason for this is because of human impacts, changes in lake typology, such as organic inputs, may also alter sedimentation rates.

Organic sediments accumulate at different rates and in different ways depending on their environment. The three main types of environments in which organic sediments accumulate are: bogs, fens and lakes (Birks & Birks, 1980: 46). The vegetation of these environments, which affects the organic content of the sediments, depends on the water level and nutrient status of the environment. Bogs, for example, are shallow and have a poor nutrient status, and therefore only support a small plant community. Fens, also shallow water environments, are rich in vegetation species such as sedges because of their rich nutrient levels and high pH. Shallow water environments, that is swamps, tend to have coarser sediment particles. Deep lakes usually accumulate fine silt, and because of their depth, generally support aquatic plants such as macrophytes (Birks & Birks, 1980: 49, 51).

Changes in water levels can also result in changes to sedimentation rates (Williams *et al.*, 1993: 122). Permanent lakes tend to have higher sedimentation rates and greater sediment preservation, and therefore better preservation of fossils such as pollen (Williams *et al.*, 1993: 122-125). Ephemeral lakes and lakes that are becoming increasingly saline due to a decrease in water level have poor aquatic life, low levels of sedimentation and poor preservation of fossil pollen (Williams *et al.*, 1993: 122-125). The presence of aquatic organisms varies according to the status of the lake, that is, its water level, and chemical and nutrient levels (Williams *et al.*, 1993: 127).

In this thesis, a sediment core at a strategic location in the Washpool Creek catchment, a few metres from the coastline, will be examined. The core should provide detail of changes in sedimentation rates, and possible changes in the lagoon's environment. Whereas it would be expected that most of the sediment of the Washpool Creek has been trapped in the Washpool Lagoon and is available for analysis, all sediment from the adjoining Sellicks Creek catchment would be expected to find its way onto Aldinga Reef because it has no such lagoon. The next chapter describes these two catchments.

CHAPTER 2: THE STUDY AREA

The region under consideration has two components: a terrestrial system comprising Washpool Creek and Sellicks Creek catchments; and a marine system comprising Aldinga Reef. Together they form one intricate system located approximately 45 kilometres south of Adelaide in the Fleurieu Peninsula, at about 35° 15′ S latitude and 138° 25′ E longitude (Figure 1).

Washpool Creek and Sellicks Creek catchments are within the Willunga Basin and are the southern most of seven catchments (with the exception of Cactus Canyon) within the Basin. Aldinga Reef is an aquatic reserve in Gulf St. Vincent, located offshore of Aldinga Beach.

2.1 The Terrestrial Environment

The catchments of both Washpool Creek and Sellicks Creek are bounded by the crest of Sellicks Hill scarp to the east and the coastline of the Gulf of St Vincent to the west. The north-western boundary of Washpool Creek catchment runs parallel to the residential areas of Aldinga Beach and Port Willunga, and its northern edge runs just south of Aldinga, which is in the Willunga Creek catchment. Sellicks Beach Road partly demarcates the division between Washpool Creek and Sellicks Creek catchments, and Old Sellicks Hill Road follows the division between Sellicks Creek catchment and Cactus Canyon catchment. The southern boundary of Sellicks Creek catchment crosses Main South Road just north of Cactus Canyon (Figure 2).

Washpool Creek catchment is larger than Sellicks Creek catchment, totalling approximately 4,270 hectares, whereas Sellicks Creek catchment is 771 hectares in area.

2.1.1 Geology, geomorphology, soils and climate

The basin in which the two catchments lie was formed by the uplifting of the Clarendon and Willunga faults during the Tertiary period, creating the Sellicks Hill Range (Ward, 1966: 16). Sellicks Creek catchment is in the southern part of this range, and is more uplifted than Washpool Creek catchment. In Sellicks Creek catchment, 62% of the area is above 100 m, whereas only 28.6% of Washpool Creek catchment is above 100 m (GISCA, 1995). This is

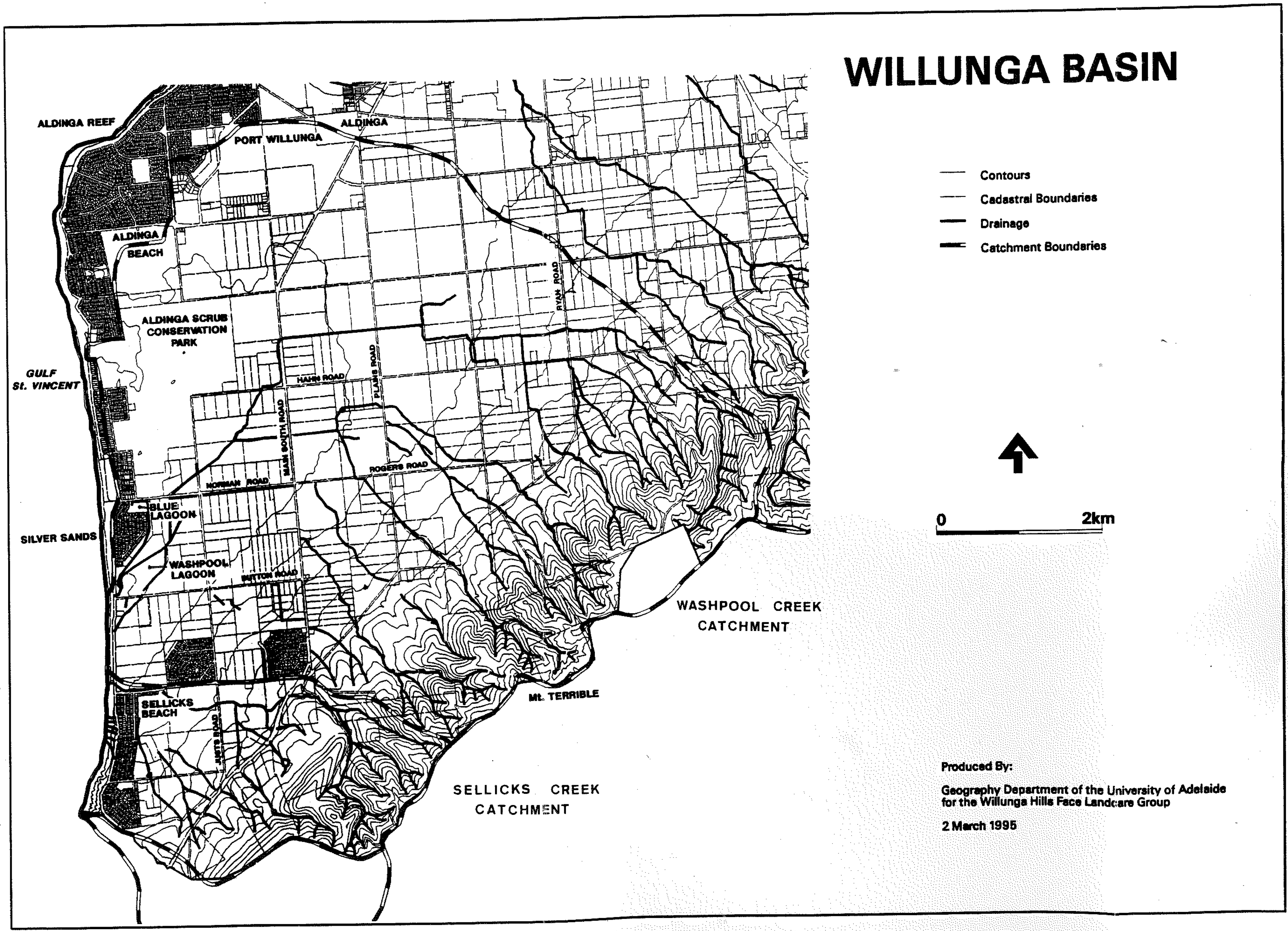

WILLUNGA BASIN
Contours
Cadastral Boundaries
Drainage
Catchment Boundaries
0
2km
ALDINGA REEF
PORT WILLUNGA
ALDINGA
ALDINGA BEACH
ALDINGA SCRUB CONSERVATION PARK
GULF St. VINCENT
RYAN ROAD
HAHN ROAD
PLAINS ROAD
MAIN SOUTH ROAD
ROGERS ROAD
NORMAN ROAD
BLUE LAGOON
SILVER SANDS
WASHPOOL LAGOON
BUTTON ROAD
WASHPOOL CREEK CATCHMENT
Mt. TERRIBLE
SELLICKS BEACH
SELLICKS CREEK CATCHMENT
Produced By:
Geography Department of the University of Adelaide for the Willunga Hills Face Landcare Group
2 March 1995

Figure 2: Washpool Creek and Sellicks Creek catchments.
Source: author.

important in explaining the erosion potential of each catchment.

The hills in the study area rise up to 380 metres with the highest point being Mt. Terrible in Washpool Creek catchment. Most of the slopes of the escarpment have a gradient of 20% or more (Overton, 1993: 12).

Cambrian limestone rocks are a common feature on the Willunga scarp, outcropping in various places. The beds of these rocks are highly calcareous (Ward, 1966: 15). The sediments in the region of the study area are of both marine and terrestrial origin, and are of Tertiary and Quaternary age. During the Pliocene and Pleistocene, sediments consisted mostly of 'variously consolidated unfossiliferous alluvial silts and gravels, inter-bedded in places with aeolian clays and marls' (Ward, 1966: 16). These sedimentary rocks are therefore much younger than the older basement rocks.

In the Willunga Basin there are two main soil landscapes: the coastal landscape; and the hill landscape. Soils of the hill landscape have deeply weathered profiles which form the oldest soil landscape in the region. The soil types vary from loams to clays, and are generally calcareous below the B horizon (Northcote, 1976: 62-66). In the coastal landscape between Aldinga Beach and Sellicks Beach, and including the Aldinga Plains, soils are more recent with parent soils originating from the hill landscape (Northcote, 1976: 67). Soils of this sub-region consist mostly of sands with a generally uniform profile, and clays, which have a marked change in texture between A and B horizons.

The climate of the two catchments is of a Mediterranean type, that is, rainfall is greatest in the winter months, and is followed by hot, dry summers. Two-thirds of the rainfall for the year occur from April to September (Cochrane, 1956: 2). Precipitation generally increases with elevation, with coastal areas receiving 450 mm and the hill slopes receiving 750 mm of rain (Ward, 1966: 8). Because of the climate type for the region and the seasonal pattern of rainfall, there are no permanent streams within either of the two catchments. Streamflow for the ephemeral watercourses occurs during the months of maximum rainfall.

2.1.2 Vegetation and wetlands

The only remaining stand of remnant native vegetation in either of the two catchments is Aldinga Scrub in Washpool Creek catchment (Figure 2). While there are isolated stands of native vegetation along Sellicks Hill range, these are small, especially in both Washpool Creek and Sellicks Creek catchments. Visual surveillance of the southern section of the scarp highlights the sparse vegetation cover (Plate 1). According to Newman (1994: 106), trees on Sellicks Hill Range were first removed in the late 1860s and 1870s, and the cover was almost completely gone by the 1880s across a substantial part of the hills. A great deal of this tree clearance occurred to make the land suitable for agriculture. These changes in vegetation cover are significant in regards to gullying, as decreases in vegetation cover can be directly correlated with increases in streamflow, which ultimately contributes to the incidence of gullying.

Plate 1: Sellicks Hill Range.
Note the distinct lack of native vegetation, especially trees.
Source: author.

Native vegetation in the basin was originally represented by woodland, low woodland, open woodland and open forest. Dominant tree species included *Eucalyptus obliqua* (Messmate Stringybark), *E. fasciculosa* (Pink Gum), *E. baxteri* (Brown Stringybark), *Acaciaverticillata*

(Prickly Moses), and *A. rotundifolia* (Round-leaf Wattle) (Overton, 1993: 15). Most native vegetation has been replaced with exotic species such as *Pinus radiata* (Montery Pine), olives (*Oleaeuropaea*) and almond trees, European grasses and weeds such as Salvation Jane (*Echium plantugineum*), crops and pastures. This has resulted in a change in vegetation communities in the basin.

Washpool Creek catchment contains three prominent features which differentiate it from Sellicks Creek catchment. This includes the stand of remnant native vegetation, Aldinga Scrub, and the swampy sites of Washpool Lagoon and Blue Lagoon (Figure 2 and Plates 2, 3 & 4).

Aldinga Scrub (now preserved as a conservation park), is near the coast south of Aldinga Beach and comprises some 250 hectares (Nurton, 1991: 3). It is an 'ecologically unique area' as it contains the 'last remnant of native coastal scrubland along the greater Adelaide coastline and [is] the only example of coastal scrubland of its type which still exists in the world' (Kinhill Engineers, 1994: 1). The coastal scrubland is also known for its 'boggy nature' (Nurton, 1990: 2). Prior to European settlement, groundwater levels in the Conservation Park were higher 'as the park . . . was subject to inundation in the north eastern, eastern and southern sections for periods of up to six months each year' (Nurton, 1990: 4). As a result the scrub supported a vegetation community common to wetter environments including *Muehlenbeckia cunninghamii* (Tangled Lignum), a species commonly found in the low-lying areas in the Murray-Darling Basin; *Dipodium punctatum* (Hyacinth Orchid); *Ophioglossum lusitanicum* (Adder's Tongue); and *Cladia retipora* (Lacy Coral Lichen), a species rare to South Australia (Nurton, 1990: 6).

While these and other species are still present within the Conservation Park there is evidence that suggests that Aldinga Scrub is drying out. Such evidence includes the dieback of large gums, and increases in salinity levels. In the swamp areas the extent of stands of Bullrush *(Typha domingensis)* and Common Reed *(Phragmites australis)* have apparently declined. Much of this 'drying out' of the scrub is due to changes in groundwater regimes associated with the draining of the catchment and of Washpool and Blue Lagoons in the 1950s, and increases in the number of bores used for agriculture, both of which are having the effect of lowering the watertable (Nurton, 1990: 4). As a consequence, it is not known whether 'the vegetation . . . [is] in transition from one dependent on, or at least supplemented by, high groundwater levels to one suited to drier circumstances' (Nurton, 1990: 3).

Plate 2: Washpool Lagoon.
Source: author.

Plate 3: Blue Lagoon.
The patch of Tangled Lignum growing in the centre of the photograph marks the site of Blue Lagoon.
Source: author.

Plate 4: Aldinga Scrub.
From the foothills, Aldinga Scrub is the only patch of remnant native vegetation evident in the study area.
Source: author.

The wetlands of Washpool Lagoon and Blue Lagoon were once enclosed by Aldinga Scrub, but following land clearance for residential development, the two lagoons have become isolated from the main body of the scrub. Nurton (1990: 6) described them as 'an integral part of the ecosystem of the Aldinga Scrub.' The Washpool Lagoon originally provided water and acted as a drainage system to the Aldinga Scrub. Now the lagoon is generally dry over the summer months and contains water only during winter. Blue Lagoon rarely now holds water. Washpool and Blue Lagoons are of regional conservation importance as they are 'the last remaining example of a sub-coastal freshwater wetland on the Adelaide Plains.' (Nurton, 1990: 12).

As with Aldinga Scrub, there are a number of plant taxa at Washpool Lagoon of considerable local conservation value. They include *Muehlenbeckia cunninghamii* (Tangled Lignum); *Wilsonia humilis* (Silky Watsonia) and *W. rotundifolia*; *Gahnia filum* (Chaffy Saw-sedge); and *Hemichroa pentandra* (Trailing Hemichroa) (Nurton, 1990: 7).

Not only is Washpool Lagoon significant ecologically, it is important to Washpool Creek catchment as it acts as a stormwater settling pond, collecting stormwater runoff and sediment. This helps trap silts and clays, reducing the amount of sediment which reaches the gulf; a feature not apparent in Sellicks Creek catchment.

2.1.3 Aboriginal heritage

The whole coastal region of Washpool Lagoon, Aldinga Scrub and Aldinga Reef was an important resource for the Kaurna people of the Adelaide Plains (Wood, 1994: 3). The Kaurna people utilised the resources available to them in this area, and Aldinga Reef was significant in the summer months, when the Kaurna occupied the coastal areas (Wood, 1994: 3). The reef, and coast in general, provided plentiful sources of fish such as salmon, mullet, tommy ruff and mulloway.

Aldinga Scrub was a source of shelter and provided numerous plant foods, as well as animals such as kangaroos, emus, birds, lizards and insects. Most aboriginal archaeological sites in Aldinga Scrub are found in close proximity to the fringes of the scrub (within 100 m of the outer edge). It is therefore believed that the Kaurna people took refuge in the scrub during the winter as it provided shelter from the cold winds and was a plentiful source of firewood (Wood, 1994: 9-10).

Washpool Lagoon, known to the Kaurna people as *Wangkondanangko,* meaning 'possum place' (Wood, 1994: 4) was particularly significant to them. The Kaurna aboriginals relied on Washpool Lagoon as a source of freshwater, as well as a food source rich in bird life. But the significance of Washpool Lagoon lies in its aboriginal name, *Wangkondanangko*. The lagoon was known by the Kaurna people as the site where animal skins, particularly those of possums, were pegged out to cure before being used for cloaks and rugs (Wood, 1994: 4). The Washpool Lagoon is also significant in the legend of Tjirbruki, which 'tells of the travels of an ancestral hero, Tjirbruki, and his creation of a series of springs along the coast' (Gara, 1988: 2), and therefore is a site of aboriginal significance.

During the winter months, the Kaurna people migrated away from the coastal regions to more shelter and safety of the wooded hills and valleys (Ellis, 1976: 116). However, Nobbs (Wood, 1994: 3) presumed that since the distance between the coastal plains and the hills is quite short in this region of the Adelaide Plains, it is more likely that aboriginal occupation along the Aldinga-Sellicks Beach section of the coast was more permanent than seasonal.

2.1.4 European land uses: past and present

Since the beginning of European occupation of this region in the 1840s and 1850s, the study area has been largely developed for agriculture (Figure 3). Agricultural development has been more extensive in the Washpool Creek catchment than in the Sellicks Creek catchment. In both catchments sheep and cattle grazing is prominent, particularly on the hill slopes. The floodplain of the Washpool Creek catchment is used for crop production. Although the area of non-irrigated agriculture is greater in Washpool Creek catchment, a larger proportion (90% c.f. 75%) of Sellicks Creek catchment supports non-irrigated agriculture (Table 1).

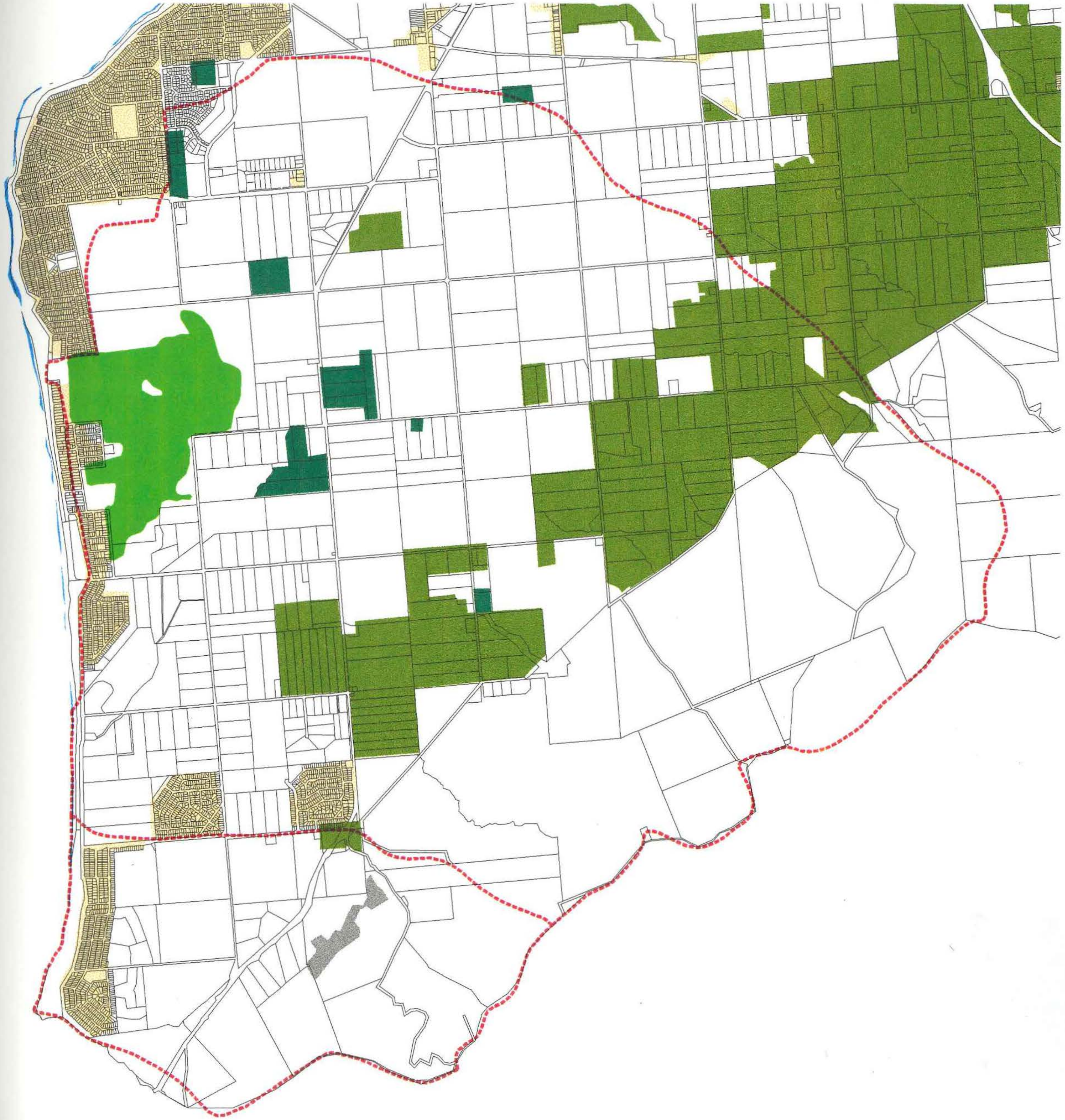
TABLE 1: LAND USE AS A PERCENTAGE OF TOTAL CATCHMENT AREA

Land use	Sellicks Creek (ha)	Sellicks Creek % of total (771 ha)	Washpool Creek (ha)	Washpool Creek % of total (4270 ha)
Vineyards/Orchards	5.5	0.7	614	14.4
Irrigated agriculture	0	0	69	1.6
Non-irrigated agriculture	692.3	89.8	3243	75.9
Residential	53.5	6.9	106.6	2.5
Quarries	14.2	1.8	0	0
Unclassified	5.7	0.7	72.9	1.7

Source: GISCA, 1995.

Other agricultural practices which are features of the Willunga Basin, notably the growing of vineyards and almond groves, are also present in both the Washpool Creek and Sellicks Creek catchments. There are only 5.5 hectares of vineyards and almond groves in Sellicks Creek catchment, representing less than one percent of the total area of vineyards and orchards. When comparing the percentage of vineyards and orchards to other land uses in Washpool Creek catchment, they constitute 14.4% of land use, the second most prominent land use in the catchment (Table 1).

Landcover



Orchards/Vineyards

Irrigated Crops/Pasture

Native Vegetation

Residential Urban/Rural

Quarries

Water Bodies

DCDB

Sellicks & Washpool Creek Catchments

Scale 1:38000

0 2km

Produced By:

Geography Department of the University of Adelaide
for the Willunga Hills Face Landcare Group

2 March 1995

Figure 3: Landcover for Washpool Creek and Sellicks Creek catchments.
The landcover map was derived from 1985 colour aerial photographs.
Source: GISCA, 1995.

The other significant land use within the two catchments is residential. Nearly 7% of the total area of Sellicks Creek catchment is dedicated to residential zoning, as opposed to only 2.5% in Washpool Creek catchment (Table 1). While residential zoning is only a small proportion of land use in both catchments, the Planning Advisory Services (1993: 7) predict that future expansion of metropolitan Adelaide will extend into the Willunga Basin, expanding those areas already zoned as residential. According to the Land Capability Assessment carried out by the Planning Advisory Services (1993: 55-59), the most suitable areas for potential urban development occur in Washpool Creek and Sellicks Creek catchments.

Another land use, exclusive to Sellicks Creek catchment, is the extraction of limestone and dolomite from a quarry east of Main South Road near Sellicks Beach. Since the beginning of European settlement in this region mining and quarrying have been an important land use, although affecting less than two per cent of the catchment area. While slate mining was the most prominent form of mining in the region from the 1840s to 1890s, limestone and dolomite are the main materials mined today (Newman, 1994: 121, 123).

2.1.5 <u>Changes in drainage of the terrestrial environment: the development of gullying</u>

Drainage of both Washpool Creek and Sellicks Creek catchments has been altered considerably during the period of European occupation. According to early survey maps of the Hundred of Willunga, the only known drainage lines in the study area at the beginning of European occupation existed on the scarp and foothills of Sellicks Hill Range. Since the 1880s, there has been a notable increase in the size, length and number of watercourses within the study area (Newman, 1994: 53). The watercourses in Washpool Creek catchment appear to have developed more than Sellicks Creek catchment (Table 2). In 1883, for example, there was a total of 30 kilometres of drains in both catchments. By 1896, drainage for the two catchments had extended to approximately 40 kilometres, with Washpool Creek catchment gaining the additional 10 kilometres of drains.

While some of these drains have been formed by natural processes of erosion and gullying, a substantial proportion of drains in Washpool Creek have anthropogenic origins. Most of the constructed drains post-date the 1950s when the District Council of Willunga undertook a regional drainage scheme (Nurton, 1990: 4). It is possible that drains were constructed in Washpool Creek catchment as a response to complaints from farmers about the accumulation of surface water on the plains, or to divert streams so that they followed roads or paddock margins instead of flowing through the middle of paddocks. Increased drainage of water from paddocks helps to explain the linear nature of the drains in Washpool Creek catchment, a distinguishable feature of the catchment watercourses.

TABLE 2: TOTAL LENGTH OF MAJOR CHANNELS FOR WASHPOOL CREEK AND SELLICKS CREEK CATCHMENTS

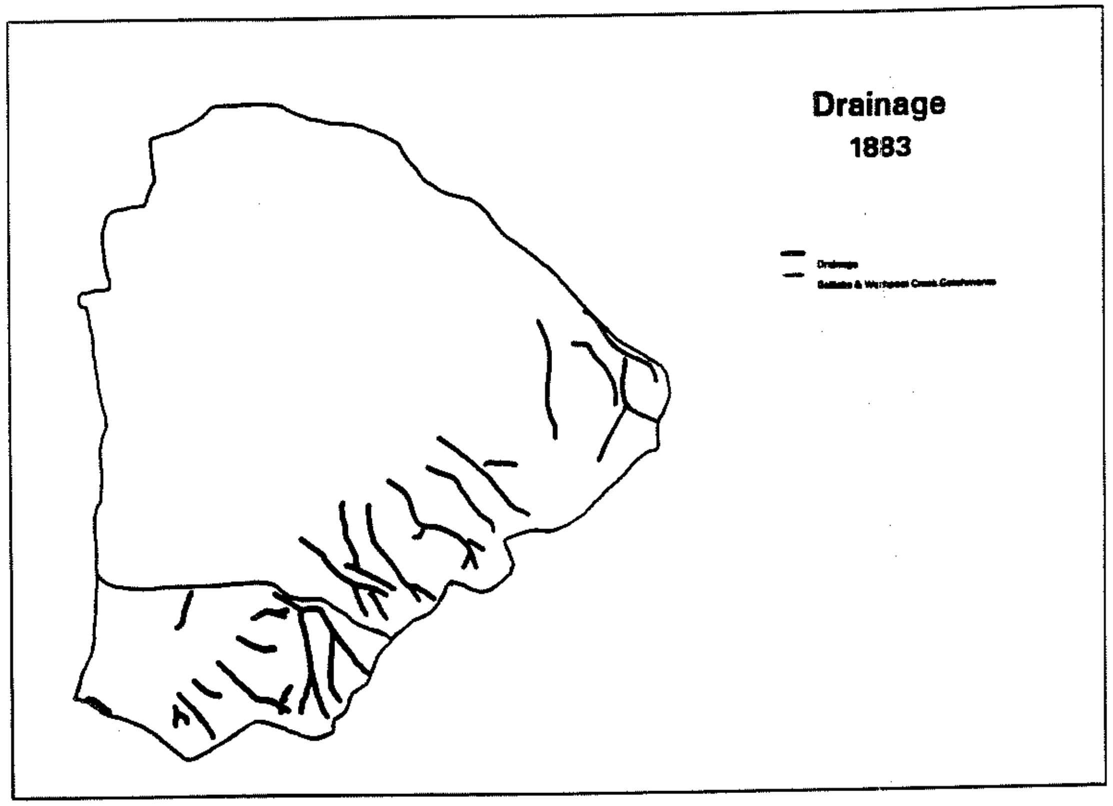
Year	Washpool Creek (km)	Sellicks Creek (km)	Total (km)
1883	18.7	11.2	29.9
1896	30.6	10.8	41.4
1915	30.2	10	40.2
1959	40.2	14.9	55.3

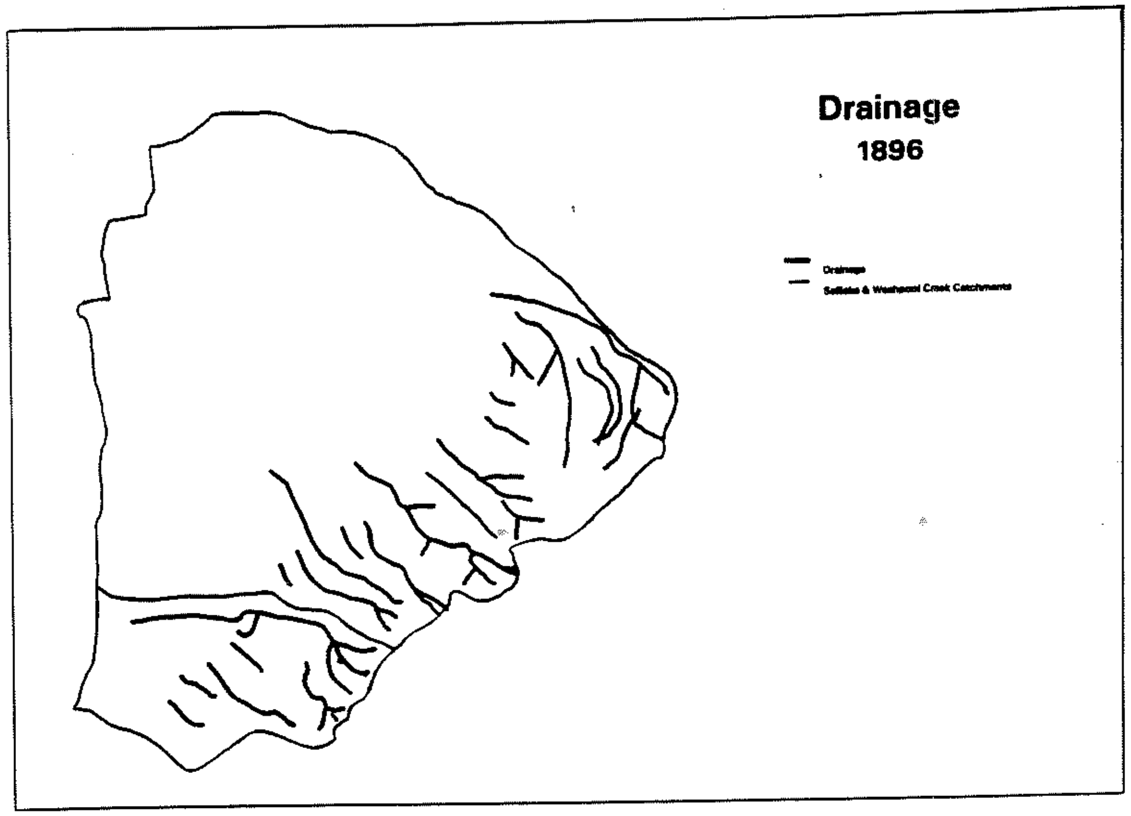
Source: GISCA, 1995.[1]

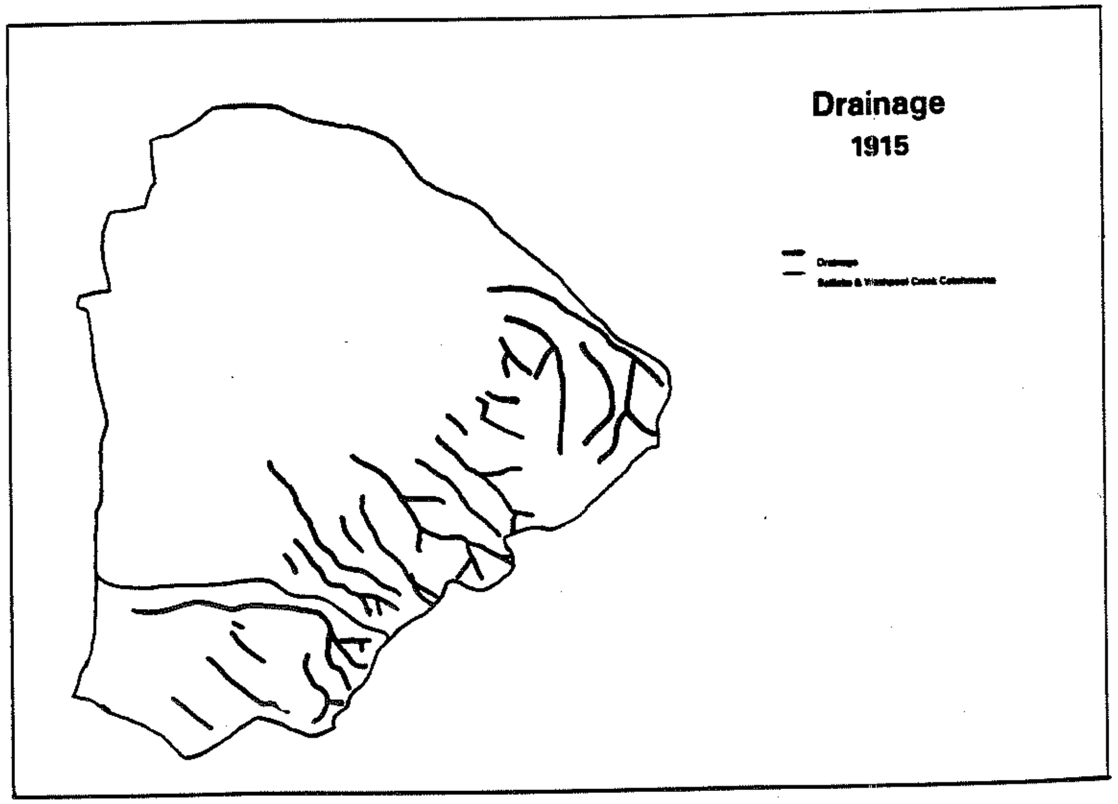
Most gully initiation along Sellicks Hill Range took place between approximately 1860 and 1910-1920 (the period between earliest living memory and original surveys) (Dragovich, 1966; Newman, 1994). The initiation of gullies has been attributable to factors such as land clearance and droughts. For example, 1945 was an important phase of gully initiation due to rains breaking the 1944 drought (Dragovich, 1966). Bourman (1975: 4) states that the 'combination of land clearance, steep slopes, unconsolidated soils or deposits together with periods of intense and persistent rainfall account for the majority of flows.'

While not all drainage is attributable to flood control measures, it is fair to conclude that the clearance of vegetation from Sellicks Hill Range has been a notable contributor to increases in runoff, which directly contributes to any increases in water lying on the plains. Between 1883 and 1896 there was a significant increase in the length of drainage lines between the Sellicks Hill Range and the coast in the two catchments (Table 2 and Figure 4). It was during this period that the greatest increases in drainage occurred. Also during this period most of the tree cover for Sellicks Hill Range was cleared. This coincidence supports a connection between land clearance and runoff.

1 In the earlier years of surveying, ie. pre-1900s, identification of channels was subjective, and possibly inaccurate. For example, in a wet year more channels were likely to have been marked on survey maps than during a 'normal' or dry year, when the channels were dry: this may explain a decrease in channels in 1915 (Newman, 1994: 50).


Drainage
1883


Drainage
1896


Drainage
1915

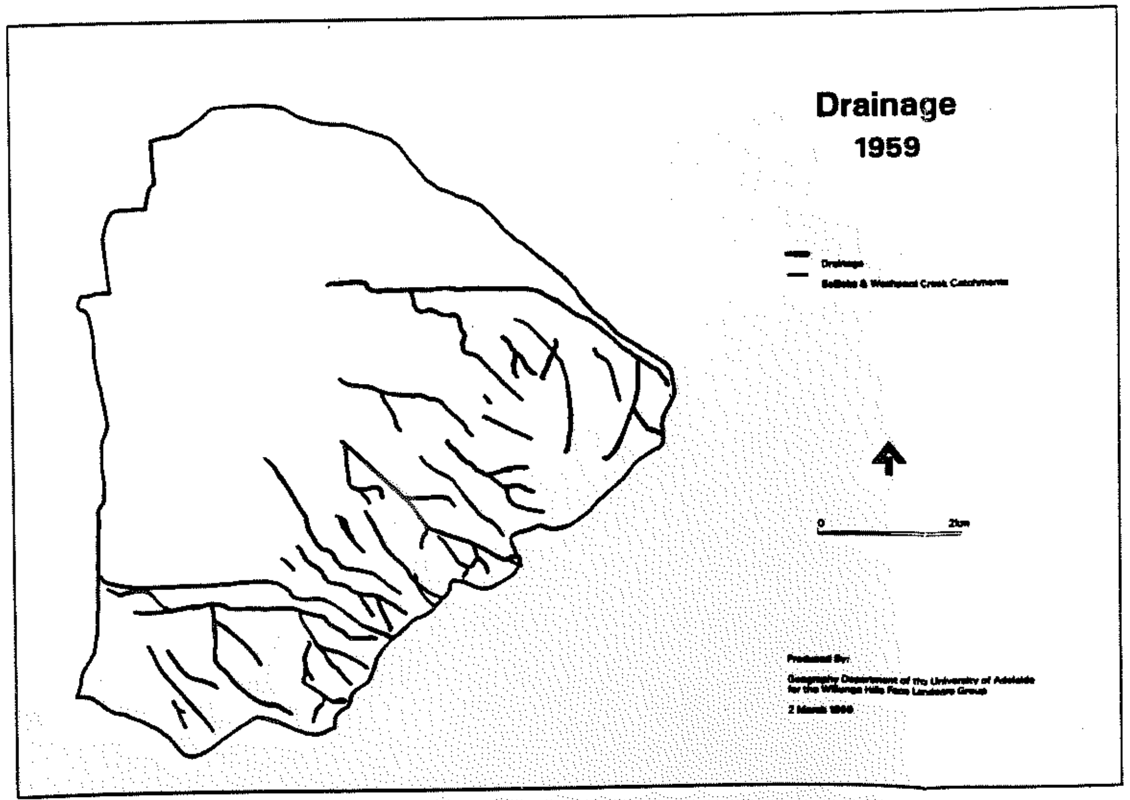

Drainage
1959

Figure 4: Changes in drainage patterns from 1883 to 1959 for Washpool Creek and Sellicks Creek catchments.
Source: GISCA, 1995.

Many studies have been conducted which address the connection between land clearance and runoff. One particular study conducted by Burch *etal.* (1987) compared the impact of runoff on two neighbouring catchments in the central highlands of Victoria. One of the catchments was vegetated by natural remnant eucalypt forest, the other covered by grassland which had been cleared of forest 80 years previous. The study concluded that there was little runoff from the native forest compared to the high discharge from the grassed catchment. High sediment yields and widespread erosion were also noted in the grassland catchment. It was evident from that study that land clearance was responsible for important changes to the hydrology of the catchment and for the problems of soil erosion and stream sedimentation. A similar event is likely to have taken place in Washpool Creek and Sellicks Creek catchments.

As there is no record of streamflow for this region, it is difficult to ascertain how runoff characteristics have been altered in this region due to land clearance. Analysis of rainfall trends for Willunga based on data from the Bureau of Meteorology however, suggest that rainfall for the region has decreased by nearly 15% over the last 120 years (Newman, 1994: 39). This suggests that any increases in runoff in both catchments is probably not attributable to rainfall, but to other factors such as land clearance. But in terms of erosion, rainfall intensity is the key and this is often inversely proportional to mean annual rainfall

2.2 The Marine Environment

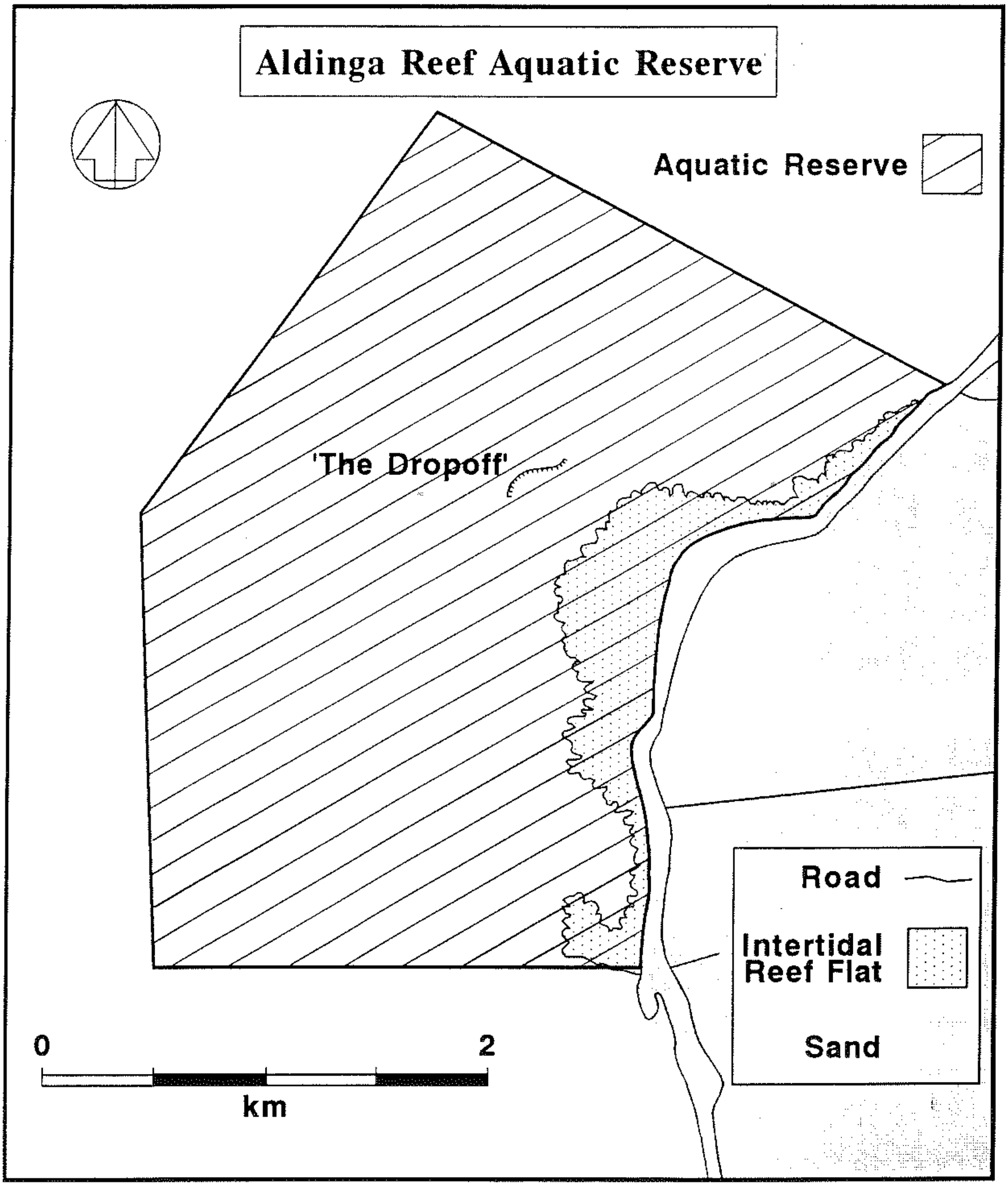
2.2.1 Coastal landforms of the Willunga Basin

The coastline of the Fleurieu Peninsula consists of a succession of 'rugged cliffs and promontories with intervening coves and beaches' (Twidale, 1976: 55). Where fault blocks reach the coast, headlands and bays occur, resulting in a raised coastal plain, such as that of the Clarendon block at Hallett Cove. In the intermediate regions of tectonic lows, such as the Adelaide Plains, the coastline is characterised by long sandy beaches. In the case of the coastline of Aldinga Bay, the fault angled depression of the Willunga Basin exposes horizontal Tertiary sequences of steep cliffs, which are backed by the sandy beaches of Aldinga.

Most of the coastline from Second Valley to Outer Harbour is of moderate wave energy with a littoral drift movement from south to north. Rocky reefs, such as Port Noarlunga Reef and Aldinga Reef, are characteristic along this coastal region.

Figure 5: Aldinga Reef Aquatic Reserve.

Source: SARDI, 1995.



2.2.2 Location and structure of Aldinga Reef

Aldinga Reef is a temperate zone littoral reef located near Aldinga Beach in the Gulf of St. Vincent (Figure 5). It is a limestone reef with a 'spectacular cliff or "drop-off"' (South Australian Research and Development Institute (SARDI), 1995). The reef has three distinct sections: a large intertidal platform; the cliff 'drop-off'; and the lower reef. Each section supports different biotic communities (Figure 6). The first section of the reef, the large intertidal platform (Plate 5), is of Tertiary age. In parts of this platform sandy rock pools are found. During periods of low tide, the platform is often exposed, making the platform and its organisms susceptible to human disturbance. The second section of the reef is the 'spectacular cliff "drop-off"'. The cliff is found 500 metres off-shore, and is about 10 metres in height. Because of the vertical nature of this section, siltation is not a serious problem to biota found here. The third section, known as the lower reef, supports a more diverse biota. This section of the reef is subjected to the greatest amount of siltation.

In 1971 the reef was declared an Aquatic Reserve, and at 505 hectares in area is, the largest such reserve in South Australia. It was established to protect the diverse flora and fauna of the reef, and in particular to protect the fish from spearfishing activities (Edyvane, in press (b): 12). It is important as a shelter and breeding ground for fish communities of the Gulf of St Vincent. The moderate wave energy coastline of Aldinga Reef is a popular location for SCUBA divers. Other permitted activities on the reef are boating, swimming and walking. Fishing and the collecting of any marine organisms is prohibited on the reef (Edyvane, in press (b): 24).

2.2.3 Biotic communities

In Australia, there are few studies on rocky shore ecology, all of which tend to be locally restricted (Fairweather & Quinn, 1995). Little literature is available on the biotic communities of Aldinga Reef. From the literature available it seems that the species, communities and assemblages mentioned are those which are commonly recognised. Very few species on Aldinga Reef are recognised for their conservation status. It is possible that there are many unidentified species on Aldinga Reef whose conservation status may need evaluation. Shepherd and Sprigg (1976: 166-174) provide a general description of biotic communities found in the Gulf of St Vincent. The South Australian Research and Development Institute for marine sciences (SARDI, 1995) provided the best list of biotic communities of Aldinga Reef.

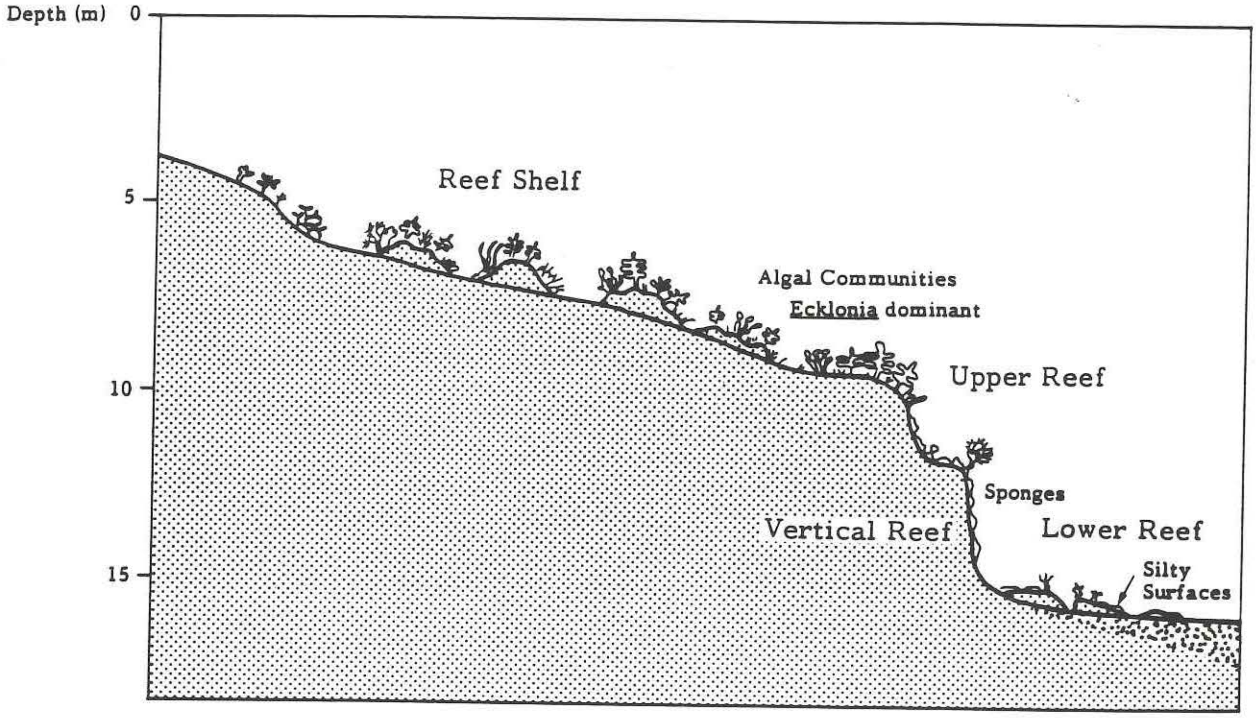


Figure 6: Biotic communities of the upper, vertical and lower sections of Aldinga Reef.
Source: Kinhill Engineers, 1987: 6.

Plate 5: The intertidal platform of Aldinga Reef.
Source: author.

Five main seagrass and sea-lettuce communities are found on Aldinga Reef. Of these, *Heterozostera* spp. (Eelgrass), *Amphibolis antarctica* (Wireweed) and *Posidonia sinuosa* (Tapeweed) are quite widely distributed across the Gulf of St. Vincent. Other seagrass communities found include *Zostera muelleri* (Garweed) and the sea-lettuce communities of *Ulva* spp. (Green Sea-lettuce).

A variety of algal communities have been identified on Aldinga Reef. The distribution of algae along any coastline is dependent primarily on a substrate suitable for attachment, the intensity of light reaching the habitat, and water movement. Algal communities are best developed on rocky coasts of moderate wave movements (Shepherd & Sprigg, 1976: 168-169). Aldinga Reef therefore has a structure quite suitable for the growth of algae. The most common algae communities found on Aldinga Reef are those species of brown algae, namely *Cystophora* spp., *Sargassum* spp., *Hormosira banksii* (Sea Grape) and *Ecklonia radiata* (kelp). *Caulocystis uvifera* is another brown algae species found on the reef. Brown algae, canopy-forming plants, are a dominant feature of many open coast reefs (Keough & Butler, 1995: 40). Red algae species tend not to be as well studied as brown algae groups (Keough & Butler, 1995: 41). Red turf algae species have also been identified, with *Gelidium pusillum* being the most common species present.

Faunal species noted on Aldinga Reef mainly comprise zooplankton and the sponges. Gorgonian corals are also common on the reef, especially *Mopsella zimmeri*. Gorgonian corals of the genus *Melithaea* are, however, locally endangered. The other locally endangered species is the blue groper, *Achoerodus gouldii*. A variety of crustaceans, such as the hermit crab, *Paguristes frontalis*, and ascidians including the orange-red ascidian (*Pyura spinifera*) are also found on the reef.

Keough and Butler (1995: 48) point out that 'appropriate management activities [of temperate subtidal reefs] ... requires much more detailed biological information than is currently available.' Therefore, further research needs to be carried out to investigate the conservation status of floral and faunal species on Aldinga Reef. Studies need to identify which species are more susceptible to the impacts of sedimentation due to their feeding structures; which species, if any, are becoming endangered because of too much sedimentation; and, whether species can adapt to a silted environment.

CHAPTER 3: FIELD OBSERVATIONS OF CATCHMENT DRAINAGE

3.1 Introduction to field observations

Field examination of both Washpool Creek and Sellicks Creek catchments was carried out over numerous visits from March through to September, 1995. The aim of the visits was to gain some understanding of the general environment; and to observe, quantify and map how the environment of these catchments had changed as a result of erosion. The field observations provide a prelude to the examination of the sedimentation history of Washpool Creek catchment.

A variety of weather conditions were observed during the survey period. It was useful to observe as this provided valuable information about surface runoff. Except for the month of May, rainfall for Willunga (the climate station nearest to both catchments and Sellicks Hill Range) in 1995 was generally below average (Figure 7). Such periods of lower than average rainfalls may not represent the typical pattern of runoff and erosion in the catchment. Further more, the higher than average rainfall in May, after a period of dryness, may have resulted in a greater than usual pulse of erosion. This could not be evaluated as the survey period was necessarily restricted and a full range of climate scenarios could not be studied.

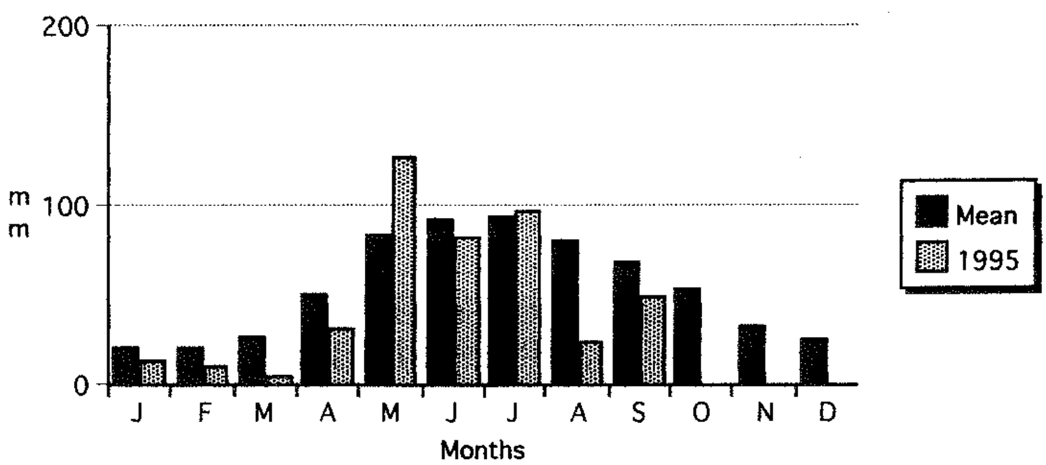


Figure 7: Comparison of 1995 rainfall to the mean rainfall for Willunga

Source: Bureau of Meteorology, 1995.[1]

1 The mean rainfall for Willunga is based on 133 years of data.

Streamflow in both catchments is ephemeral. The drains or watercourses take a variety of shapes, lengths and sizes. Each of the drains or watercourses were classified according to depth and width, which was used to calculate sediment volumes in order to identify which parts of the catchment contribute the most sediment. It was clear from field observation that there was spatial variation in the transportation of sediment loads across each catchment. The other aim of field observations was to recognise the features of drains and their local watershed area which have been implicated in accelerated soil erosion and sedimentation, for example, the presence or absence of vegetation cover, the type of land use, and the direction of paddock ploughing (downhill or following contours).

A key based on size classes was devised to classify drains while in the field. The smallest width and depth limit for drains was 30 cm. Any drains less than this were considered to be roadside runoff, and therefore only minor features in the overall catchment drainage. At the other end of the scale, drains greater than 150 cm in width and depth were considered to constitute a gully. Gullies have been classified by size for agricultural purposes to be as small as one metre deep (Schumm *et al.*, 1984: 7), however, 150 cm was considered to be a more suitable measure for the minimum size for gullies because it provided greater distinction between a 'drain' and a 'gully'. Two categories of gullies were identified: one representing a V-shaped incision; the other, a U-shaped gully. The latter classification describes a more classic gully, that is, a permanent, dynamic feature with vertical channel walls. In between the two extremes, drains were also classified not only by depth and width, but also if they resembled a natural meandering drain, or whether they were a roadside construction.

A map of the two catchments was drawn showing the differences in drainage according to the classification of the drains (Figure 8). The drainage characteristics of the two catchments was added to a base map of the region (GISCA, 1995). While an attempt was made to map the entire area of both catchments, poor accessibility made it difficult to reach some drains. As a result, estimations were made of the size and depth of these drains from photographs taken during the survey and from aerial photographs taken in 1992.

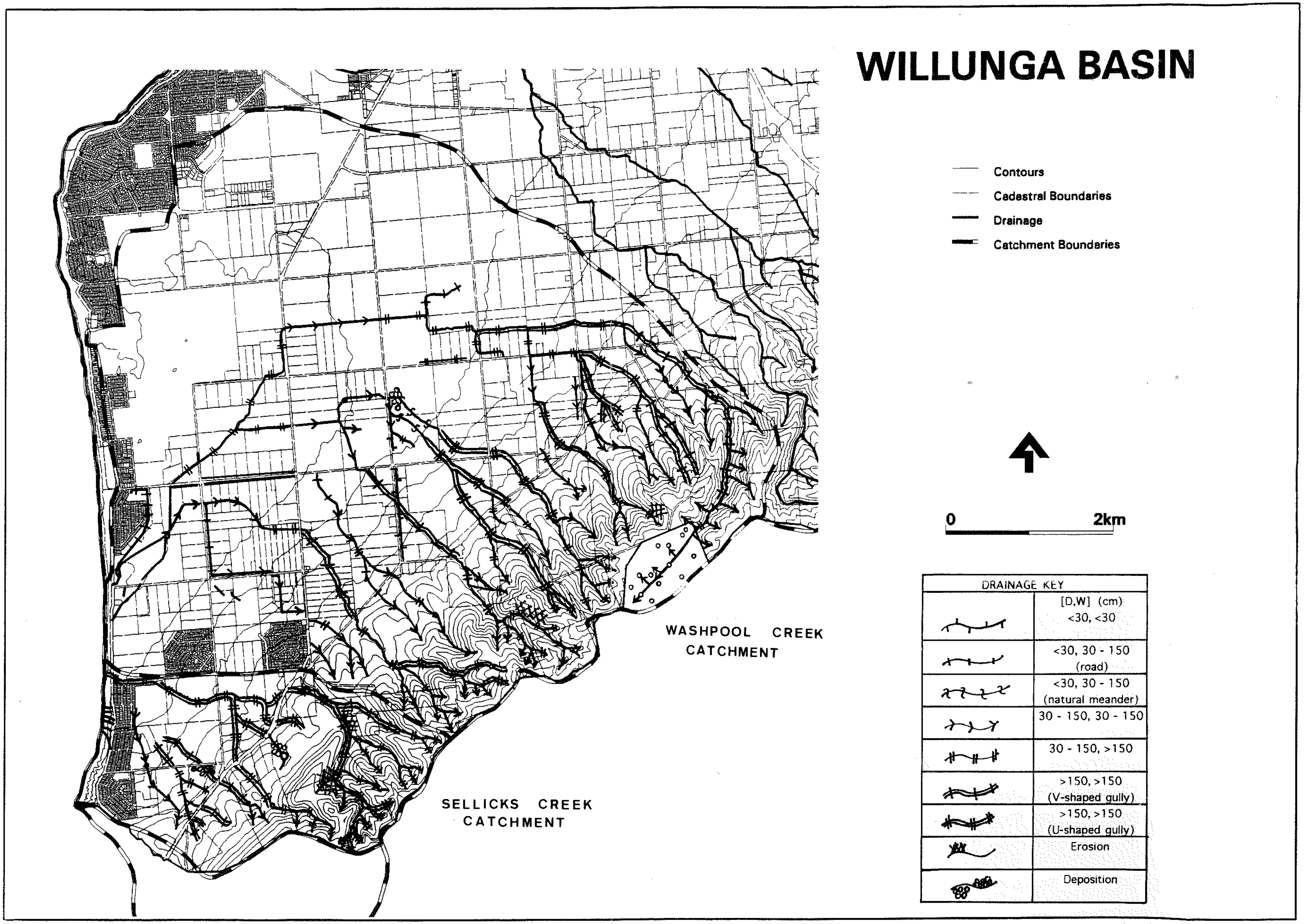

WILLUNGA BASIN
Contours
Cadastral Boundaries
Drainage
Catchment Boundaries
0
2km
WASHPOOL CREEK
CATCHMENT
SELLICKS CREEK
CATCHMENT
DRAINAGE KEY
[D,W] (cm)
<30, <30
<30, 30 - 150
(road)
<30, 30 - 150
(natural meander)
30 - 150, 30 - 150
30 - 150, >150
>150, >150
(V-shaped gully)
>150, >150
(U-shaped gully)
Erosion
Deposition

Figure 8: Drainage in Washpool Creek and Sellicks Creek catchments.
Source: author.

3.2 Causes of soil erosion

'Soil erosion results when soil is exposed to the erosive power of rainfall energy and flowing water' (Haan *et al.*, 1994: 238). Two basic processes are involved with soil erosion by water: detachment of soil by raindrop impact on the land surface; and entrainment of soil particles by overland flow (Turner & Grayson, 1986: 11). Sediments are transported downslope by flowing water. The mean size fraction and the quantity of material transported downhill increases with velocity. As the slope decreases, the velocity and transport capacity of the stream also decreases, allowing for deposition of sediments to occur.

Deposition or aggradation occurs anywhere downslope of the point of erosion where the transport capacity of the flow is less than the soil available for transport, that is, where velocity of the flow is reduced. The larger particles and aggregates are usually deposited first. Sediment-controlling structures such as vegetation filters, terrace channels, check dams and the practice of horizontal contouring of paddocks, can all reduce the flow of water downhill.

Eroded soil from exposed upland areas near the watershed divide (here, Sellicks Hill Range) comes from the rill and interrill areas of the slope. The interrill area is that zone between small channelized flows. Erosion in this zone is a result of shallow overland flows or sheet flow, and the impact of raindrop energy on exposed soil. In a natural or vegetated catchment, overland water flow moves around rocks, grass and other surface matter and concentrates to form rills (Turner & Grayson, 1986: 16). In these rills, erosion occurs when 'flow is concentrated in microrelief channels with sufficient depth and slope to cause channel incision' (Haan *et al.*, 1994: 239). Soil detachment in this zone occurs primarily from the shearing forces of the channelized flow in the rills. Rill density and its effects on erosion varies depending on factors such as slope steepness and length, runoff rate, soil texture, soil erodibility, soil cover and the presence or absence of rainfall. Highly erodible soils have high rill density, with rills being the same size from beginning to end.

Tunnel erosion or tunnel gully erosion is another form of erosion. It is initiated by sub-surface water movement through highly permeable soils. Water moves through soil cracks and eluviates material. This leads to the development of tunnels which continue to erode as gullies following surface collapse of the tunnels (Lynn & Eyles, 1984).

3.3 The nature of gullying

Many definitions have been given for gullies, most of them being inconsistent and quite broad. For example, the term has been used to describe both submarine slumping and mudflows on the Mississippi River delta (Schumm *et al.*, 1984: 7). The American Geological Institute have defined gullies as '... any erosion channel so deep that it cannot be crossed by a wheeled vehicle or eliminated by plowing (sic) ...' (Schumm *et al.*, 1984: 7). A more general definition of gullies has been given by Schumm *et al.* (1984: 45) who recognised gullies as 'incised channels that form where no well-defined channel previously existed.' The key factor in any definition of a gully is that it is 'an unstable landform, it is dynamic and changing, and it is part of a drainage network transformation' (Schumm *et al.*, 1984: 7).

Gullies result from increased runoff or from concentration and acceleration of flowing water (Schumm *et al.*, 1984: 46). The 'cutting' ability of water is responsible for the movement of large quantities of soil. Gully formation is often affected by soil horizons. For example, a C horizon composed of weak weathered rock underlying a resistant B horizon results in a breaching of the B horizon and leads to rapid gully enlargement (Schumm *et al.*, 1984: 47).

Gullies can be V-shaped in appearance, while others, because of undercutting and lateral collapse of gully walls, are U-shaped. Expansion of gullies upslope occurs by 'fingering' and downslope by increasing length and depth (Holmes, 1946: 7).

Four stages in the development and stabilisation of gullies have been identified (Schumm *et al.*, 1984: 47):

> Stage 1: slow channel-cutting through the A and B horizons. This is the best time to undertake protective measures to stop severe gullying;
>
> Stage 2: the gully penetrates the base of the B horizon and begins cutting the weak parent material. Characteristics of this stage, the most violent of gully growth, are headward migration of a 'nickpoint' (an abrupt break in the longitudinal profile of an incising channel) and plunge pool, and rapid caving and slumping of walls and deepening of the channel;
>
> Stage 3: the period of healing when slopes of gully walls are reduced by weathering, slope-wash and mass movement. Revegetation may occur on the lowered slopes;

Stage 4: the period of stabilisation, characterised by the slow development and accumulation of new soil over the old scarred surface.

Attempts to stop gullying by placing wire netting, logs of wood, rocks and car bodies in the path of the flowing water, especially at nickpoints, invariably leads to branch gullies developing round the ends of these 'controls' (Holmes, 1946: 7).

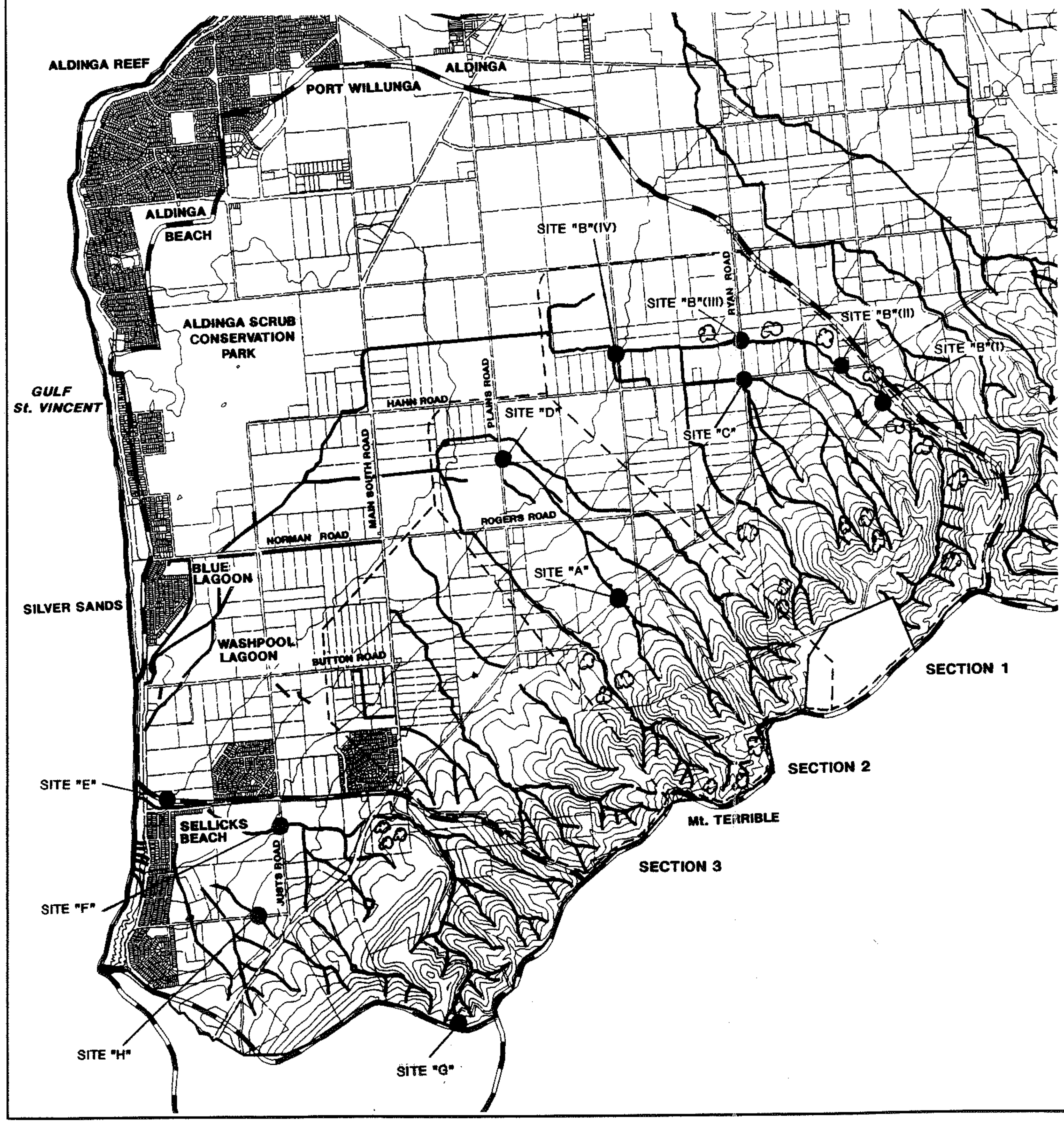
3.4 Observations of catchment erosion based on fieldwork

3.4.1 Drainage lines in the Washpool Creek catchment

There are three sections of drainage in the Washpool Creek catchment (Figure 9). The northern section (Section 1). is distinguishable by its extensive drainage system. While most of the watercourses in the catchment run off the western slopes of Sellicks Hill Range, there is one watercourse in Section 1 which is nestled in a valley between two ridges and extends quite some distance back into the range. This watercourse is riddled with farm dams near its origin. Section 2 is characterized by some quite large, deep gullies in the foothills of the scarp which subside on the plains to be more characteristic of flood channels. Drainage in Section 3 is not as extensive as elsewhere and is concentrated around two drainage lines. Each of these sections is linked by drains constructed in the area west of Main South Road, and directly flow to Washpool Lagoon. The different sections highlight the spatial variation in the distribution of drains in this catchment.

Constructed drains, distinguishable by their linear appearance, vary in width and depth, but are generally shallow. The natural watercourses vary much more dramatically than the constructed drains. Some take the form of small rills at the highest elevations of the scarp, while others are quite wide. Deep gullies have formed as these rills have grown in width and depth. For the last 50 years all runoff in Washpool Creek catchment has drained into Washpool Lagoon. Aerial photographs from 1949 indicate that some drains extended to Washpool Lagoon, and from Washpool Lagoon to the ocean, however, according to the Willunga Basin GIS, none of the drains existing in 1959 were linked to the lagoon (Figure 4).

WILLUNGA BASIN



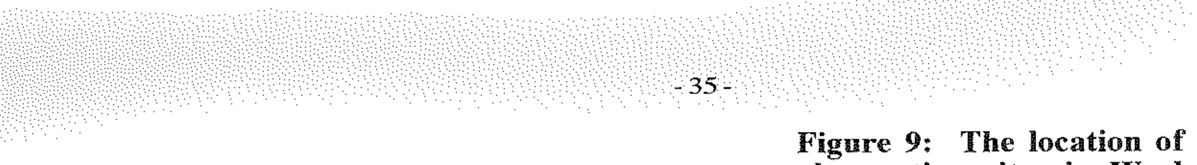
Contours
Cadastral Boundaries
Drainage
Catchment Boundaries
Tree cover

0 2km

Produced By:

Geography Department of the University of Adelaide
for the Willunga Hills Face Landcare Group

2 March 1995



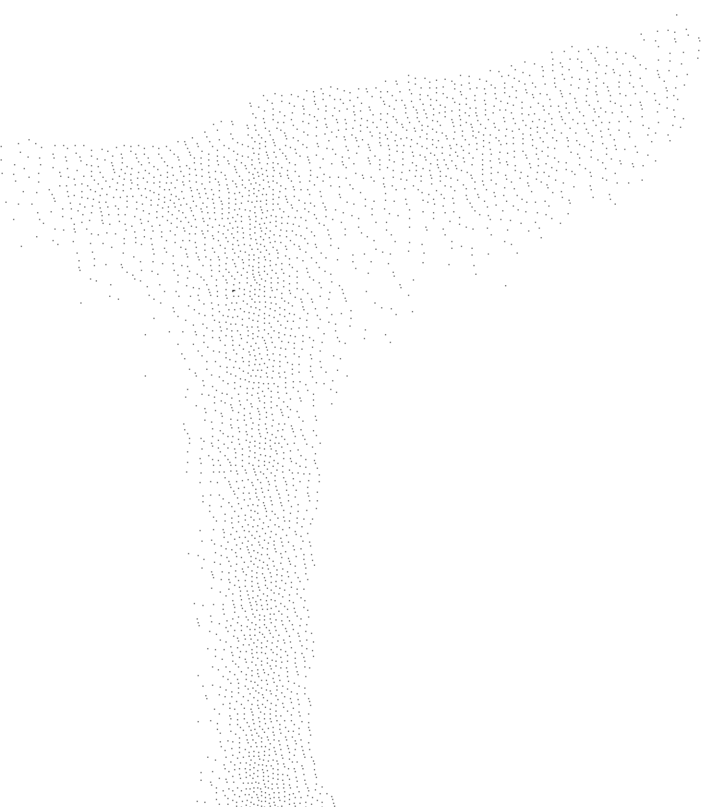


Figure 9: The location of observation sites in Washpool Creek and Sellicks Creek catchments.
Source: author.

A number of catalysts found in Washpool Creek catchment have enhanced the natural processes of soil erosion, transferring it from a relatively harmless process of nature, to quite a severe and aggressive reaction to human manipulation of the natural environment, which has resulted in some quite unsightly landforms, especially gullies. Such catalysts are: clearance of native vegetation from hill slopes; grazing of sheep and cattle on Sellicks Hill Range; cropping of the hill slopes for agriculture; establishment of vineyards and almond groves in the foothills and plains; construction of roads; and the construction of the Myponga to Happy Valley pipeline.

Agricultural practices have the principle effect of loosening the top soil making it unstable and more susceptible to erosion, such as rainsplash erosion of exposed soils. Cropping of hill slopes may also contribute to sheet erosion, depending on the direction in which the paddock is contoured. Downhill ploughing creates rills which focus water flow, whereas horizontal contours slow the flow of water. Vineyards and almond groves can also have a similar effect; the rows between vines and almonds tend to initiate drains channelling water flow.

From 1949 aerial photographs it is evident that agricultural practices in Washpool Creek catchment appeared to be confined to low intensity activities such as grazing. However. 1992 aerial photographs demonstrated far more intensive land use in the catchment, particularly the development of land for vineyards, almond groves and cropping. Along some gullies there is a clear buffer zone between the gully and the paddock being cropped. However, in other areas streams flow across the land unaffected by the regular pattern of vineyards and almond trees.

The effect of land use practices on the stability of the catchment was clearly evident after the heavy rainfall events in June and August 1995. Roads appear to play an important role in catchment erosion. Scouring along the side of roads by water was noted along the southern section of Plains Road. Scouring and washing out of Button Road, a gravel road leading to Washpool Lagoon, and of Louds Hill Road along the higher elevated sections, was also noted. Regardless of whether they are gravel or bitumen, roads are another conveyor of water and sediment down hillslopes.

The pipeline from Myponga Reservoir, constructed in the 1960s, seems to have contributed to changes in gullies caught across its path. A comparison of aerial photographs from 1949 and 1992 indicated that the gully marked at Site A (Figure 9) has expanded laterally. It is possible that the disturbance of soil for the construction of the underground pipeline may have weakened the soil structure, making the gully at this location more susceptible to soil erosion (Plates 6a, 6b & 6c).

Plate 6a: Soil profile of the gully at Site A.
The presence of stones in the soil profile is an indicator of the soil's unconsolidated nature.
Source: author.

Plate 6b: The Myponga-Adelaide pipeline at Site A.
Source: author.

Plate 6c: The Site A gully in Washpool Creek catchment.
Note dumping of rubbish in the base of the gully.
Source: author.

Most drainage in Washpool Creek catchment is centred on, and near, Sellicks Hill Range. However, there are a couple of drains that run into Washpool Lagoon that emanate from residential areas to its north. Along Norman Road, just north of Blue Lagoon, lies a drain coming from residential lots at Silver Sands. The construction of this drain occurred between March and June 1995. Closer to Aldinga Beach another constructed drain along How Road carries water from a site near an industrial area close to Washpool Lagoon. These drains contribute water of a contrasting quality to Washpool Lagoon. While water quality and sediment yield of these drains is not being measured, it is important to acknowledge this input to the whole drainage of this catchment.

While all watercourses in Washpool Creek catchment transported water of some capacity, the proportion of water drained in each varies with the flood stage, that is, some carry more water during periods of heavy rainfall. It is important to identify these watercourses as they may be proportionally greater contributors of sediment than anticipated.

The watercourses yielding the greatest discharges were noted mostly in Section 1 of Washpool Creek catchment. In particular, the northern most watercourse (and the longest in the catchment) appeared to carry the most water, probably attributable to its more elevated reaches. A number of features along this watercourse indicated that it supplies a great deal of water, and possibly sediment, to the plains below. Gullies of the kind seen in Section 2 and in Sellicks Creek catchment were not evident along this drain. It was obvious from the size of the drains, however, that large volumes of water have passed down this watercourse at high velocity. At Site B(i) (Figure 9) washing out of the drain wall had produced a wide channel. At Site B(ii) a rapidly running waterfall had formed a small plunge pool alongside Hahn Road where the drain crossed (Plate 7a). A further site downstream (B(iii)) where the drain is intersected by Ryan Road, a large culvert supported the watercourse on the downstream side of the road (Plate 7b). Finally, near the aerodrome (Site B(iv)), two drains join immediately above a very large washed out landform. This feature has been formed through processes of erosion, but it also contains some depositional features. This junction was once crossed by a road, but is now closed for public access as it has been undermined. Each of these features gives an indication of the impact of water on this watercourse, particularly in terms of erosion. This was the only watercourse which had any significant vegetation including tree covering: most watercourses in this catchment were not well vegetated.

The drain immediately to the south of this, which runs along Hahn Road, can also carry considerable volumes of water. The drain displays gully features and at Site C (Figure 9), a large culvert and junction further illustrate past high discharge events (Plate 8). Large rocks have been placed at the nickpoint of this site in an attempt to reduce further headward cutting of the gully.

Plate 7a: The waterfall and plunge pool of the northern most drain at Site B(ii).
Source: author.

Plate 7b: A large culvert intersected by Ryan Road at Site B(iii), Washpool Creek catchment.
This culvert is an indication of the width and depth of drains found in this catchment.
Source: author.

Plate 8: The Hahn Road gully, Site C.
The majority of water in this gully flows through the culvert in the top left of the photo. At the centre right another gully coming from the south joins the main gully. Past the point of the rocks the gully evolves into a narrower, yet still a very deep gully.
Source: author.

These examples provide an indication of the velocity of streamflow and the erosive powers of water flowing down these streams. While these examples are of more active forces of erosion, there are other examples in the catchment of lower energy processes of sedimentation, such as the flood channel along Plains Road at Site D on Figure 8 (Plate 9).

Plate 9: A possible fluvial flood channel along Plains Road, Site D.
The meandering and shallow nature of the channel is characteristic of water flow when it reaches gentler slopes which reduce the velocity of the flow.
Source: author.

3.4.2 Drainage lines in the Sellicks Creek catchment

Drainage in Sellicks Creek catchment is centred mainly around Sellicks Creek gully (Figure 8). There are very few shallow watercourses in this catchment, least of all in the lower elevations close to the Gulf. Tunnel erosion is a feature of this catchment which helps explain the deeply incised watercourses at their origin (Plate 10). Such erosion originates in the steep slopes of Sellicks Hill Range.

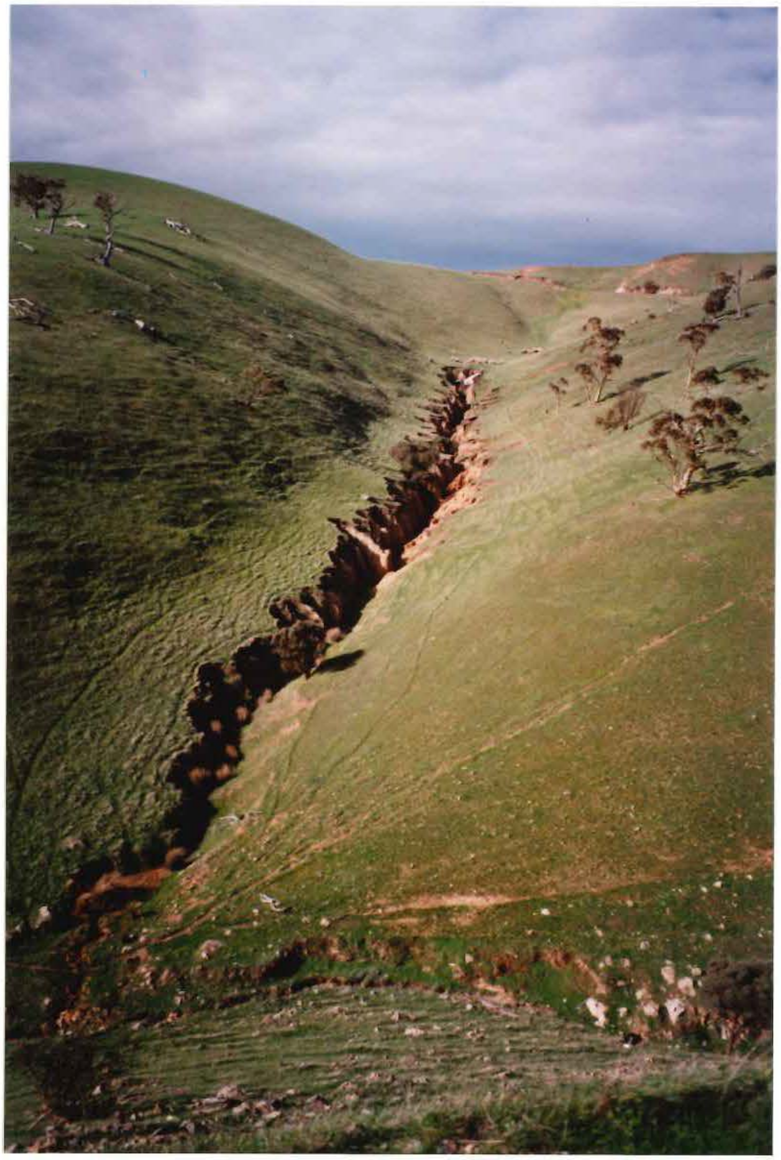


Plate 10: A deeply incised channel common in Sellicks Hill Range
Source: author.

Sellicks Creek gully is a very prominent feature in both catchments, and is visually intrusive. It is the longest drain in the catchment and transports the greatest volumes of water of any of the other drains. At its mouth, where it empties into the Gulf of St. Vincent, it measures approximately fifteen metres across and fifteen metres deep (Plate 11a). In the section of the gully between the coast and Justs Road, it has deep vertical walls. A cross-section of the gully walls at Site E (Figure 9) displays the soil layers which may reveal the sedimentary history of this catchment (Plate 11b).

Plate 11a: Sellicks Creek Gully at its mouth.
It is a very large and dynamic feature which has evolved from severe environmental degradation.
Source: author.

Plate 11b: The soil profile of Sellicks Creek Gully at Site E.
Distinct soil horizons are evident from the photograph.
Source: author.

Justs Road appears to be a break point in Sellicks Creek gully. On the eastern side (upstream) of Justs Road (Site F, Figure 9) the gully is not as pronounced, and is wider than it is deep. However, on the western side of Justs Road (where there is an outlet for a culvert under the road) the gully appears to have become dilated, producing a very wide and deep gully with vertical walls (Plates 12a & 12b). Headward erosion of Sellicks Creek gully is a continuing process at this location. Justs Road was once straight, but continuing erosion of the gully has resulted in the diversion of the road upstream of the nickpoint to avoid the destabilising effect of the eroding gully.

The operation of the limestone quarry in the catchment is another contributor to gully erosion. Mining operations disturb the structure of the soil, making it less stable and therefore more susceptible to erosion. In aerial photographs from 1949 the quarry was not evident, however, 1992 aerial photographs show the quarry in quite active use and also indicate that gully erosion has been quite active since 1949.

Plate 12a: Sellicks Creek Gully upstream of Justs Road at Site F.
Source: author.

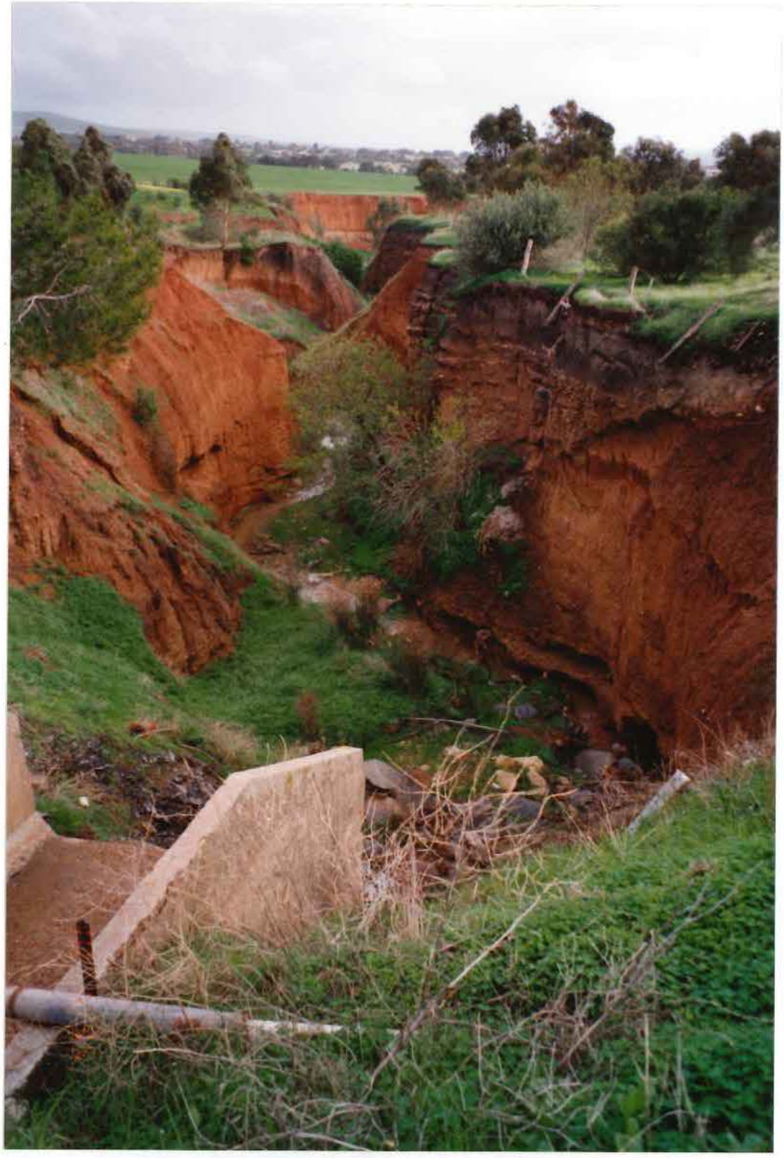


Plate 12b: Sellicks Creek Gully downstream of Justs Road at Site F.
There is a dramatic contrast on either side of Justs Road. Note the fence line in the top right: severe erosion of this gully has occurred during the time of European occupation. Rocks and other rubbish have been dumped at the base of the gully in an attempt to slow down erosion; possibly a futile attempt.
Source: author.

A number of features in this catchment, such as Sites G and H (Figure 9), have been recognised as useful indicators of sediment erosion and deposition. At Site G an exposed crown of a tree stump found on Sellicks Hill Range along Old Sellicks Hill Road illustrates how much sediment has been eroded from the hillslope in the lifetime of the tree but more so after it was chopped (Plate 13). While the life of the tree and the time at which erosion began could not be established, it is evident that some 30 cm of soil has been eroded from this hillslope, at this particular location. Site H is representative of sediment deposition, occurring in the gentler slopes of the catchment where streamflow velocity has slowed (Plate 14). At this site a new fence replaces one which has been buried by sediment. Up to 30 cm of the old fence still shows, however, another one metre of the fence is buried. This buried fence, which has only been constructed since European occupation of the region, is indicative of how much sediment has been deposited at this site in a given time. The road which crosses this watercourse acts as an obstruction to the flow of sediment, contributing to the build up of sediment on the upstream side, and the erosion of sediment below it.

Plate 13: Tree stump on Sellicks Hill Range at Site G.
Note the amount of soil which has eroded away from the crown of the stump.
Source: author.

Plate 14: Sediment aggradation in Sellicks Creek catchment at Site H.
While not shown in this photograph, an old fence line was buried at this site due to the aggradation of sediment.
Source: author.

In both Washpool Creek and Sellicks Creek catchments there is evidence of the impact of erosion associated with roads across watercourses or gullies. On the downstream side of these obstructions, deep gullies are evident. It is common to see car bodies, rocks or other rubbish dumped in gullies at these locations in an attempt to reduce erosion. However, the extent to which erosion is reduced by such rubbish is often negligible as they often work in the same capacity as the roads and culverts, contributing further to erosion.

3.5 Volumetric calculations of soil erosion

From Figure 8, which represents the various categories of drainage, crude estimate calculations of the amounts of material eroded from the gullies and drains in this catchment were made (Table 3). These calculations consider the amount of sediment that had been lost from the drains only and do not include sediment from the slopes washed down the drains. Volumes for gullies were calculated at the minimum size considered (ie. 150 m deep and 150 m wide), therefore, volumes for gullies much wider and deeper than this, such as Sellicks Creek gully, are quite an underestimate of the actual volumes of sediment eroded. Calculations of the drain lengths were made from a 1: 25 000 map, from which it was quite difficult to ascertain just when the width and depth of a drain changed, and so lengths measured are likely to be an underestimate.

Volumetric calculations were made by calculating width by depth by length. In the first five categories volume was calculated as the average of the measurements and each drain was considered a V-shape. For example, for the drain 30 - 150 cm deep x 30 - 150 cm wide, its volume was calculated as 90 cm deep x 45 cm wide. Tunnel erosion was not calculated because dimensions for tunnels could not be measured.

TABLE 3: VOLUMETRIC CALCULATIONS OF MATERIAL ERODED THROUGH DRAINS IN WASHPOOL CREEK AND SELLICKS CREEK CATCHMENTS

DRAIN TYPE	WASHPOOL CREEK			SELLICKS CREEK		
	Length	Total Volume		Length	Total Volume	
[D,W] (cm)	(km)	(m3)	(mm3)	(km)	(m3)	(mm3)
<30, <30	1.4	31.5	31,500.0	0	0.0	0.0
<30, 30 - 150 (road)	6	810	810,000.0	0	0.0	0.0
<30, 30 - 150 (natural)	1.25	168.8	168,750.0	0	0.0	0.0
30-150, 30-150	27	14,580.0	14,580,000.0	2.8	1,485.0	1,485,000.0
30 - 150, >150	21.4	17,334.0	17,334,000.0	6.0	4,860.0	4,860,000.0
>150, >150 (V-shaped gully)	9.4	12,690.0	12,690,000.0	3.0	4,050.0	4,050,000.0
>150, >150 (U-shaped gully)	12.4	27,900.0	27,900,000.0	8.8	19,687.5	19,687,500.0
Tunnel erosion	0.25	N/A	N/A	0.5	N/A	N/A
TOTAL VOLUMES		72,672.8	72,672,750.0		30,082.5	30,082,500.0

These results showed that there was more tunnel erosion in Sellicks Creek catchment. This was the smallest type of drainage in Sellicks Creek catchment and was only found in the steep slopes of the Range. There was no drainage below 30-150 cm depth and 30-150 cm wide which suggests erosion in Sellicks Creek catchment has been quite severe. This may be because of the generally steeper slopes than Washpool Creek catchment which generate greater velocity of streamflow and therefore more active erosion.

Results from volumetric calculations indicate that gullies are the main form of drainage Sellicks Creek catchment. Gullies are also prominent in Washpool Creek catchment, but a large proportion of drains are between 30 cm and 150 cm wide and depth: the constructed drains. Such gullies have produced approximately 40,590 m^3 and 23,740 m^3 of sediment respectively over the period of their erosion. Total erosion for Washpool Creek and Sellicks Creek catchments was about 72,600 m^3 and 30,000 m^3 respectively. Converted to unit area, this is equivalent to 1.7 mm of material eroded in Washpool Creek catchment, and 3.9 mm in Sellicks Creek catchment. This is a conservative estimate of erosion. In the case of Sellicks Creek catchment, which has erosion rate per unit area double that of Washpool Creek catchment, the majority of the sediments would have been discharged into the Gulf of St. Vincent. Fortunately, the Washpool Lagoon would have reduced the quantities of sediment discharged from Washpool Creek catchment into the Gulf.

Therefore, from the field observations and volumetric calculations, the following hypothesis can be developed: assuming that the Washpool Creek catchment is a closed system because of the lagoon, the volume of the material eroded from Washpool Creek catchment is equivalent to the volume of material deposited in Washpool Lagoon. Consequently, because it is not a closed system, the material eroded from Sellicks Creek catchment would be discharged into the Gulf of St. Vincent.

Thus in this chapter it has been shown that sheet, tunnel and particularly gully erosion are extensive in both the Washpool Creek and Sellicks Creek catchments. On a per unit basis, Sellicks Creek catchment has a greater volume of gullies and material eroded than Washpool Creek and the vast majority of the sediment lost from that creek would now be in the Gulf of St. Vincent. It is assumed that the Washpool Lagoon has trapped sediment in the Washpool Creek catchment, and that will be examined in detail in the next two chapters.

CHAPTER 4: METHODS USED FOR ANALYSIS OF THE WASHPOOL LAGOON SEDIMENT CORE

The core site chosen was located in Washpool Lagoon, about 10 m to the north of Button Road. The sediment core was extracted in June 1995. Heavy rains in May and June had caused the Lagoon to fill and overflow so that at time of extraction the sediment core had to be removed from under approximately 40 cm of water. Although Washpool Lagoon is an ephemeral lagoon, it is the only lake-type feature within either Washpool Creek or Sellicks Creek catchments where a sequence of sediments were likely to be deposited. It was therefore the only suitable location in which a record of sedimentary history could be obtained.

The core was removed using a 44 mm diameter PVC tube and post driver. The core, measuring 25 cm when removed from the PVC tube, was not accurately measured for compaction, however, sediment had been compacted down from 38 cm based on the depth of the PVC tube after it had been hammered into the sediment. A degree of about 34% compaction is assumed for the length of the core. Compensation is made for this compaction in later analysis. The core was analysed for its physical properties, pollen content and concentration, and was dated using Lead-210 (^{210}Pb).

4.1 Physical analysis of the sediment core

A total of 34 samples were extracted from the core to determine the moisture, organic and carbonate contents. Samples were taken from the core at every half centimetre for the first ten centimetres, and every one centimetre thereafter. Dry weight, loss on ignition (LOI) and carbonate content were determined following the methods and calculations described by Bengtsson and Enell (1986: 425-428) (Figure 10).

Porcelain crucibles of a known weight were placed in a muffle furnace heated to 550°C for 1 hour to dry, after which they were cooled to room temperature. Fresh samples of approximately 2 gm were added to the crucibles and weighed. The crucibles were placed in an air-circulation oven at 105°C and dried for about 12 hours. After cooling the samples and crucibles in a desiccator, the weight of the dry sample and crucible was determined. From the dry weight of each sample, moisture content could then be calculated for the length of the core.

Loss on ignition of the core was determined by placing the crucibles with their dry samples in a muffle furnace at 550°C for 2 hours. After the samples and crucibles had been allowed to cool in a desiccator, they were weighed before being ignited for a final time to determine carbonate content. Carbonate content was ascertained by placing the crucible and ignited sample in a muffle furnace for 4 hours at 925°C. Likewise with each other step, the sample and crucible were cooled in a desiccator and then weighed.

The correlation between organic content and LOI is quite good (Bengtsson & Enell, 1986: 427) and so LOI is used to determine the relative amount of organic matter in the sample. Moisture, organic and carbonate content were calculated as a percentage of the bulk density of the total sediment for each sample.

4.2 Pollen analysis of sediment core

At the same time samples were taken for physical analysis of the core, another 34 samples were taken from the core in preparation for pollen analysis. Approximately one gram of the sediment samples were prepared following the techniques described by Berglund and Ralska-Jasiewiczowa (1986) (Figure 11).

Each sample was treated with 10% potassium hydroxide (KOH) to digest fine organic matter, and then sieved through 100 μm wire mesh to remove coarser organic and inorganic material. The hydrofluoric acid treatment followed this in order to breakdown and remove silica sand from the sample. The cellulose from organic matter was removed and the pollen grains stained during acetolysis. A mix of acetic anhydride and sulphuric acid were used to stain the grains. The samples were mounted on slides in silicon oil equal to 150% of the volume of sediment, and covered and sealed with nail varnish to prevent the slides from drying out.

While 34 slides were prepared for analysis, only every second slide to the depth of 18 cm was counted for pollen due to time constraints. Fifty dryland pollen grains were counted for each slide at a magnification of 400x using a binocular light microscope. Pollen concentration was calculated in order to determine and assess sedimentation rates. During preparation quantities of samples were lost during acetolysis. This loss, which was not calculated, may have affected concentration ratios. Percentages of the pollen sum for each taxon counted were also calculated in order to gain a measure of the proportion of the taxa in the vegetation.

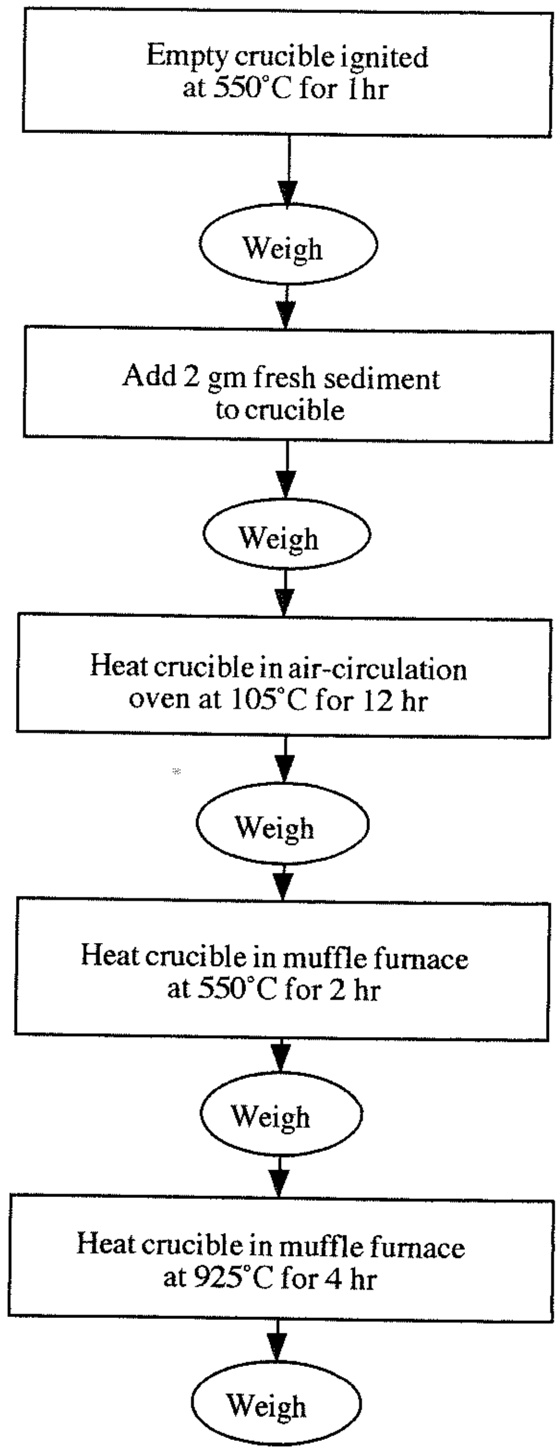


Figure 10: Procedures followed for preparation of samples for dry weight, loss on ignition and carbonate analysis.
Source: Bengtsson & Enell (1986: 426)

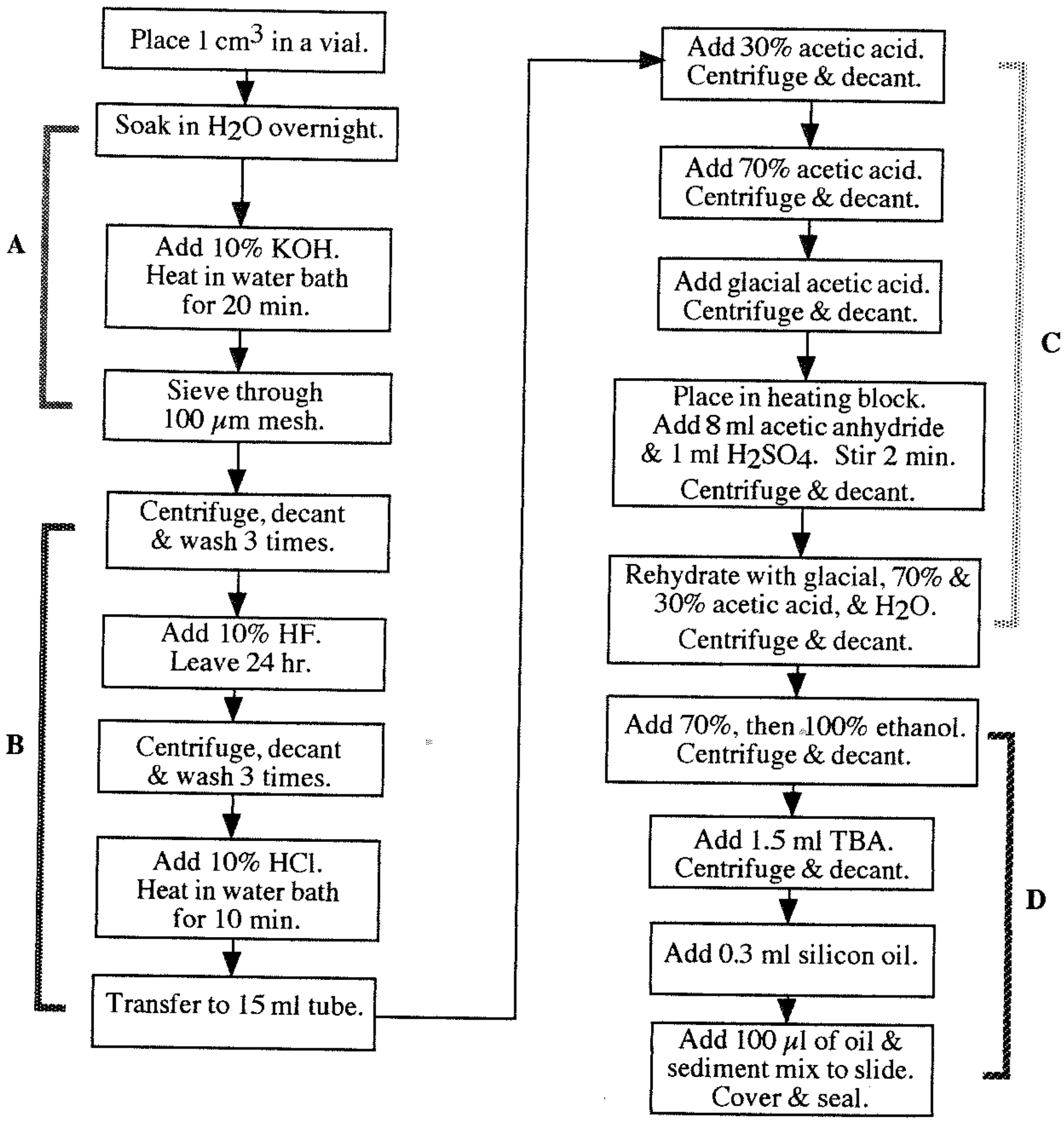


Figure 11: Laboratory techniques followed for pollen analysis.
The main stages are highlighted as: A) Hydrolysis; B) Hydrofluoric acid treatment; C) Acetolysis; D) Mounting.
Source: Gell *pers comm*, 1995.

4.3 Chronological dating using Lead-210

Dating was carried out in order to give an indication of sedimentation rates, and to obtain a correlation with dates inferred from the arrival of exotic pollen in the record. Eight samples were prepared for ^{210}Pb dating. The first sample was taken from the surface of the core and the last sample from the 23 cm level. The remaining six samples were taken at 2.5 cm, 5 cm, 7.5 cm, 9.5 cm, 13 cm and 18 cm. The samples were dried using the same method as for dry weight, that is, 12 hours in an air-circulation oven at 105°C. Loss of ignition (550°C in a muffle furnace for 2 hours) was also calculated.

The samples were analysed by Dr. J. David Smith of the Marine Chemistry Laboratory at the University of Melbourne. The sediment accumulation rates were calculated following Appleby and Oldfield's (1978) constant rate of supply of ^{210}Pb model.

Lead-210 is produced within sediments by the decay of radium-226 to radon-222. The radon-222 escapes to the atmosphere leaving ^{210}Pb. The age of the sediment can be calculated by either assuming a constant initial concentration of ^{210}Pb in sediments which have accumulated at a constant rate, or by assuming a constant rate of ^{210}Pb supply to sediments (Birks & Birks, 1980: 103).

In optimum conditions ^{210}Pb covers approximately five half-lives. The half-life of ^{210}Pb is 22.3 years, therefore materials can be dated to about 110 years BP (Gell *et al.*, 1993: 154). However, Birks and Birks (1980: 103) claim ^{210}Pb can date sediments up to 150 years old. Lead-210 is therefore a suitable chemical dating method for the purposes of this project where the dates of deposition of younger sediments (less than 200 years) are sought.

CHAPTER 5: ANALYSIS OF THE WASHPOOL LAGOON SEDIMENT CORE

5.1 Results

5.1.1 Physical analysis

There is little apparent variation in the stratigraphy of the core sediments. While small shells were found at 1 cm and small calcite flecks between 20 cm and 23 cm, the sediment of the core was of very similar colour and texture throughout.

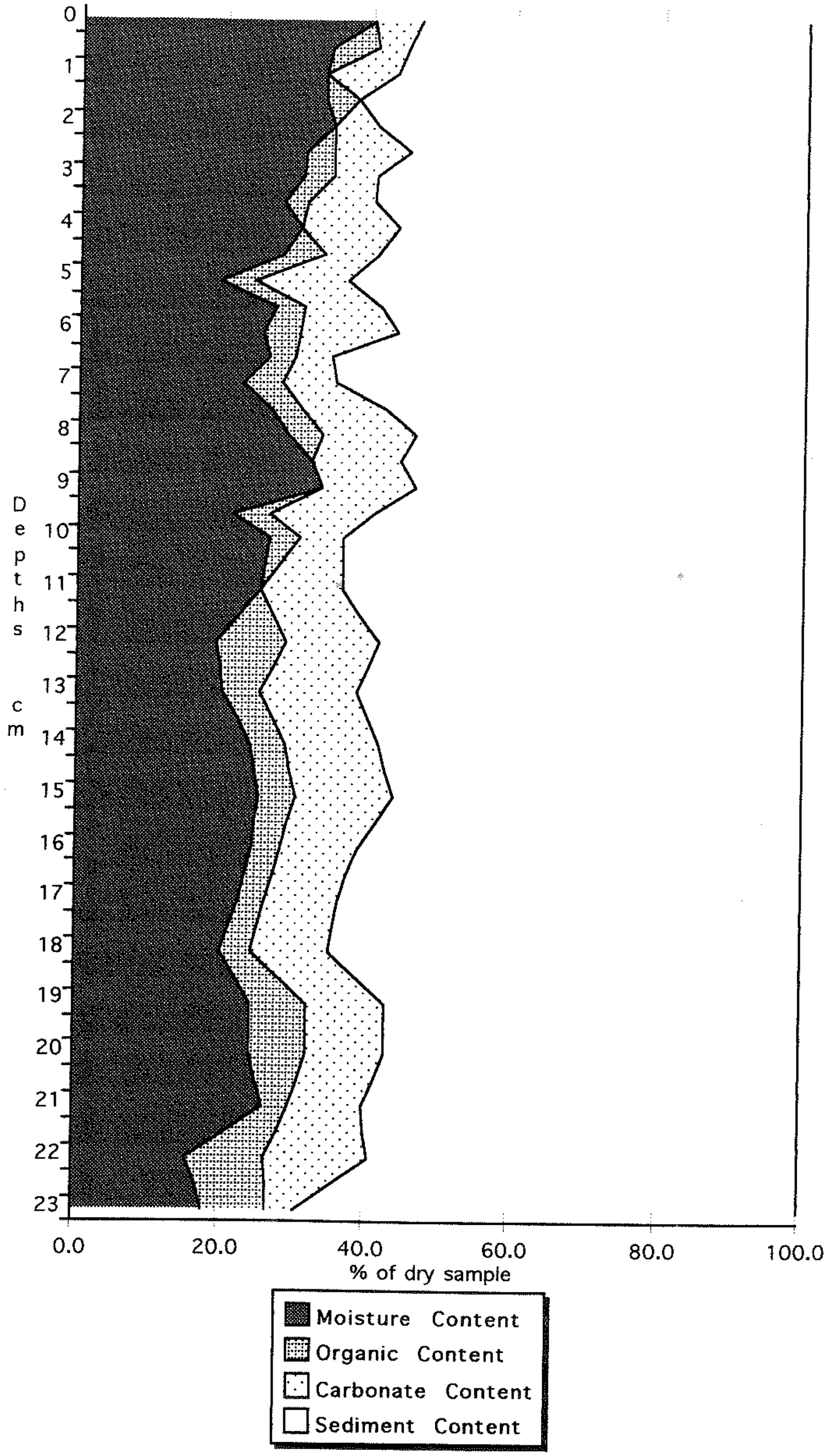
The moisture content increased towards the surface of the core (Figure 12). At the bottom of the core moisture content was less than half that at the surface. At 9 cm moisture content increased to 33%, but quickly decreased to about 25%. At 5 cm there was a sharp drop in moisture by over 5%, which soon returned to 27% content.

The organic content generally decreased towards the surface (Figure 12). At 22 cm 10.5% of the sample was organic, the highest for the core. Between 8.5 cm and 9 cm there were no discernible organics, the same depth at which the moisture content was high. Other depths with no discernible organic content were at, and within, 2 cm of the surface, and at 4 cm and 11 cm.

The carbonate content was variable throughout the core and displayed no clear trend (Figure 12). Carbonates tended to be greater when dry sediment content decreased. The only depth where there were no discernible carbonates present was at 1.5 cm. Carbonates reached a maximum value of 14% at 22 cm, coincident with the highest recorded organic content. Below this the carbonate content decreased by 10%.

Apart from a number of peaks, the remaining sediment content of the core was relatively stable (Figure 12). There was only a very slight overall decrease in inert sediments towards the surface. Inert sediments ranged from 70% at the base to 53% at the surface, with the average content being around 60%. Peaks in inert sediments occurred at 23 cm, 17 cm - 18 cm, 9.5 cm - 10 cm, 6.5 cm - 7 cm and 1.5 cm. A decrease in sediment content as a proportion of the total sample occurred at 18 cm - 19 cm, 8 cm - 9 cm, 6 cm and at the surface.

Figure 12: Physical analysis of Washpool Lagoon sediment core



5.1.2 Pollen analysis

Pollen concentrations were highest in the top 4.5 cm of the core (Table 4). Below 10 cm pollen concentrations were quite low with the lowest concentrations being just over 400 grains per dry gram compared to over 7000 grains per dry gram in the uppermost centimetres. The pollen count decreased with depth to less than 50 grains below 10 cm.

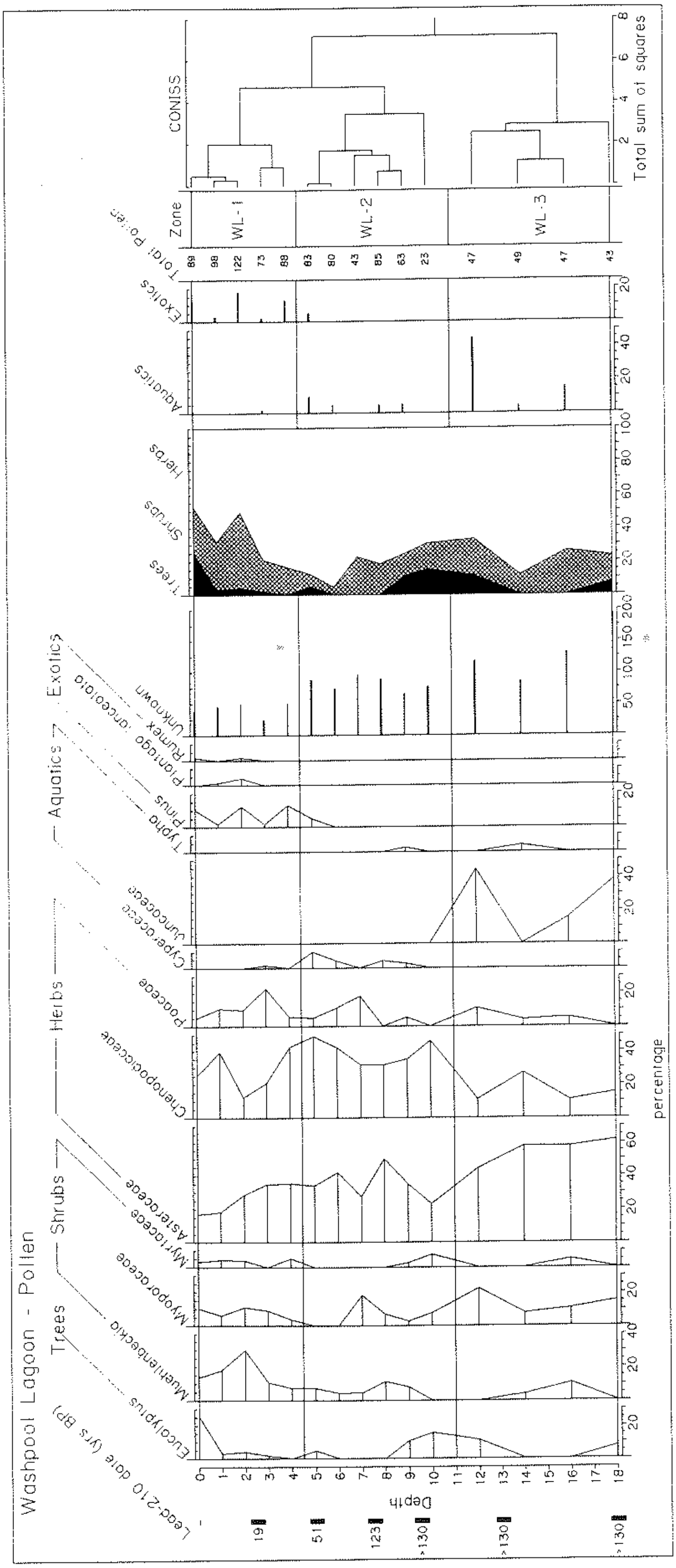
Generally, the pollen concentrations varied directly with the moisture content. There were three exceptions to this along the core. At 1 cm, pollen concentration increased significantly while the moisture content remained stable. Below this the moisture content increased where the pollen concentration decreased. While the pollen concentration decreased at a fairly steady rate below 5 cm, the moisture content dropped quite significantly. At 10 cm the pollen concentration decreased dramatically, yet at the same depth the moisture content did not decrease markedly compared to the pollen concentration. Periods of specific decreases in pollen concentration occurred at 7 cm, between 10 cm and 12 cm, and below 16 cm.

Three pollen zones were identified by reference to the dendrogram produced with the computer program PERCINF (Figure 13). They were labelled as WL-1 (0 - 4.5 cm), WL-2 (4.5 - 11 cm) and WL-3 (11 - 18 cm). In the zone WL-3 pollen abundances were quite small: seen through low pollen concentration and poor representation of taxa; a consequence of low numbers of total pollen counted. Pollen abundance was greatest in the top zone (WL-1).

TABLE 4: POLLEN CONCENTRATIONS FOR WASHPOOL LAGOON SEDIMENT CORE

CORE DEPTH (cm)	POLLEN CONCENTRATION (grains/ dry gm)
0 - 0.5	4414.7
1 - 1.5	7130.3
2 - 2.5	6486.2
3 - 3.5	4469.5
4 - 4.5	3308.3
5 - 5.5	2072.0
6 - 6.5	1904.8
7 - 7.5	744.2
8 - 8.5	1488.1
9 - 9.5	2015.4
10 - 11	498.8
12 - 13	812.7
14 - 15	1178.9
16 - 17	764.9
18 - 19	448.4

Figure 13: Pollen diagram for Washpool Lagoon



In most of the lowest zone, WL-3, aquatics were the predominant pollen types (Figure 13). Trees, shrubs and herbs were also found in this zone. However, other than at 14 cm, the proportion of trees and shrubs was proportionally less than the aquatic pollen types identified. Aquatic pollen types were represented by Juncaceae and *Typha*. Juncaceae (rushes and sedges) was the best represented aquatic type in this zone. A small concentration of *Typha* (bullrushes) was found at 14 cm coincident with an absence of Juncaceae. Asteraceae, a herb of disturbed environments and grasslands, dominated the dryland component in this zone, representing over 60% of dryland pollen. Asteraceae, along with Chenopodiaceae, a herb of saline soils, were most abundant at 14 cm, after which Asteraceae began to decline. Myoporaceae pollen, which is a representative of coastal shrubs, was the most prominent shrub pollen in WL-3. Unknown pollen was greatest in this zone and gradually decreased towards the surface. In some instances unknown pollen was greater than the total pollen types identified (Figure 13).

Despite a decline in Asteraceae, herbs predominated zone WL-2, reaching their peak for the record at 6 cm (Figure 13). Above this herb pollen declined. Herbs were mainly represented by Chenopodiaceae and Poaceae (grasses). Chenopods increased at 10 cm and Poaceae peaked at 7 cm coincident with an absence of *Eucalyptus* between 9 cm and 5 cm. Myoporaceae was once again the dominant shrub pollen, followed by *Muehlenbeckia* (lignum), and Myrtaceae (such as *Melaleuca*). Shrubs were not encountered frequently in this zone, particularly at 6 cm. However, above 6 cm their abundance increased. In this zone aquatic pollen decreased quite markedly. Cyperaceae, which represents sedges, and *Typha* were the only aquatic pollen found in this zone. *Pinus* was recognised for the first time at 5 cm.

The presence of shrubs and trees increased in zone WL-1 (Figure 13). Shrubs were most dominant at 2 cm, represented mostly by *Muehlenbeckia*. The abundance of Myrtaceae increased in WL-1 relative to other zones where there was little Myrtaceae pollen identified. *Eucalyptus* began to increase at 1 cm and was best represented for the record at the surface. At the same time that shrubs increased, herbs decreased, most obviously Chenopodiaceae, at 2 cm. Asteraceae had declined further from zone WL-2. Poaceae pollen peaked at 3 cm and then decreased towards the surface. Despite decreases in herbs, they were still proportionally the most dominant pollen throughout the core.The only aquatic taxon in zone WL-1 was Cyperaceae (Figure 13). Cyperaceae abundance was however, very low relative to the proportions of other pollen types found. Exotic pollens became most prominent in this zone of the core (Figure 13). They were represented by *Pinus, Plantago lanceolata* and *Rumex*. *Pinus* was the most common exotic species. *Plantago lanceolata* and *Rumex* are introduced weeds of disturbed and agricultural land.

The results from pollen analysis indicate some changes in vegetation communities. Aquatics, for example, decreased closer to the surface. Unknown species also decreased towards the surface representing a decline in the diversity of pollen types. Above 6 cm, herbs also decreased. The decrease in herbs coincided with an increase in *Eucalyptus* and shrubs. It was expected that some *Casuarina* pollen may have also been found as it is a common tree in the region, however none was identified. The identification of exotic species was one of the most important aspects of the pollen counting. Exotic pollen was important in providing evidence for the beginning of the post-European/historic period.

5.1.3 Dating, chronology and sedimentation rates

Results for supported ^{210}Pb were obtained in the top 8-10 cm of the core. Loss on Ignition for the data points was small so these calculations were not used for sediment density. The sedimentation rate for the samples above 8 cm was constant over the last 60 years, with 8 cm being about 120 years BP. The sedimentation rate for the lagoon over the past 120 years was calculated to be about 0.9 mm per year.[1] Below 8 cm the total ^{210}Pb content of samples became uniform representing ages beyond the range of the dating method. Even minor errors in ^{210}Pb measurements of the older sediments constitute large errors in age and sedimentation rate and so the upper dates are the most reliable.

The accumulation rate of sediment was steady averaging 186 mg of dry sediment material per cm^2 per year, over a period of 110 to 130 years (Smith *pers comm*, 1995) (Figure 14). This extrapolated to 30 mBq/g of unsupported ^{210}Pb at the surface, and indicated a ^{210}Pb flux of 5.6 $mBq/cm^2/y$. The integral of excess ^{210}Pb for the core was 135 mBq/cm^2 which corresponded to an annual flux of 4.2 mBq/cm^2 per year; the accepted ^{210}Pb flux for Adelaide is 4.9 $mBq/cm^2/year$ (Smith *pers comm*, 1995).

An age accumulation curve (Figure 15) was made based on the three data points in the last 100

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1 If the sediment in the core was compacted by 34%, then 8 cm of the core is equivalent to 10.7 cm of actual sediment deposited. Therefore the rate of sedimentation is 10.7 cm divided by 120 years.

Figure 14: Total ^{210}Pb vs Accumulated sediment

#	Depth cm	Depth cm	Pb-210 Total	Pb-210 Unsupp	Sediment g/cm^2	Sediment mg/mL
1	**0-0.5**	0.25	**53.1**	27.7	0.923	923
2	**2.5-3**	2.75	**43.4**	18.0	2.084	1160
3	**5-5.5**	5.25	**35.2**	9.8	3.619	1536
4	**7.5-8**	7.75	**27.6**	2.2	4.918	1299
5	**9.5-10**	9.75	**25.4**	0.1	6.380	1462
6	**13-14**	13.5	**26.0**	0.7	7.880	1500
7	**18-19**	18.5	**25.4**	0.0	9.380	1500
8	**23-24**	23.5	**25.4**	0.1	10.966	1587

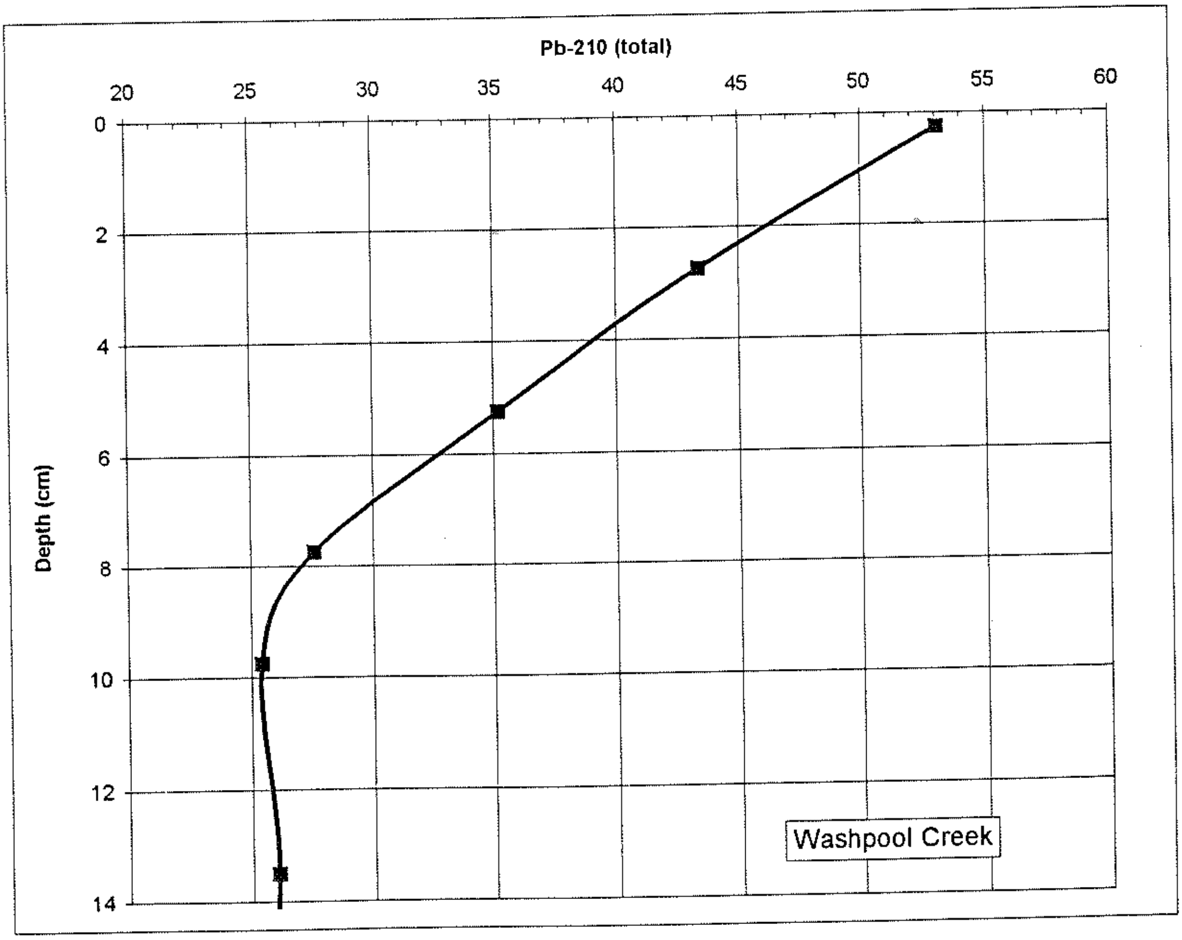
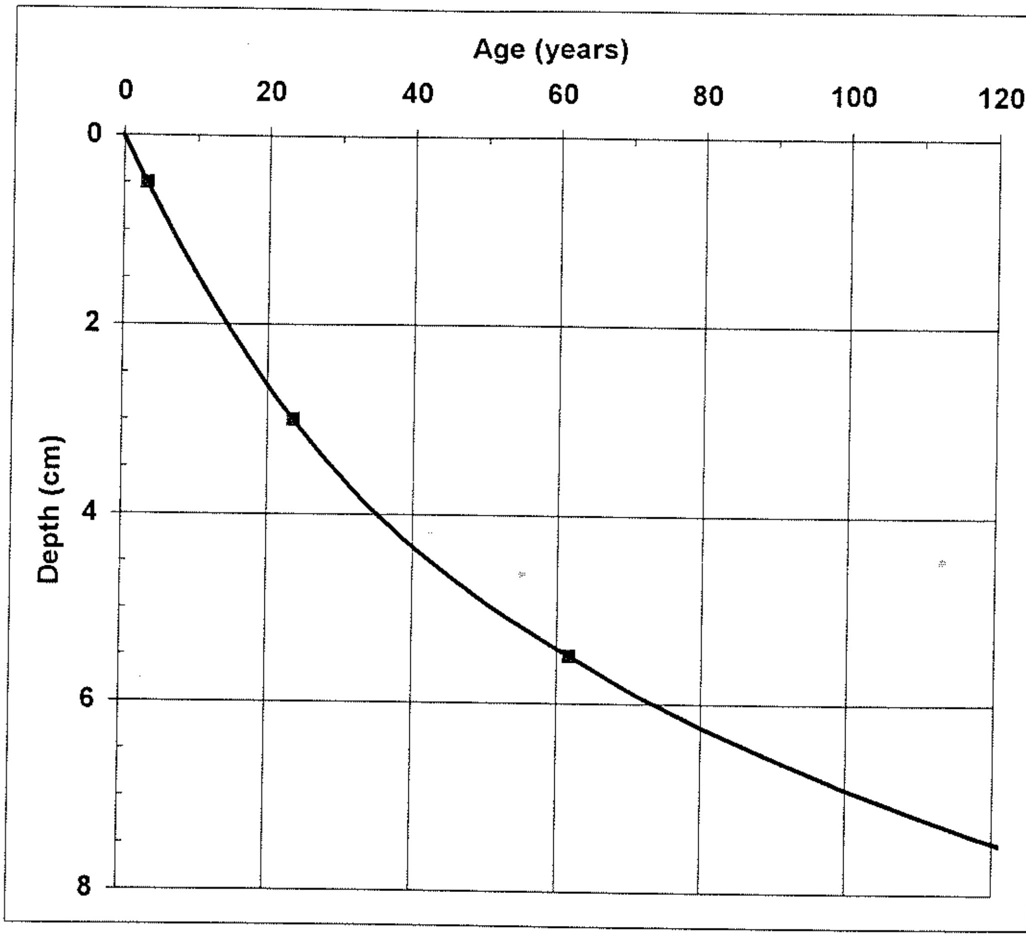


Figure 15: Age accumulation curve of Washpool Lagoon sediment core.



CRS Ages	
Depth cm	Age y
0.0	0
0.5	3
1.0	7
1.5	10
2.0	14
2.5	19
3.0	24
4.0	35
5.0	51
6.0	73
7.0	103
8.0	143

Note: the ages are calculated using interpolations
and the Constant Rate of Supply model.
Do not push them too far.

years. Inventory and ages for the curve were calculated using the constant rate of supply model (CRS) and was interpolated at 0.5 cm.

The area of Washpool Lagoon was calculated as about 0.5 km^2. Therefore, at a rate of 0.9 mm/year of sedimentation, and assuming a constant sedimentation rate across the lagoon, it would expect to have accumulated 450 m^3 of sediment over its surface each year, which is equivalent to 54,000 m^3 over 120 years. The conservative calculation of material eroded from the drains in Washpool Creek catchment was 72,600 m^3. This does not include the volume of sediment removed from the land surface of the catchment outside the gullies. Therefore, at the absolute maximum, less than 75% of sediment from drains only in Washpool Creek catchment is being deposited in the lagoon.

5.2 Discussion of results

5.2.1 Dating, chronology and sedimentation rates

The absence of exotic pollen below 6 cm suggests that sediment below this depth was deposited before, or at the time of, initial European impact. This is also supported by the absence of *Eucalyptus* between 5 cm and 9 cm, and Myrtaceae shrubs between 4 cm and 9 cm, suggesting this layer in the sedimentary record probably represents the period when native vegetation was cleared from the Sellicks Hill Range, after which time *Pinus* replaced native vegetation. The increase of Poaceae at 7 cm also indicates likely clearance. A significant decrease in pollen concentration at 7 cm may be another indicator of vegetation clearance and therefore, an indicator of European arrival. Vegetation clearance would lead to a decrease in total pollen, and increase erosion and, therefore, sedimentation. From the pollen it seems European impact made its mark on the core at around 8 cm.

Below 8-10 cm the unsupported ^{210}Pb became uniform, therefore indicating an age of approximately 120 years at about 8 cm. This is the known period in which the scarp was cleared of native vegetation and so supports the palynological record of the timing of European arrival and impact.

The pollen and ^{210}Pb provide a coherent picture of the core's historic dates. This is probably one of the first ^{210}Pb dated pollen sequences from South Australia and so it has implications for future analyses. A further implication of the ^{210}Pb dating is that it has established an absolute date for the arrival of *Pinus* in the sedimentary record and so allows pine pollen be used as a proxy for dating European arrival in this part of South Australia.

It is evident that all ^{210}Pb is being retained in the lagoon (Smith *pers comm*, 1995). This is seen through the annual ^{210}Pb flux which corresponds with the accepted flux for Adelaide. Aerial photographs of sediment plumes from Washpool Lagoon show that sediment is being discharged from the lagoon. The ^{210}Pb results suggest that the amounts being discharged are negligible. This suggests that the impact of sedimentation from this catchment on the Gulf of St. Vincent and Aldinga Reef is negligible.

The sedimentation rate for the lagoon was determined to be 0.9 mm per year, which is very low for an area in which erosion is active. A number of studies of regions in southern Australia which used ^{210}Pb as a chronometer for historic sedimentation rates measured considerably higher mean sediment accumulation rates for areas impacted by Europeans. Dodson *et al.* (1994a) measured a mean sedimentation rate of about 1.8 mm/year for the historic period in a closed lake system in south-western Victoria which was subjected to similar European activities as Washpool Creek catchment. This rate was ten times greater than that of the prehistoric period. In East Gippsland in Victoria mean sedimentation accumulation rates for a swamp in a logged catchment varied from 2 mm/year to 5 mm/year (Gell *et al.*, 1993), while those from Burrinjuck Reservoir were about 10 mm/year (Clark, 1990). The low sedimentation rate for Washpool Lagoon does not support general theories of increased rates of sedimentation as a result of European impact, and it stands in contrast to field observations of severe gullying and erosion in the catchment and losses of up to 30 cm of soil from Sellicks Hill Range.

A possible conclusion is that the sediments are not reaching the lagoon and are either being deposited elsewhere in the catchment, or being eroded from the range by wind action. The former is supported by the ^{210}Pb fluxes which show that '... there is not a substantial focussing of the fine particles transported from the surface of the surrounding land ...' to the lagoon (Smith *pers comm*, 1995). Also crude calculations of erosion and deposition in Washpool Creek catchment indicate that less than 75% of eroded material from the drains is being deposited in the lagoon. If a calculation of sheet erosion was included in this estimate, the proportion of deposition in the lagoon would be much less.

5.2.2 Physical analysis

The variability in sediment content of the core would suggest that sediment accumulation in the lagoon has not occurred at a constant rate (Figure 12). Variation in moisture content also indicates changing rates of sedimentation. However, this conclusion is not supported by ^{210}Pb results which indicated a constant average rate of sedimentation between the points sampled for dating. Therefore, variations in sediment content may be due to changes in the types of sediment deposited or be changes on short time scales only which do not greatly affect the longer term average rate.

While a vertical decrease in water content in the core may be due to sediment compaction, fluctuations in moisture content may reflect the conditions of the environment. For example, low moisture values are usually associated with shallow water and coarser materials. Higher values are usually related to deeper lakes (Bengtsson & Enell, 1986: 427). Organic content is also important in helping to determine the environment of the lagoon. In wetter, swampy environments the organic content is generally higher. A lake that remains constantly moist will preserve organic matter better, and therefore is represented by higher values of organic content. However, in deep waters plants only grow at the margins and there is less organic input relative to the size of the water body. Ephemeral lakes tend to have oxidised organics, therefore the organic content would be lower. In saline water only salt tolerant taxa grow, therefore there is a decrease in plant productivity and so in organic input. Organic content therefore tends to vary with the stage of the lake and the nature of its waters.

At Washpool Lagoon, the state of higher organic content and moisture content in the lower third of the core may reflect a swampy environment as suggested by Nurton (1990). It is supported by the increase of aquatic pollens in WL-3. *Typha*, which was represented here, is a species common to shallow water. The shift to lower organic content closer to the surface suggests a drying out of the lagoon and possibly a move to a more saline lagoon during the period represented in Figure 13 as WL-1. This is supported by the growth of samphire on the lagoon, and by the increase in abundance of Chenopodiaceae pollen in WL-2, and so predates European activity.

The period of high inorganic content between 8.5 cm and 9 cm may also indicate a phase of greater erosion where more inorganic sediment was deposited. This could be related to land clearance by Europeans, but the input could also be from blowouts of the nearby sand dunes.

5.2.3 Pollen analysis

Pollen concentrations also provide indications of changes in rates of sedimentation. Since it is expected that pollen produced from plants remains fairly constant each year, a decrease of pollen concentration in sediment would suggest increased rates of sedimentation. With that being the case, pollen concentrations for Washpool Lagoon indicate greater rates of sediment deposition in the lower, pre-European, section of the core. This contradicts the theory that sedimentation rates increased after vegetation clearance with initial European settlement. Alternatively, there may be a problem with the preservation of pollen at this site. This is supported by the absence of Cyperaceae, an easily eroded pollen grain, in zone WL-3. So evidence that the rates of sedimentation were greater than before European settlement is inconclusive.

Although the possibility of poor preservation makes pollen concentrations in WL-3 unreliable for analysis, some conclusions can be made of pollen concentrations in the other two zones. The decrease in pollen concentration at 7 cm is likely to represent an increase in sedimentation; the only depth in WL-1 and WL-2 where a significant decrease in pollen concentrations occurred. This coincides with decreases in native vegetation (as seen through pollen) which probably resulted from land clearance. As a consequence of land clearance erosion, and so sedimentation, is likely to increase.

A number of changes in the native vegetation communities are also apparent from the pollen. The change in aquatic taxa may suggest the core site has become drier. Closer to the surface of the core this may certainly have been the case as a result of the drainage scheme introduced to the Washpool Creek catchment which changed the lagoon from being an undrained wetland.

The abundance of Asteraceae and, to a lesser extent, Juncaceae in WL-3, along with high proportions of unknown pollens, may be an indication of different swamp communities in the past. However, this may also be a reflection of poor and selective pollen preservation lower in the core, in which case only a few known pollen types are represented. The better representation of a variety of known pollen types in WL-1 may therefore be a result of better pollen preservation.

Other possible hydrological changes as noted from pollen is an increase in groundwater, and an increase in salinity. This is highlighted by the increase in Chenopods from 10 cm. Nurton (1990) has inferred that groundwater in Aldinga Scrub has been increasing, which may reflect a regional increase in groundwater. The impact of clearance would also alter hydrology for the catchment, causing more flashiness: wetter winters and drier summers, which is likely to contribute to changes in the aquatic vegetation of the lagoon. However, the sediment at 10 cm. which is where a change in vegetation occurs, is equivalent to about 150 years BP or 1845. It is unlikely that in 1845 anthropogenic activities would already be affecting the groundwater and consequently vegetation.

If the pre-European condition of the lagoon was wetter, as earlier stated, then better pollen preservation would be expected. This is however, contrary to the findings. Not much is known about the full range of conditions in which pollen is preserved. Most however, would consider it surprising to find pollen in an ephemeral lake or a floodplain. Rutherfurd and Kenyon (submitted) however, recently provided pollen records from a floodplain along the Murray River. Therefore, it may be that pollen is still eroding within the sediments of the lagoon, in which case pollen in older sediments have a greater chance of being broken up. The palynology of ephemeral systems is an area of study which ought to be developed in order to answer questions of why pollen does not preserve in certain circumstances. The likelihood of differential preservation, such as the possible loss of Cyperaceae in the Washpool Lagoon core (Figure 13), also needs further study.

5.2.4 Summary

The main points to emerge from the core analysis is that the environment of Washpool Lagoon has become drier. Three 'environmental phases' have been identified for the lagoon: a pre-European freshwater phase (12-18 cm); a pre-European brackish phase (8-12 cm); European phase (0-8 cm). This coincides with rainfall trends found by Newman (1994: 39). However, groundwater flow and runoff versus rainfall ratio would have also changed and so rainfall alone is insufficient to explain this change. Furthermore, the change began to take place prior to European impact in the region. European impact was expressed in the core at around 8 cm.

Lead-210 results found that the levelling of unsupported ^{210}Pb occurred at around 8 cm, giving the core at this point a date of about 120 years BP, which is approximately 1870; the period of greatest European impact in Washpool Creek catchment. This impact was indicated in a number of ways, but was best seen through changes in vegetation, particularly the appearance of exotic species. The mean sedimentation rate between 8 cm and the surface of the core was 0.9 mm/year. This rate of sedimentation was not as great as was expected. In Chapter 3 it was found that a minimum 72,600 m^3 of material was eroded from drains in Washpool Creek catchment. This is somewhat greater than the amount of material which has been deposited in the lagoon over the last 120 years (54,000 m^3). The hypothesis that a substantial volume of fine particles have been eroded from the surface of the catchment into Washpool Lagoon is not supported, and even contradicted, by the ^{210}Pb results. A question therefore remains as to the ultimate fate of the eroded sediments.

CHAPTER 6: CONCLUSION

6.1 Summary of results

The principle aim of this thesis was to determine whether sedimentation from the rural catchments of Washpool Creek and Sellicks Creek had increased since European settlement in the region. The results from ^{210}Pb dating gave a mean sedimentation rate of 0.9 mm/year for the top 8 cm of the Washpool Lagoon core; the historic period of the record. It was not possible to determine whether this rate had increased or decreased from the prehistoric period. However, it is anticipated that sedimentation rates have increased both in the catchment and to the lagoon as a result of European activities in the catchment based on patterns found from other studies throughout Australia. So if Washpool Lagoon has always been a major site of sediment deposition for the catchment, the pre-European sedimentation rates would be anticipated to be less than 0.9 mm/year.

Results from field observations showed that there was a distinct spatial variation in soil erosion in the two catchments, with Sellicks Creek catchment suffering more erosion than that of Washpool Creek. Through maps and aerial photographs it was evident that erosion was a continuing process in the two catchments. From ^{210}Pb dates, which showed a constant rate of sedimentation, and field observations it can be assumed that the pattern of erosion in Washpool Creek catchment, and no doubt, Sellicks Creek catchment, has changed very little over the last 120-130 years. Erosion began in the 1860s with small and shallow watercourses (Stage 1 gully development (Schumm *et al.*, 1984: 47)). Since that time gullies have continuously deepened and widened, so that by the 1990s gully development in the two catchments is still predominately Stage 2 gully development (violent gully growth), with very little healing of the gullies (Stage 3 development) occurring. The conclusion therefore is that gully erosion is still active and constant in both Washpool Creek and Sellicks Creek catchments. Given the potential for the eroded material from Sellicks Creek catchment to enter the Gulf of St. Vincent, there exists a need for integrated catchment management of the study area to reduce this potential.

Significantly, ^{210}Pb analysis also showed that all ^{210}Pb was being retained in the lagoon, which suggests that only negligible amounts of sediments are being discharged from Washpool

Lagoon into the Gulf of St. Vincent. This leaves the catchments of Sellicks Creek and Cactus Canyon as the main contributors to Aldinga Reef sedimentation. In Washpool Creek catchment it was calculated that in excess of 1.7 mm of material per unit area of the catchment had been eroded from the gullies alone, but ^{210}Pb results from the lagoon showed that very little sediment was leaving the lagoon, and furthermore very little sediment from surface runoff was entering the lagoon. Therefore, the majority of this material was retained in the catchment, and was not entering either the lagoon or the marine zone. In Sellicks Creek catchment 3.9 mm of material per unit area of the catchment was eroded from the gullies. Considerably more material would have been eroded from the intact land surfaces. It is assumed that most of this material has been discharged into the Gulf of St. Vincent, given the steeper slopes of Sellicks Creek catchment.

In summary, it is fair to conclude from evidence put forth by Kinhill Engineers (1987) that Aldinga Reef is being impacted upon by sediment discharges from rural catchments south of the reef, such as Sellicks Creek catchment. However, results from core analysis indicate that the discharges and impacts from Washpool Creek catchment are only negligible, and therefore not a threat to Aldinga Reef. While the lagoon feature at the seaward end of this catchment appeared likely to be partially responsible for this, ^{210}Pb values show that not only is the lagoon not a significant barrier for sediment leaving this catchment, it was evident that Washpool Lagoon is not trapping all of the sediment that is being eroded from the catchment, particularly that from Sellicks Hill Range.

Three possible scenarios exist which could explain where the eroded material from Washpool Creek catchment is going:

a) Sediment is being trapped in the catchment and moved by fluvial activity within the catchment;
b) Sediment is being removed from the catchment by wind;
c) Sediment is being removed from the lagoon by overspill.

While some material is being removed by overspill, as seen in aerial photographs of sediment plumes, ^{210}Pb results do not reinforce this. There is also a possibility that material is being eroded by wind, however this is not likely to be a major effect as wind erosion is principally a process of arid lands. Therefore the final conclusion is that the eroded material is being trapped in the catchment.

Is it possible that the top grey layer of sediment in Plate 11b (Sellicks Creek gully) is eroded material from the catchment that has been deposited by fluvial movement on the soil surface? Is this where eroded material is being deposited in the two catchments?

6.2 Integrated catchment management

It is clear that both Sellicks Creek and Washpool Creek catchments are severely eroding. In the former it is likely that eroded sediments are inundating soils and also finding their way to the marine environment. In the latter, it appears that all the eroded sediment has been retained in the catchment and so must be smothering the soils on the lower slopes and plains. Both these impacts are detrimental to the general environment and demand direct management.

Various management strategies need to be implemented in order to deal with the problem of erosion and gullying of Washpool Creek and Sellicks Creek catchments, and to deal with the sedimentation and possible nutrient discharges into the Gulf of St. Vincent and onto Aldinga Reef. In the past, problem areas would have been considered isolated cases and dealt with individually. However, it is becoming more widely acknowledged in Australia and throughout the world that the best and most successful way to manage environmental problems in terrestrial and marine environments is through integration: to consider the needs of both the terrestrial environment and the marine environment, and work together to achieve the necessary goals.

In the 1995 *State of the Marine Environment Report for Australia* (Zann, 1995: 100) full support was given to those states (NSW, QLD, VIC, WA) which had already adopted integrated or total catchment management strategies. The Resource Assessment Council (RAC) also suggested that a program similar to Landcare, called 'Coastcare', should be developed for coastal areas to complement catchment activities (Zann, 1995: 101). This endorses what is already happening throughout Australia: a variety of groups who care for their environment working together as a community in order to protect and manage the environment's resources.

There are a number of management strategies which apply generally that could be used in managing the resources and environment of both the Willunga Basin, and the environment of the Gulf of St. Vincent on and near to Aldinga Reef. Such strategies include: minimum tillage of the land, revegetation of buffer strips along stream banks, and the control of road side erosion (Zann, 1995: 100).

There are other management strategies which apply specifically to the study area that are aimed at reducing erosion of the water catchments and possible sedimentation in the Gulf at Aldinga Reef. Strategies to prevent further gully erosion include the revegetation of Sellicks Hill Range, particularly along the ridge tops and the fencing of, and revegetation along, gullies in order to increase stability and reduce erosion. Revegetation of the two catchments is very important as it will reduce the amount, and slow down the velocity, of runoff, resulting in a much more stable environment.

Degradation by sedimentation of the Aldinga Reef cannot be directly controlled on site. However, the implementation of the above strategies should reduce the total amount of sediments reaching the Gulf and, ultimately, the reef due to integrated catchment management. Wetlands are one particular management strategy which, if properly managed and preserved, can act as a filter of water. They can reduce the total load of sediments discharged into the marine zone and cleanse the water by reducing nutrients such as nitrogen and phosphorous which, in excess, can be lethal to marine organisms. While evidence from ^{210}Pb suggests that Washpool Lagoon does not play a significant role in preventing sediment discharges to the Gulf, as most of the eroded material is retained in the catchment, it is likely that sediment discharges will increase from this catchment to the Gulf. Therefore, the maintenance of Washpool Lagoon as a wetland would also prove beneficial to the Gulf and the reef community in the long term.

In the Willunga region there are a number of groups which have been active in the area in terms of managing and caring for the local environment. The establishment of a Landcare group in the region in October 1991 followed a nationwide push to promote Landcare in Australia. Many groups have undertaken their own specific project of care in the Willunga Basin, yet together, in an integrated effort, their underlying aim is to manage and prevent the environmental problems of the region.

The key strategy for the Willunga Hills Face Landcare Group is the reforestation of Sellicks Hill Range (Campbell *pers comm*, 1995) for the entire Willunga Basin. Their project, titled 'Regreen the Range', aims to reduce water flow from the scarp; increase infiltration into the aquifer; and rebuild the soil on the scarp through revegetation. While the former and latter aims are likely outcomes of reforestation, it is undetermined as to whether reforestation will increase infiltration. Increased vegetation may reduce total infiltration by increasing evapotranspiration and by using more of the groundwater supply. Therefore the impact of revegetation on water supply to surface and groundwater needs to be known before fulfilling such projects. Generally, however, by stabilising the scarp and reducing surface water runoff through reforestation, sedimentation and erosion should be reduced on the plains below. This would ultimately reduce sedimentation and nutrient supply to the Gulf from Sellicks Creek catchment.

A number of management methods can be applied at point locations throughout the two catchments, but the key strategy of reforestation, along with the creation of vegetation buffers along gullies and streams, would be the most active way of reducing sedimentation and stabilising the severe gullying problem in these two catchments. Because of the long history of degradation, rehabilitation will require the management of the entire catchment over a long period.

6.3 Future areas for research

A primary focus for future research of this region is to determine where the eroded sediment has been deposited. Further research of erosion and sedimentation of the Washpool Creek and Sellicks Creek catchments, including a detailed sediment budget, is required to evaluate the full impact of the recent changes.

The second area of primary focus is to ascertain the likely hydrological impact of reforestation. A study of this nature would need to incorporate the establishment of streamflow measurements and aquifer recharge rates. This study has shown that some well accepted theories as to the natural processes of catchments are not always borne out by the empirical evidence. While the motives of groups such as Landcare are based on the well being of the catchments, there is a need for preliminary studies of a region to understand the natural processes within the environment before changes of such significance are implemented.

Research of the marine environment of Aldinga Reef and the coastline of the Gulf of St. Vincent from Noarlunga to Sellicks Beach is inadequate. Specific issues which need further research include: the local and regional significance of organisms and the ecosystem of Aldinga

Reef and the coastal region; analysis of discharges into the coastal zone and their effects on temperate reef systems, particularly Aldinga Reef; continued observations of reef organisms and sediment trap collections on Aldinga Reef in order to monitor sediment levels on the reef and any apparent deteriorations to marine species.

Despite evidence for sediment discharges from Washpool Lagoon to the Gulf being small, thorough analysis of discharges from creeks and other watercourses needs to be carried out for not only this catchment, but for those of Sellicks Creek and the other streams in the Willunga Basin which are likely to impact upon the marine environment. Data on total suspended solids and nutrient concentration discharges should be collected in order to assess the degree of impact these discharges are having on the Gulf of St. Vincent and on Aldinga Reef.

Further palaeoecological studies need also to be carried out in this region so as to establish a more comprehensive picture of the pre-European environment. This is important for effective management of the catchments under consideration and of the Willunga Basin as a whole, as it will provide the necessary temporal context for the development of appropriate management strategies.

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