SURFACE WATER HYDROLOGICAL CHANGE IN THE UPPER SOUTH EAST OF SOUTH AUSTRALIA

BY

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B.A.(HONS.)

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Conducted as a cross-institutional student between the University of Adelaide and the Australian National University.

For all the people I love,

especially Nanna.

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ABSTRACT

The study area, the Upper South East of South Australia, is currently facing devastation by a rapid increase of dryland salinisation and surface water flooding. These are affecting both agricultural and remnant wetland areas. The problem has been investigated by the South Australian government through an environmental impact assessment (EIA). Despite the huge amount of data collected for the EIA much information on the nature of the Upper South East environment prior to European settlement remained a mystery. This thesis aimed to obtain the entire history of the environment of the region using an approach known as environmental history.

Using both historical and palaeoenvironmental techniques the fluctuations in the environment due to both climate and human induced factors were revealed. Palaeoenvironmental results indicate that the surface water hydrological environment of the Upper South East has been a very dynamic one. Penultimate deep lake conditions were experienced sometime in the period between the last interglacial and 15 000 to 13 000 years BP, and wetlands dried sometime between the onset of the last glacial and 13 000 to 11 000 years BP. The most recent period (estimated to be the Holocene) has been characterised by ephemeral and saline conditions, but with large amounts of surface water flowing through the watercourses.

The historical record reveals that initially European landuse activities increased the amount of surface water in the watercourses of the Upper South East, reducing the salinity of wetlands. However, since 1960 the Upper South East has been deprived of surface water flow from the Lower South East due to drainage constructions. The reduced surface water flows, in addition to the subsequent impacts of vegetation clearance, have caused an increase of salinisation within the watercourses. Thus, European activities have produced a hydrological regime not previously experienced by the Upper South East watercourses within the period of time represented in the Upper South East sediment cores.

The environmental history of the Upper South East revealed that the current management plan recommended by the EIA may benefit dryland areas, but degradation of wetland areas is likely to continue. Periods of drought and flood with large amounts of surface water flowing through the wetlands, similar to the hydrological regime in place prior to European settlement, must be recreated if dryland salinisation is to be curtailed, and the conservation, of what was once a huge and diverse wetland region, ensured.

DECLARATION:

I hereby declare that none of the material contained in this thesis has been accepted for the award of any other degree or diploma in any other institution and that, to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except where due reference has been made in the text of the thesis. I consent to this thesis being made available for photocopying and loan, if applicable, and if it is accepted for the award of the degree.

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1.0 ENVIRONMENTAL HISTORY

Australia has had a very rapid transition from non-agricultural to full industrial settlement. Within that time massive landscape changes have occurred. Written records of the natural environment prior to European impact are rare and not detailed. Where records do exist they are mostly descriptive records rather than quantitative data on the environment of the region. This lack of long term knowledge is a problem for rational land management. The concept of environmental history is a relatively new approach aiming to establish the nature of the environment prior to human occupation and then to assess the relative impacts of historic changes on that environment.

1.1 Environmental History: The Methodology

Environmental history is a method of reconstructing changes that have occurred in a given environment. Dovers (1994, p. 4) defines environmental history as "the investigation and description of previous states of the biophysical environment, and the study of the history of human impacts on and relationships with the non human setting". Its aim is to deepen our understanding of how humans have been affected by their natural environment through time and, conversely, how humans have affected their environment and with what results (Worster, 1988). It achieves this through utilisation of historical and palaeoenvironmental evidence. By linking historical information with palaeoecological data, the history of any one study area can be extended back in time. In addition historical information can provide detail on the palaeoecological record.

Historical information provides descriptive information on the development of an area, and in some cases, quantitative information obtained from instrumental records. It is rare in Australia, however, to have instrumental records extending back very far in time. By contrast, palaeoecological records provide records of the evolution of the environment through the Quaternary period and in some instances even further back in time.

To some extent fine resolution palaeoecological studies enable the interaction between humans and the environment, in addition to natural climatic changes, to be studied. However, sites suitable for fine resolution palaeoecological methods are limited. Most study sites in Australia, especially those outside south eastern Australia, do not have a full detailed record of the Quaternary period. It is information from these areas that are required to further climate and human impact research in Australia.

Thus to study the interaction of humans and the environment a melding of the historical record with the palaeoecological record is essential. Such a merger will provide more available information on the history of environmental fluctuations from which probabilities of change in the future may be predicted. Being able to anticipate human environment interactions in the future is essential to the management of land and water resources. That is, once the environment's likely reaction to human activities is known, then the area can be managed to minimise the environmental impact. The purpose of environmental history therefore, is to examine the past as it relates to environmental and resource issues in the present (Dovers, 1994, p. 6). Of course, environmental history is site specific. The history of one area can not necessarily be extrapolated to another area.

Once the environmental history of an area is known, strategies for the conservation of that area can be constructed. Methods of conservation of resources are outlined in management strategies or management plans. A management strategy aims to manage the environment in a way most beneficial to the environment and its users (Lipscombe, 1987). This definition does not always result in the preservation of the natural environment but rather a balance between utilisation of its resources for human use and conservation of that resource for its intrinsic value. In many areas of south eastern Australia, where conflicting land uses coexist, there is a need to preserve agricultural productivity as well as natural vegetation remnants. The ecosystem must therefore be managed in such a way that retains it in as natural state as possible whilst not degrading agricultural areas. Vice versa, the natural attributes of the environment cannot be compromised for agricultural productivity.

Thus the basis of a management strategy is both knowledge of the ecosystem's current status plus knowledge of the history of the ecosystem: that is, the environmental history of the region. How the ecosystem has responded previously to natural and human interactions provides a guide to how it should be managed in the future. With knowledge of the human activities upon the environment in the future, reaction of that environment can be predicted from historical evidence. Management of the area can then be based upon a constructive plan rather than a presumptive ideology with no scientific foundation. Such a methodology is of prime importance to the conservation of natural resources and makes the environmental history of any region a requirement for its long term preservation.

1.2 The Origin of the Concept of Environmental History[1]

The concept of environmental history originated within a number of fields, including historical geography, historical demography, industrial history and social history (Blaschke, 1990). In particular historical geography played an important role in the development of environmental history as it combined the essential ingredients of history, geography, and the use of both historical and field evidence. However, historical geography focuses on the impact of changing environments on the activities of society within a landscape, as evidenced by the close link between historical geography and

[1]This review focuses on the development and use of environmental history within Australia. Dovers (1994, p. 6) includes a more general discussion on the predecessors of environmental history and includes case examples.

anthropology and archaeology (Butlin, 1993; Simmons, 1993). By contrast, environmental history emphasises the impact humans have had upon the environment. This emphasis was developed in the 1970s through geological applications (Doe, 1983), and was initiated by environmental concerns and the need to be able to predict environmental changes that may result from human actions in the future.

In essence, environmental history directly evolved from two fields of research, both of which were concerned with the impact of humans upon the environment, and both of which have continued independently. There is a growing amount of literature that combines the two fields into one: that of environmental historical studies. The first field included a collection of studies that utilised only fine resolution palaeoecological techniques to examine human-environment interactions (Head, 1988; Edwards and MacDonald, 1991; Crowley and Kershaw, 1994). These types of studies could only be conducted within ideal environments that were likely to provide the detailed information necessary to reconstruct environmental change within a several hundred year period. They were generally confined to south eastern Australia. Secondly, there were many studies that examined human impacts on the environment utilising only historical records, such as those of Hobbs and Hopkins, 1990; Lake and Marchant, 1990; Schot and van der Wal, 1992; and Rolls, 1994. These studies were restricted to an examination of environmental change occurring within approximately a one hundred year period, and did not provide detail of changes occurring over the medium or long term past. In addition, they were limited spatially and temporally to instrumental and observer location.

The first full use of the concept of environmental history was for flood frequency analysis. In this application environmental history is of particular relevance because historical records are rarely of sufficient length to record floods with return periods of greater than 50 years. In areas where catastrophic floods have return periods of one hundred to two hundred years, it is important to know of their existence in order to protect houses and associated structures from their path of destruction. Costa (1978) and Stedinger and Baker (1987) provide examples of such an application. Both studies utilised a multitude of methods to reconstruct both the historical and palaeoecological history of flooding. By melding the two fields of evidence, they were able to reconstruct previous flood events ranging from catastrophic floods to more recent flood events.

In the past decade, studies utilising the concept of environmental history have become more common. Although not all studies utilise the method to its full advantage, many studies utilise historical information simply to reinforce palaeoecological findings and others utilise historical information to provide detail to the palaeoecological record and to compare pre and post historical environmental change. Clark (1990) reviewed several studies that have utilised the approach of environmental history effectively for a range of purposes.

One of the first Australian studies utilising the concept of environmental history was conducted by Clark (1986). Clark studied Rotten swamp, a peat bog at the head of the Cotter River in the Brindabellla Ranges (Australian Capital Territory). Rotten Swamp had been badly burnt in a bushfire in January 1983 causing erosion and sedimentation problems in the Cotter River, a water supply area for Canberra. Clark (1986) used palaeoenvironmental evidence such as pollen and charcoal in combination with historical documents to provide management recommendations aimed to prevent a recurrence of such an event.

Another example of the combination of historical and palaeoenvironmental records was conducted by Clark and Wasson (1986) at Lake Burrinjuck (south east New South Wales).

Lake Burrinjuck has a wide range of conflicting users including tourism, water storage, and grazing. Using historical written records, instrumental records, palaeoenvironmental records (pollen, diatoms, charcoal, chemistry, dating and seismic sounding among them), and catchment studies (mapping, remote sensing and sediment tracing) the effect of land use change on the environment was assessed. This study was able to identify floods, droughts and erosion events from all four sources of data. After identifying the environmental history of the reservoir the authors felt that recommendations for better management of the land, given specified users and sequences of climatic or hydrological conditions, could be better made.

A good example of the use of environmental history is a study conducted by Pickup *et al.* (1987) on Magela Floodplain, Kakadu National Park (Northern Territory). The aim in this study was to predict the likely fate of uranium mill tailings should they be stored above ground when the Ranger Mine ceased operation. Palaeoenvironmental records were used to improve predictions of environmental conditions over the next thousand years or more to aid the design of a containment structure. Historical records were used to predict where any escaped tailings might be deposited and in what concentration. The combination of the two records enabled more accurate and effective management plans to be developed and implemented.

Boon and Dodson (1992) utilised the historical record of Lake Curlip in western Victoria to add detail to the palaeoecological record. They recognised that "by connecting the historical information with the responses of both physical and biotic elements, the impact of European occupation on elements of the landscape can be assessed" (Boon and Dodson, 1992, p. 219). Similarly, Gell *et al.* (1993) and Dodson *et al.* (1993) used historical records to provide detail to the recent palaeoecological record of East Gippsland and two New South Wales sites respectively.

In contrast, Dodson *et al.* (1994a and 1994b) used the sedimentary record to extend the observations and experimental records at Club Lake (Kosciusko National Park) and Cobrico Crater (south west Victoria). In these instances the historical record provided a basis for interpreting the sedimentary record and for ascribing causes to changes observed in the sedimentary record.

In 1995, Williams took the method of environmental history one step further and utilised information obtained after conducting an environmental historical study for management purposes at Lake Corangamite in Victoria. In this study Williams combined instrumental and palaeoecological data on salinity changes to construct management options and recommendations for the lake which were successfully utilised.

Applications of environmental history exist wherever there is competition over natural resources due to conflicting land uses. However, the development of environmental history is not yet complete. The problems inherent in merging different types of data sets are far from resolved. The methodology though, is essential to the understanding of human and environment interactions.

1.3 Advantages and Disadvantages of Environmental History

The main advantage of environmental history is that it overcomes the shortfalls of both historical and palaeoecological techniques. Because it is a multi-disciplinary concept the combination of a variety of techniques will overcome the disadvantages of any one technique.

The historical, or conventional methods, have a number of disadvantages. Historical records tend to be purely descriptive and only cover events where an observer is present. While written and ethnographic records can provide much information about the nature of the environment when Europeans first arrived, reconstructions of the medium-term past are needed in order to determine the nature and magnitude of induced changes (Clark, 1990). Historical records in Australia, at the very most, cover two hundred years of history and mostly only one hundred years. This time period is inadequate to understand the long term complexities of environmental change.

In Australia instrumental records are very short: in some cases they are incomplete, inaccurate or non-existent. Where instrumental records do exist they are often too short to enable modeling of natural phenomena. They may encompass bias towards a certain event or omit another. Also, many phenomena have been recorded rarely or discontinuously in space and time, or not at all. Instrument location and recording technique may change over time making it very difficult to compare records (Clark, 1990). Thus instrumental records have many shortfalls. It is also very difficult to substitute or combine qualitative written records with quantitative instrumental records.

The advantages of historical records are that they do provide detailed information on a variety of human activities. The length of European occupation and the nature of their activities are usually well recorded in newspaper articles, government reports and surveys. Local environmental events such as floods and fires are also usually recorded in a variety of sources. Thus, although the impact of such events upon the environment are not measured quantitatively, at least their existence, which may go unrecorded in the palaeoecological record, is known. In addition, and importantly, their absolute chronology is known which allows calibration.

Thus, the greatest problem with Australian historical records is the lack of information on processes over hundreds of years. A time scale in centuries is required in order to make effective predictions and thus constructive management plans for today. Palaeoecology overcomes the disadvantage of historical records by providing long term records. The palaeoecological record can provide longer records unlimited by observer location and bias. Sites can be located in any suitable site and cores may go to any depth within practical limitations. Palaeoecology overcomes the temporal limits of instrumental records and although still predominantly a descriptive science, there is far less observer bias than with historical records.

However, palaeoecology does have many limitations, the most important being the indirect nature of the sediment record. Not all events are recorded in the sediments, as the event must be large enough to produce a change in the vegetation or lake fauna to be detected. Gaps in sediment sequences also occur through erosion events. Also dating techniques may be problematic. The sediments must be suited to a particular dating method for the detected changes to be put into a chronological context. In addition, environmental interactions are very complex and may be difficult to interpret through palaeoecological techniques alone.

Linking palaeoecological evidence with historical evidence overcomes many of the disadvantages of either one technique. A combination of the two methods can provide an extensive and detailed knowledge of the history of a study area. The best possible management plan can then be constructed for the benefit of the environment and its users. The best possible management plan will be one that is interactive and flexible. Thus new historical information can be continually used to update management plans to overcome unforeseen change, and palaeoenvironmental information can contribute to the known environmental change of the region.

Disadvantages of environmental history do exist however and were recently highlighted by Dumayne *et al.* (1995). Problems occur when attempting to correlate events registered in the palaeoecological record with events in the historical record. Placing palaeoecological information in a statistical format to make it comparable with historical information is still in a developmental stage (Stedinger and Cohn, 1986). The easiest way to correlate the records is to use dating methods. However, lack of funding, limited number of dates, and a lack of precision as a result of sample size and calibration are all encountered (Dumayne *et al.*, 1995). In addition, ^{14}C is particularly unreliable for the period of time less than three hundred years BP, a time scale of great relevance when designing management strategies.

Baillie (1991) explored the problem of attaching calibrated radiocarbon chronologies to calendar-dated events and concluded that radiocarbon age estimates cannot be used to correlate changes registered in pollen profiles with calendar-dated archaeological events. Duamayne *et al.* (1995) extended Baillie's (1991) research using sites in Britain and found that radiocarbon dates were not precise enough to confirm expected correlations between pollen diagrams and archaeological evidence.

Possible solutions to the problem of linking historical and palaeoecological results were presented by Dumayne *et al.* (1995). A larger number of dates is one way to increase the link between the two methods although this solution is always limited by funding. The use of accelerated mass spectrometry (AMS) dating and tephrochronology were also suggested. Because AMS dates measure single objects of a single age rather than dating many objects of differing age as conventional methods do, error bars are reduced and thus the resolution of the chronology increases. With increased resolution it should be easier to link historical and palaeoecological records.

1.4 Environmental History in the Upper South East of South Australia

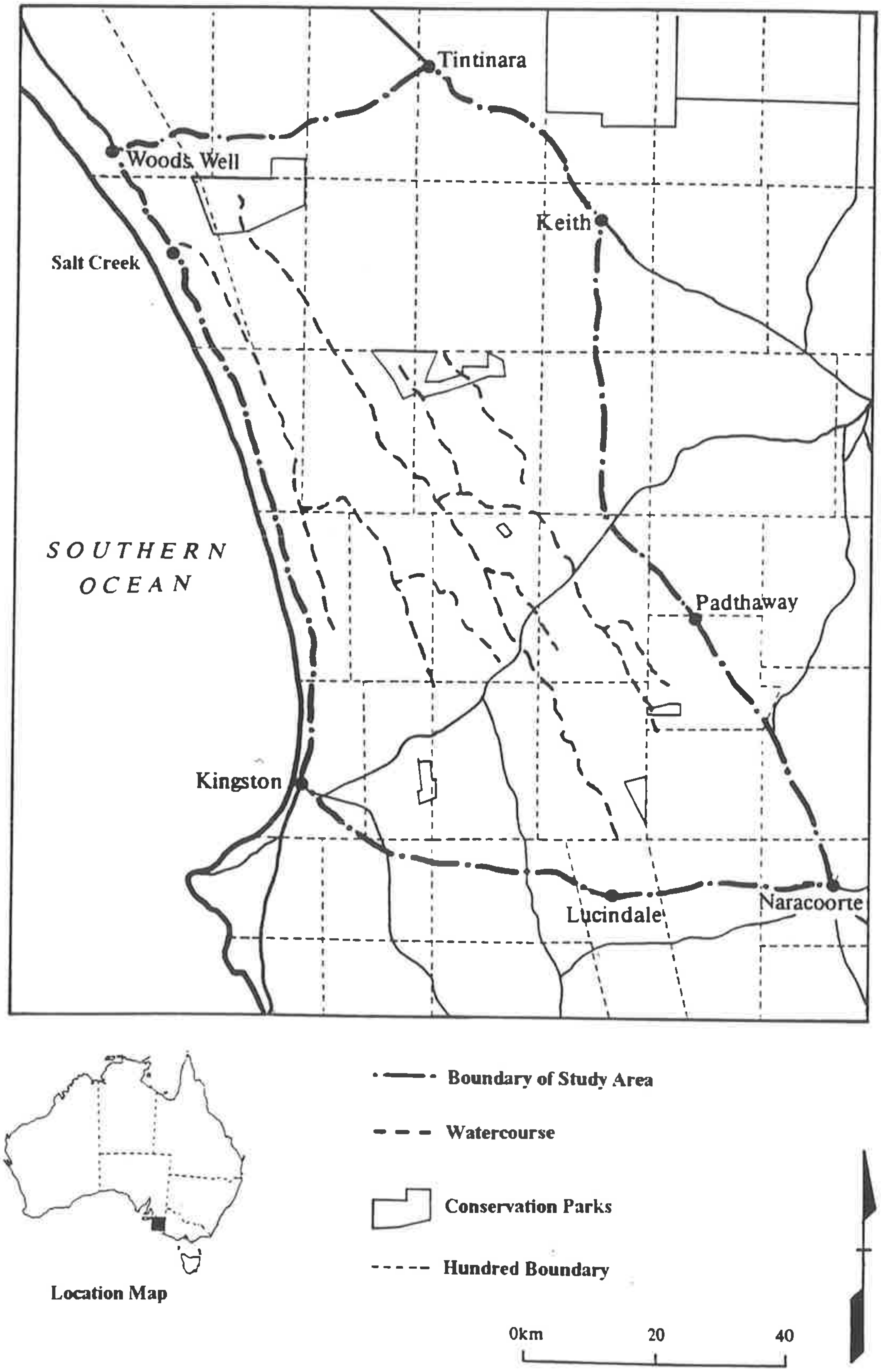
The area of South Australia approximately south of the River Murray mouth but north of the Padthaway Ridge is known as the Upper South East of South Australia (Figure 1.1). This area was selected as the study area for this research because it is a unique and complex natural environment undergoing large environmental changes due to human impact. Changes in the environment are affecting both agricultural areas and remnant natural vegetation. Thus future management of the area is critical for the benefit of all users and to prevent destruction of the environment.

Management of the Upper South East environment is complex as there is little documentation of the environment in its natural state and the changes that have occurred within it. Nance and Speight (1984) and Foale and Smith (1991) have described the historical records, but it is unknown how the ecology of the region reacts to changes in climate or the activities of humans. It has, therefore, been difficult to plan the future management of the area without a full knowledge of the environmental interactions that have occurred in the past.

In order for any management plans to be successful the history of the environment of the Upper South East must be known. Due to the lack of written records in addition to limited suitable palaeoecological sites in the region, the only way of discovering that history is utilising both the historical and palaeoecological techniques. Management of the area can then be based upon sound principles. The Upper South East is an ideal environment to examine the approach of environmental history given the uniformity of the geography of the area and limitations of both its historical record and its palaeoenvironmental record.

This situation occurs not only in the Upper South East of South Australia but right across the Australian continent. Successful maintenance and development of Australia's land,

Figure 1.1: The Study Area; the Upper South East of South Australia



Source: Adapted from Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993, p. 3).

water and vegetation resources relies upon accurate understanding of the environmental past. Until the past is known and understood, we have the risk of environmental and land use problems in the future (Chappell, 1985). Thus environmental history is the approach by which Australia's and in particular, the Upper South East of South Australia's, environmental resources can be managed more effectively for its various users.

1.5 Aims and Objectives Of The Thesis

This thesis aims to assess the management future of the Upper South East of South Australia. The key to the management of the Upper South East is knowledge of the history of the surface water hydrology and the impact European activities have had upon it. Thus the thesis concentrates on the hydrological changes that have occurred in the Upper South East through the use of both historical and palaeoecological techniques. The environmental history of this region is therefore investigated and the future management of the area suggested.

In regard to the Upper South East, the aims of the thesis are three fold:

1. to identify the changes that have occurred in the surface water hydrology of the Upper South East of South Australia during the period of European occupation using historical documentation of the region;

2. to identify the nature, magnitude and direction of hydrological change which has accompanied European settlement by analysis of the sedimentary record; and

3. to forecast the effects of current and planned drainage schemes upon the hydrological system by extrapolation of the palaeohydrological and historical data of the region.

These aims are pursued utilising the approach of environmental history. Historical records are investigated (chapter 5) and field sites sampled to analyse the sedimentary record (chapter 6) of the Upper South East. The following introductory chapters describe the environmental changes that have previously been studied in the Upper South East and surrounding regions (chapter 2). The nature of the Upper South East environment and its current plight are described in chapter 3 followed by a description of the selected field study sites. These chapters provide a background of previous research and outline the requirements for the successful management of the Upper South East, an issue addressed by this thesis in chapter 7, and concluded in chapter 8.

2.0 ENVIRONMENTAL CHANGE IN THE UPPER SOUTH EAST OF SOUTH AUSTRALIA AND SURROUNDING REGIONS

There have been two primary causes of environmental change in the Upper South East of South Australia: climatic fluctuations and human activities. Before humans developed the technology and population to affect the environment most environmental change could be attributed to climatic fluctuations. Since human society has developed sufficiently to significantly alter its surrounding environment, it has become difficult to differentiate human impact upon the environment from natural climatic fluctuations, although an attempt to do so follows.

2.1 Climatic Change and Associated Terrestrial Change

There are two main causes of climate change: firstly, changes in the input of solar radiation to the earth's atmosphere and secondly, the related distribution and altitude of land masses and oceans (Goudie, 1992). In Australia, geological and biological artefacts suggest that variations in climate are closely related to variations in the position and strength of sub-tropical anticyclones (Rognon and Williams, 1977). Bowler (1976) identified that the periods of major aridity in Australia, were correlated with periods of intensified atmospheric circulation corresponding to glacial low sea levels and reduced seasonal precipitation. More recently, Harrison (1993) illustrated that lake level fluctuations in Australia, in the past 30 000 years, were correlated with a subtropical belt of high pressure and divergence (STA). In addition, the Walker Circulation has significant correlations with rainfall but acts independently of the STA (Harrison, 1993).

Using biological and geological evidence, a number of authors have contributed to the reconstruction of climate change in Australia. Most research has been conducted in south eastern Australia because the region contains environments suitable for climatic reconstructions. In the south east of South Australia a limited number of studies reconstructing climate change have been conducted, utilising different sources of environmental evidence. Figure 2.1 shows the location of the following study sites discussed.

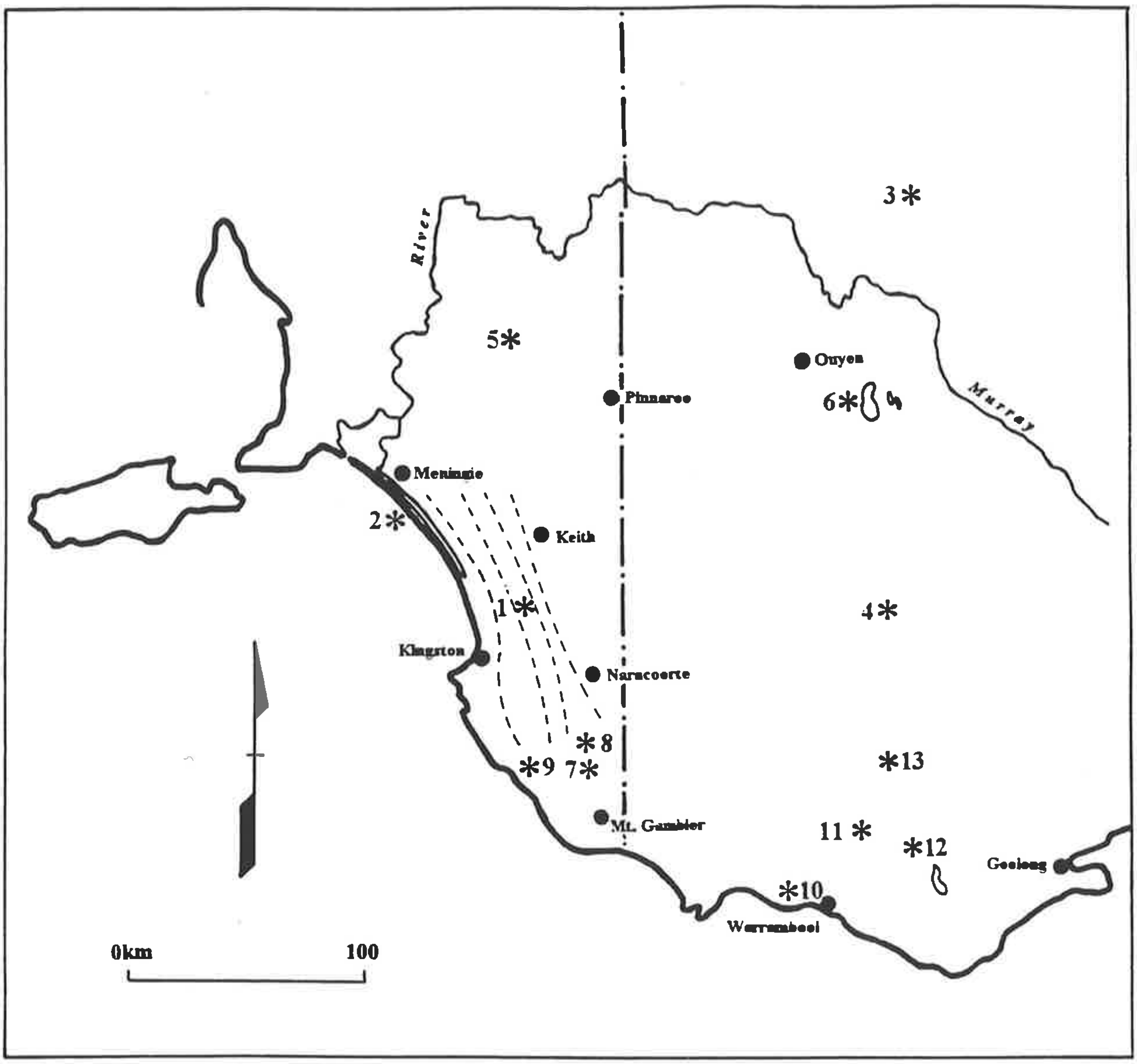
2.1.1 Sea Level Fluctuations

The topography of the Upper South East provides evidence of sea level fluctuations. The series of barrier dune systems are a result of fluctuations of the world's climate during the Pleistocene and are preserved by slow tectonic uplift (see section 3.1 for detail). Many studies have been conducted on these dune systems in order to understand the fluctuations in climate that have affected the natural environment of the region.

Fenner (1930, p. 22) was the first to recognise the dunes of the South East as "a belt, nearly 50 miles [80 km] in width, of successive dune and swale - ancient sand dune ridges ...", and Crocker (1941) was the first to recognise that the stranded coastal dunes of the South East were connected with successive stages in the retreat of the sea during the Pleistocene. Hossfeld (1950) compiled a provisional chronology of the area using evidence from aerial photographs in which the remnant shore lines were tentatively correlated with the fluctuating sea level during the Pleistocene period. Sprigg (1952) devised a chronology for the series of dunes utilising the Milankovitch astronomical theory. Hossfeld's (1950) and Sprigg's (1952, 1959) chronologies were irreconcilable due to the different methods used to obtain them.

In 1977, Cook *et al.* undertook what has been the most extensive and exhaustive field work thus far into the stratigraphy of the Upper South East of South Australia. Their main contribution was radiocarbon dating the dune sediments, which provided an indication of

Figure 2.1: Location of study sites used to provide evidence of climatic change in the Upper South East of South Australia



---- Linear Dunes
* **Study Areas**

1. Linear dunes of the South East of South Australia
2. The Coorong
3. Murray Basin sites of Martin,1989
4. Study site region of Crowley,1994
5. Murrav basin study site of Stone,1992
6. Lake Tyrrell
7. Lake Leake
8. Marshes Swamp
9. Wyrie Swamp
10. Tower Hill
11. Lake Keilambete
12. Lake Bullenmern
13. Lake Bolac
14. Kangaroo Island

the ages of the system, reinforcing the theory that the stranded coastal dunes were formed during the Quaternary period. Cook *et al.* (1977) were the first to examine the interdune sediments identifying estuarine-lagoonal and lacustrine facies.

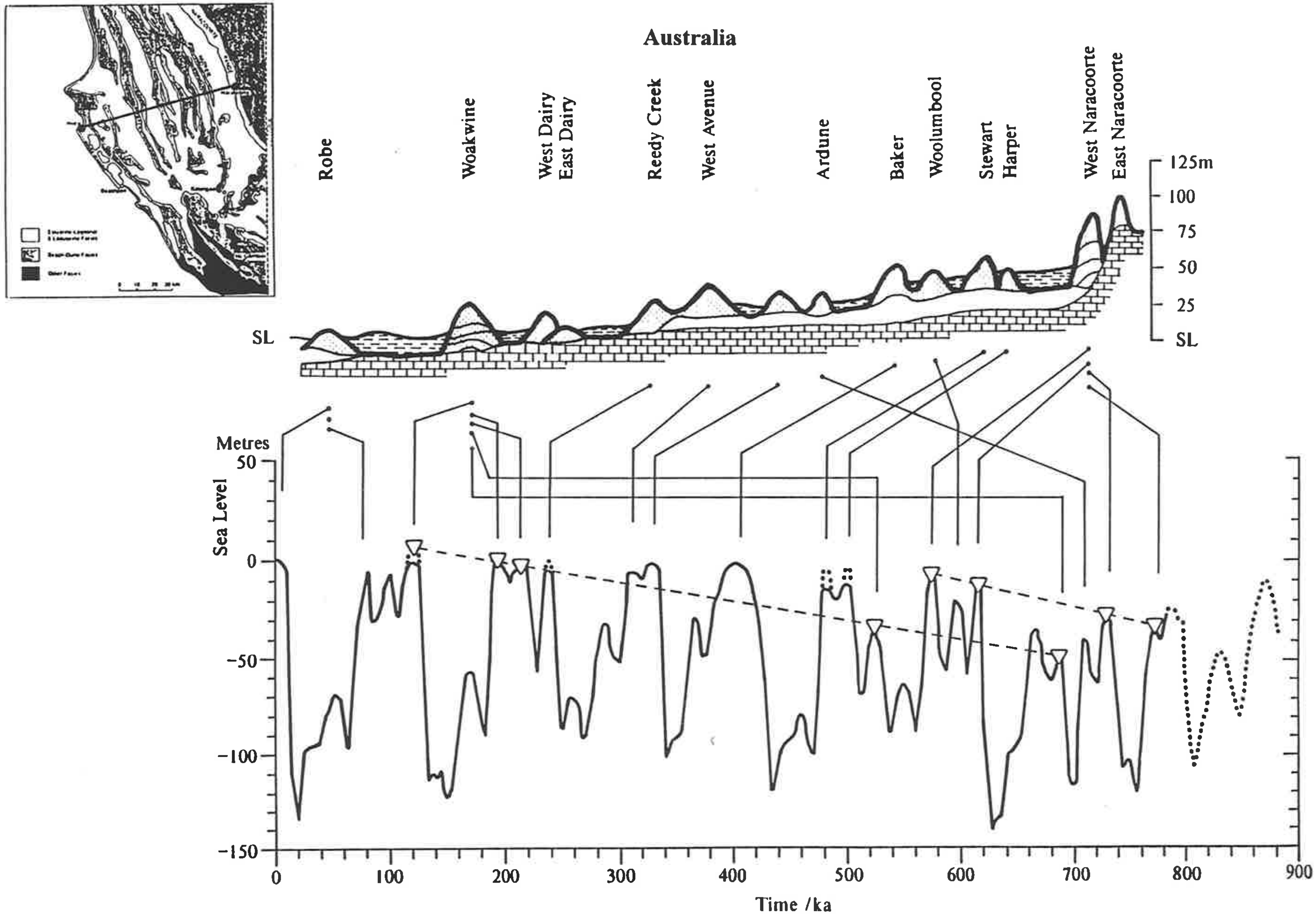
It was Schwebel (1984) who indicated that the Quaternary sequence was deposited in response to the complex interaction of slow tectonic uplift and eustatic sea-level change on a broad, gently dipping coastal plain. From the results of the combined techniques of uranium series dating, radiocarbon dating and magnetostratigraphy, Schwebel verified the time scale for the dunes and first allowed some confidence in matching the dunes to high sea-level stands.

Recently Huntley *et al.* (1993) tested the use of thermoluminescence dating on the stranded beach-dune sequence. The picture that has emerged is that the Upper South East of South Australia is almost flat, with a gradient of 1:1 600, and has been slowly rising at a rate of fifty metres in 700 000 years (Huntley *et al.*, 1993). This, combined with a sea level which oscillates with a return period of approximately 100 000 years, has produced shorelines that are approximately ten kilometres seawards from the previous one at each major high sea level stand (Figure 2.2). The detailed structure deviates from this because the land gradient is not uniform, the uplift rate may not be constant and the sea level versus time curve is complex in detail (Huntley *et al.*, 1993).

Thus evidence of sea level fluctuations indicates that the Upper South East has been affected by changes in the world climate. The sea level changes have produced an unusual topography, which subsequently influences the hydrology and biogeography of the Upper South East environment.

While the topography of the Upper South East provides evidence of long term sea level changes, they are not as detailed for the past 6000 years as some of the sea level studies

Figure 2.2: Ancient Barrier Dune Systems of The Upper South East of South Australia



Source: Huntley et al. 1993

conducted in the nearby Spencer Gulf by Hails *et al.* (1983) and Belperio *et al.* (1983). Stratigraphic coring and radiocarbon dating by the above authors in the Upper Spencer Gulf have revealed that shallow marine sedimentation commenced prior to 6000 years BP indicating a rising sea level. However, depositional evidence indicates that while the sea level was two and a half metres above the present level between 6000 and 1700 years ago, a reduction to present sea levels was due to regional tectonic uplift rather than a fall of sea levels (Hails *et al.*, 1983). The same could be inferred in the Upper South East for this time period. Evidence of change in the past 6000 years in the Upper South East is provided from sediment cores of the Coorong which are discussed in the following section.

2.1.2 The Coorong.

The Coorong is a linear estuary located between the Young Husband Peninsula and the Upper South East. In the northern section the Coorong is an open lagoon, in the southern section it is a series of ephemeral clay-filled lakes and swamps. It is a Holocene feature, and thus the sediments reveal a detailed history over a short period of time in contrast to the ancient barrier dune systems described above. Many studies have examined the sediments of the Coorong in an attempt to reveal details of its development and of associated climate change. These are primarily honours theses and usually lack a reliable chronology.

Brown (1965) conducted the first extensive study on the Coorong sediments. He found that the Coorong had become increasingly restricted since its formation, as basal sediments and fossil flora indicated a period of protected marine environment which subsequently became restricted by barrier development and became a lagoon environment (Brown, 1965). Plush's (1974) study supported the findings of Brown (1965). In 1976, when von der Borch obtained dates for the Coorong sediments, it was realised that the Coorong had progressed from a sheltered marine environment to a restricted lagoon approximately 6500 years ago. Several theses from the University of Adelaide and Flinders University have subsequently examined various sedimentary sites along the Coorong, and all have identified periods of marine regression after which the Coorong become a sheltered lagoon environment (Burton, 1979; MacDonald, 1991; Rowe, 1992; Mazzoleni, 1993).

Knowledge of the Coorong's history was extended when Thomas and Williams (1993) examined Lake Cantara South (southern Coorong). They found that Lake Cantara originated as a marine embayment, with periods of intermittent marine connection but finally became saline, with occasional freshwater inundations, in the modern period (Thomas and Williams, 1993). However, this study also lacked dates to provide a chronology.

Thus all the studies on the Coorong indicate that there was a period of major marine transgressions and numerous sea level oscillations during the Quaternary. In particular a marine transgression was identified that corresponds with that revealed in the Upper Spencer Gulf at approximately 6000 years ago (Hails *et al.*, 1983). However, the exact dates for the Coorong events are not known. More research needs to be conducted at the Coorong to provide an accurate chronology of the detected environmental changes.

2.1.3 The Murray Basin

The Murray Basin is the large catchment area of the Murray River. It incorporates the Upper South East, north west Victoria and south west New South Wales. The area is primarily semi arid and thus unpromising for palaeoecological studies. Few studies have been conducted within the area and even fewer that relate to climate change in the Upper South East.

Martin (1989) used palynological techniques to reconstruct climate and salinity changes through the Cainozoic. Evidence from Martin's study sites in south west New South Wales indicated that forest "of one kind or another" (p. 295) existed throughout the Tertiary and rainforest in the mid Tertiary. In the mid to late Miocene, precipitation decreased and the climate became more seasonal. From the late Pliocene to early Pleistocene the climate became increasingly drier (but still wetter than today) and the vegetation changed to open *Casuarina* and eucalypt woodland/grassland. Martin (1989) concluded that the problems of dryland salinity that exist in the Murray Basin today had no prelude in the history of that environment.

Evidence against Martin's (1989) conclusion was provided by Crowley (1994). Using Chenopodiaceae and *Casuarina* pollen curves from sites in western Victoria Crowley found that dryland salinity developed in arid phases and when high rainfall or high sea level caused regionally high groundwater tables. Crowley (1994) concluded that this pattern was consistent throughout the Murray Basin in the Quaternary.

The second study conducted in the Murray Basin was by Stone (1992). Stone utilised soil-water chloride profiles to estimate soil water ages and palaeorecharge rates. He showed that the soil water at the base of the chloride build up was emplaced during the last glacial interval (at least 20 000 years BP). Results indicated that recharge rates at this time were very low, indicating that the last glacial period was colder, windier and drier.

Teller *et al.* (1982) and Bowler and Teller (1986) investigated the sediments of Lake Tyrrell (north western Victoria) and found marked climatic fluctuations corresponding with those of Stone (1992) described above. Lake Tyrrell filled about 30 000 to 25 000 years BP but dried approximately 22 000 years BP. It appeared to remain that way until 10 000 years BP. Luly (1993) investigated Lake Tyrrell using pollen analysis and found marked climatic fluctuations in the Holocene. An increase of arid conditions occurred in this region after 10 000 BP converting Lake Tyrrell to an ephemeral lake. At 6000 BP an increase in rainfall transformed the lake to a permanent water body. Drier conditions prevailed between 2200 BP and 800 BP. Fully modern conditions date from 800 BP.

These studies indicate, using palaeoecological evidence, that the Murray Basin has experienced a wide range of climatic fluctuations ranging from rainforest in the Tertiary to the existing semi arid mallee. Of note are the fluctuations in climate during the Holocene found by Luly (1993) which correspond with that found in western Victoria and the Lower South East which are reviewed below.

2.1.4 West Victorian Lakes

The western portion of Victoria contains many volcanic lakes that have been well studied for palaeoenvironmental records. While this region is within a different geological and hydrological region to the Upper South East the climate is similar. The climate changes have been reconstructed using a variety of fossil evidence; primarily pollen, charcoal, and aquatic fauna. The only continuous record since the late glacial comes from two craters at Tower Hill (D'Costa *et al.*, 1989). However, a combination of evidence from surrounding lakes provides a record of climate change over the past 15 000 to 20 000 years.

Lake Keilambete has provided the longest, although discontinuous, record of environmental change. Evidence from this lake indicates lake full conditions between 30 000 and 18 000 years BP (Bowler and Hamada, 1971). The lakes dried between 18 000 and 15 000 years BP and remained that way for several thousand years (Dodson, 1979). Sediment cores from north west crater at Tower Hill and Lake Bolac indicate that these lakes maintained shallow water levels throughout the period 18 000 to 15 000 years BP

(Kershaw, 1995). Maximum aridity occurred between 15 000 and 11 500 years BP at Tower Hill (D'Costa *et al.*, 1989).

Effective precipitation increased in western Victoria at approximately 10 000 years BP (Bowler and Hamada, 1971). Maximum Holocene water levels were recorded between 8000 and 5000 years BP at Tower Hill (D'Costa *et al.*, 1989). Kershaw (1995) postulated that the changes in vegetation and lake levels were due to an increase in effective rainfall rather than a significant increase in rainfall amounts. Vegetation at Lake Bullenmerri changed composition during this period from *Eucalyptus* and *Callitris* to *Eucalyptus* and *Casuarina*. The change in vegetation composition is likely to be due to an increase in moisture as *Callitris* seeds do not travel well in wet conditions (Dodson, 1979).

Lake levels remained deep in western Victoria until 5500 years BP. At Lake Keilambete carbonate production increased indicating a return to shallow ephemeral conditions between 5000 and 3100 BP. At 3100 BP the water level rose slightly and fell again at 2000 BP (Dodson, 1974). DeDeckker (1982) provides evidence from a variety of lakes in western Victoria for a lowering of lake levels between 2000 and 3000 BP but an increase thereafter. In the past 100 years lake levels have fallen (DeDeckker, 1982).

Western Victorian volcanic lakes have provided much evidence for the reconstruction of environmental change in south eastern Australia. Regional variations of the timing and severity of vegetation changes do occur between this region and the northern South Australian lakes, the Alpine peats and the eastern Victorian lakes (Kershaw, 1995). However, west Victorian records do correspond fairly closely with the records obtained in the Lower South East lakes and Kangaroo Island which are reviewed in the following section.

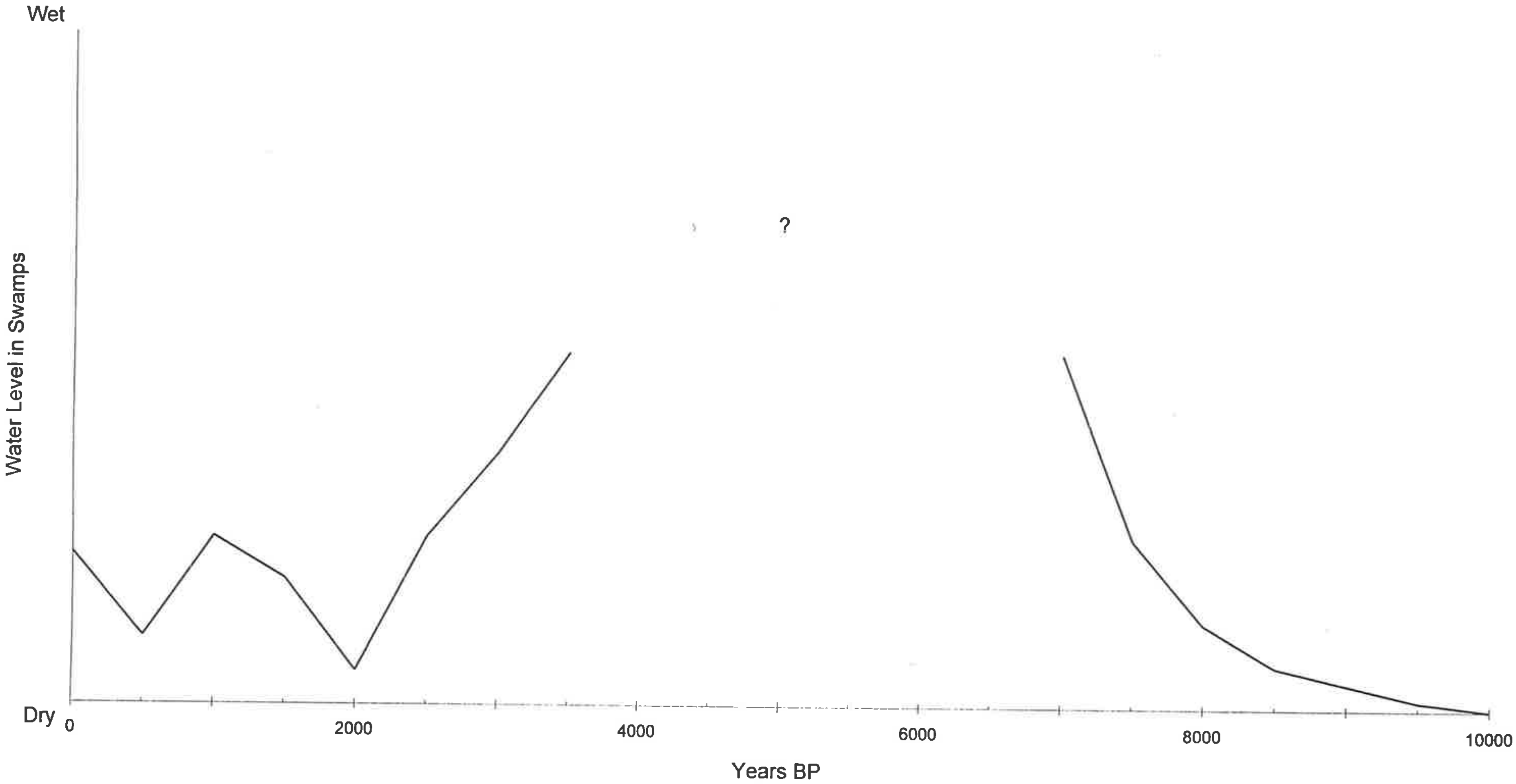
2.1.5 The Lower South East Lakes and Kangaroo Island

The Lower South East is part of the Otway hydrological basin, and is adjacent to the Upper South East, thus it has similar fluctuations in climate as evidenced through palynology. The studies on climate change were conducted by Dodson and Wilson (Dodson, 1974, 1975, 1977; Dodson and Wilson, 1975) at Lake Leake, Marshes Swamp and Wyrie Swamp. Palynology and sedimentology were used to reconstruct climatic changes.

Lake Leake and Wyrie Swamp provided records for the past 50 000 years BP (Dodson, 1975, 1977). Pollen diagrams showed that climate change had been sufficient to alter vegetation composition several times between 50 000 and 10 000 years BP. Open eucalypt woodland was replaced by eucalypt woodland and heath at about 50 000 BP and remained until approximately 39 000 BP. Open woodland then returned but was replaced by eucalypt woodland and heath by 38 000 BP. Some time after 35 000 BP open woodland conditions returned and persisted until near 10 000 BP when *Casuarina stricta* migrated into the area. From these vegetation changes Dodson (1975, 1979) concluded that the climate was drier than at present throughout the period 50 000 to 10 000 BP with wet periods occurring about 50 000 and 39 000 BP and from 38 000 to 35 000 BP. Conversely, conditions were relatively dry prior to 50 000 and between 39 000 and 38 000, and from after 35 000 until about 10 000 BP. Figure 2.3 shows a lake water level reconstruction made by Leubbers (1978) using Dodson's data.

In addition to Lake Leake and Wyrie Swamp, nearby Marshes Swamp (Dodson and Wilson, 1975) contributed information to climate change occurring in the Holocene in the Lower South East. The distribution of vegetation at Marshes Swamp is partially dependent upon flooding frequency making it an ideal site to study climatic change. At all three swamps wetter conditions prevailed from 9000 years BP. The water level rose and

Figure 2.3: Lake Levels of the Lower South East of South Australia



Source: Leubbers (1978)

continued to do so until the greatest depth was reached between 6900 and 5000 years BP (Dodson, 1974). Peat formation ended at this time in Marshes Swamp and after 3000 years BP the swamp became much drier (Dodson and Wilson, 1975). At Lake Leake evidence was found of wetter conditions between 2000 and 1300 years BP, but then relatively dry until the present day.

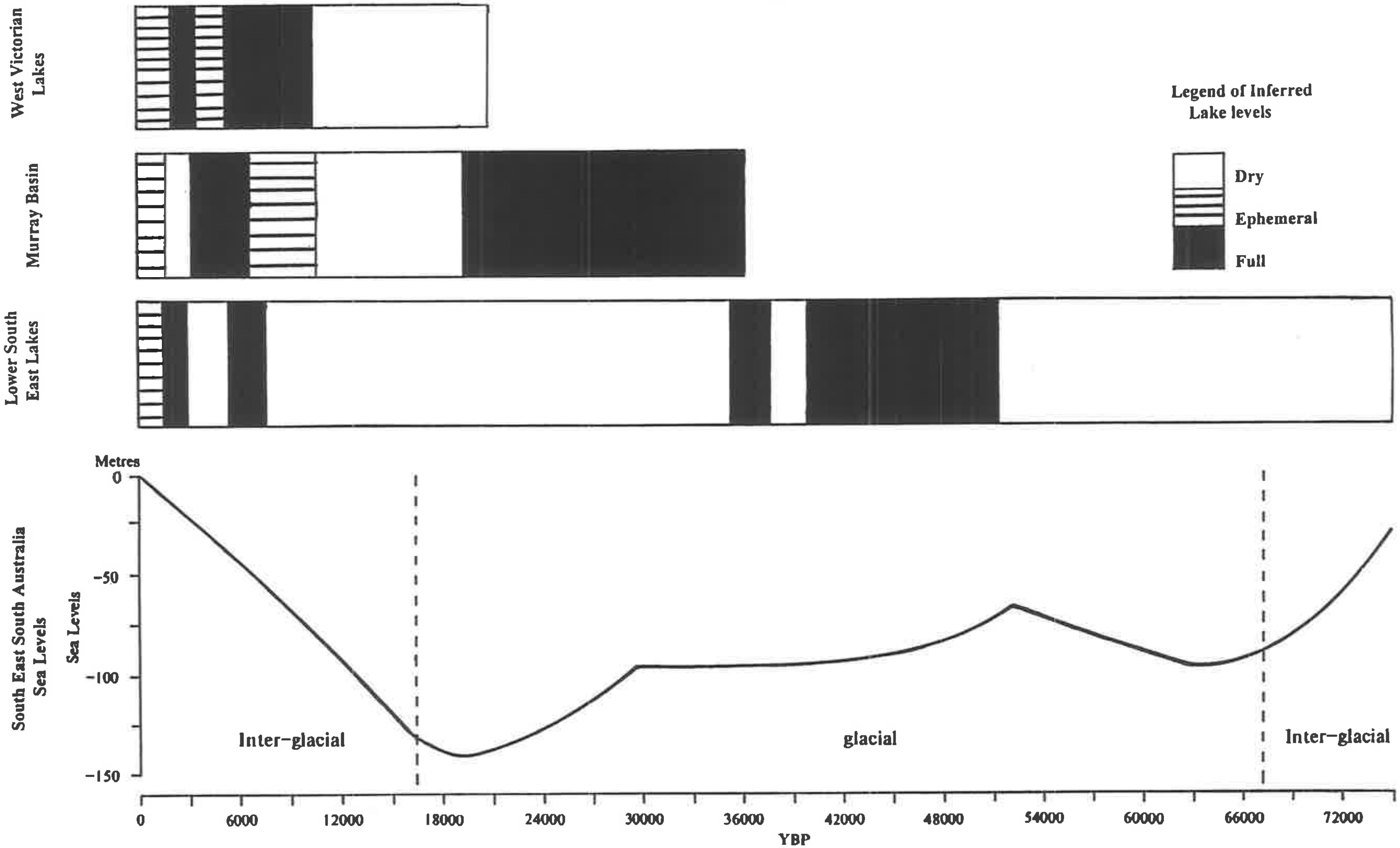
In addition to evidence from lakes in the Lower South East, Lashmar's Lagoon on nearby Kangaroo Island was examined by Clark (Singh *et al*., 1981). Lashmar's Lagoon has been under the influence of the sea for the past 7000 years BP except for two periods when the lagoon was fresh. These were between 3900 and 2700, and 400 and 150 years ago. Palynology indicated that despite the sea level fluctuations, the climate has been similar to that of today but marginally wetter than today prior to 4800 years BP. The onset of drier conditions at 4800 years BP resulted in a change of vegetation composition and an increase in fire frequency. In the past 4000 years the vegetation has altered only slightly, possibly a product of Aboriginal use of fire rather than detected climate changes (Singh *et al*., 1981).

These results from the Lower South East and Kangaroo Island correspond with those of the west Victorian crater lakes discussed in the previous section. Some slight discrepancies in the timing and significance of events occurs, such as the impact of the last glacial upon vegetation composition. These alterations can be accounted for by regional variations of climate.

2.1.5 Summary

The environment of the Upper South East has experienced a wide range of climatic conditions over the past 100 000 years. Figure 2.4 summarises the climatic changes that have occurred. The various sources of evidence do correlate, and some provide more detail within certain periods of time. The sea level curve constructed by Huntley *et al.* (1993)

Figure 2.4: Summary of Climate Change in the Region surrounding the Upper South East



provides the longest record of climate change. Palynological evidence obtained from the Lower South East and western Victoria correlates with the sea level record, indicating dry periods occurred in the glacial periods when open eucalypt woodland dominated and eucalypt woodland with a heath understorey grew during the interstadials. More detailed records revealed that there were a variety of climatic fluctuations during the Holocene, with a peak of effective precipitation occurring mid Holocene. Evidence has also been found, particularly in western Victoria, for climate change occurring in the past 2000 years. Evidence from Luly (1993) at Lake Tyrrell indicates modern conditions have prevailed for only 800 years BP in the Murray Basin. These studies imply that changes in the recent past cannot be attributed to human impact alone.

2.2 Human Induced Change

Both Aborigines and Europeans have modified Australia's environment although the nature and extent of the induced change differs greatly. Aborigines exploited plant and animal resources and learnt to modify technology and behaviour, to make their exploitation of natural resources more efficient (Dodson, 1994). Their impact upon the Australian megafauna through hunting activities (Jones, 1969; Nicolson, 1981; and Murray 1984) and upon Australia's vegetation composition through use of fire (Clark and Lampert, 1981; Kershaw, 1986; and Gell *et al.*, 1993) remains widely debated in current literature (Kershaw, 1995).

Europeans have cleared, cultivated and mined Australia within only two hundred years, causing dramatic and devastating environmental changes (Parv, 1984). The impacts of European activities upon the Australian environment are well discussed by Lake and Marchant, 1990; Recher and Lim, 1990; and McTainsh and Broughton, 1993. Predominantly, native vegetation clearance, soil degradation, hydrological interference, fauna habitat destruction and urban development have caused the greatest destruction of the environment.

Thus, it is apparent that over the last century human agents have become a significant cause of environmental change in Australia. But it remains extremely difficult to ascertain whether human influence or natural forces are responsible for observed trends. The impact of Aboriginal and European activities upon the Upper South East is investigated in detail from historical records in chapter 5.

2.3 Conclusions

Climatic change has resulted in a wide range of environmental changes in the Upper South East and surrounding regions. However, environmental change in the Holocene has occurred as a result of both climatic change and human activities. It is clear that European colonisation of Australia has had a marked impact upon the environment, but the role of Aboriginal activities in vegetation and climatic change is a much argued point. It is clear, however, that there are three major causes of environmental change in Australia. They are natural climatic changes and the impacts of both Aboriginals and Europeans. The nature of these changes are of great interest for the management of Australia's environment in the future. The effects of these influences in the Upper South East of South Australia are important to understand in order to provide effective management of its future.

3.0 THE ENVIRONMENT OF THE UPPER SOUTH EAST OF SOUTH AUSTRALIA

The coastal ridge topography and lack of surface drainage make the Upper South East radically different to the landscapes of south eastern Australia. In addition, its recent and rapid development for agriculture has produced management problems that have been caused by the use of modern agricultural technology in a fragile environment. One result has been successive surveys and an environmental impact assessment (EIA) conducted by the South Australian Government. The EIA is remarkable in the amount of background information that has had to be collected in order to make management recommendations. But despite these studies much information remains lacking on the environmental history of the Upper South East.

3.1 Physical Geography

The Upper South East is the portion of South Australia located between the Coorong and the Keith to Naracoorte road. It lies south of the road between Woods Well and Keith and north of the Padthaway Ridge (Figure 1.1). This definition of the Upper South East was utilised by the Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993) in developing the most recent management plan for the region. The boundaries were defined to include the regional problems of dryland salinity and surface water flooding. Factors contributing to the salinity and flood problems extend beyond the study area, reaching into western Victoria and the Lower South East (the portion of South Australia south of the Upper South East).

3.1.1 Climate

The Upper South East of South Australia has a Mediterranean climate with dry summers and wet winters. The rainfall varies latitudinally with higher rainfalls recorded in the south (Figure 3.1). The rainfall is moderately high with an average of 500 mm to 550 mm per year. The evaporation rate varies with distance away from the coast (Figure 3.1). Rainfall exceeds evaporation during the winter and spring months, resulting in surplus surface water supplies for that period (Jensen *et al.*, 1983).

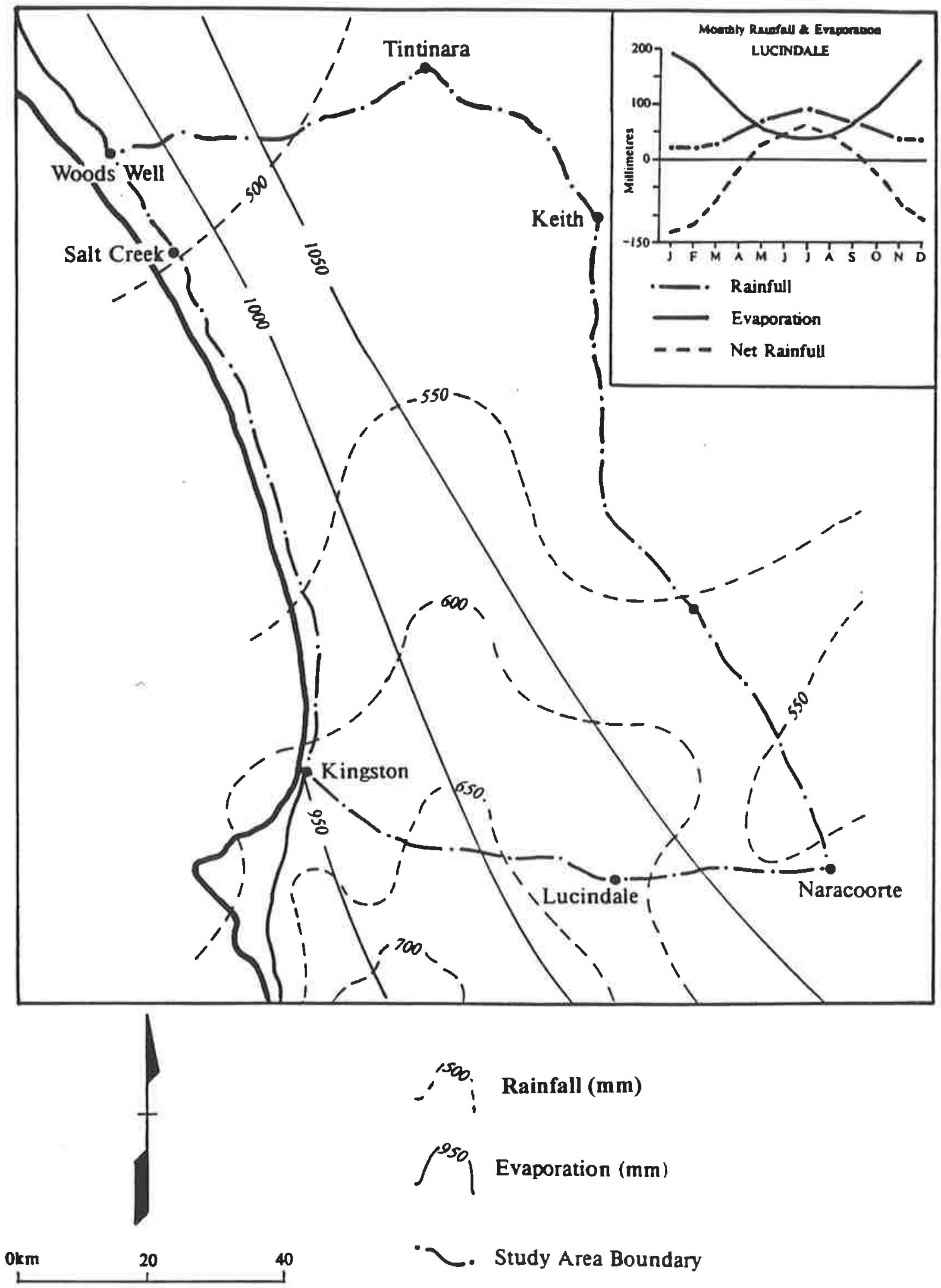
The mean annual temperature shows a similar pattern to the rainfall isohyets (Figure 3.2) with the mean annual temperature for Keith being 15.5 °C and for Mount Gambier 13.2 °C. Extremes of temperature are often experienced in the summer months when values exceed 38.0 °C and are usually accompanied by a hot northerly wind. Frosts occur during the winter months, especially in the southern region (Penny, 1983).

During the summer months high pressure cells moving eastward producing a predominance of southerly winds. The prevailing wind swings around in the autumn and during the winter the synoptic pattern produces predominantly north west to north east winds (Penny, 1983).

3.1.2 Geology

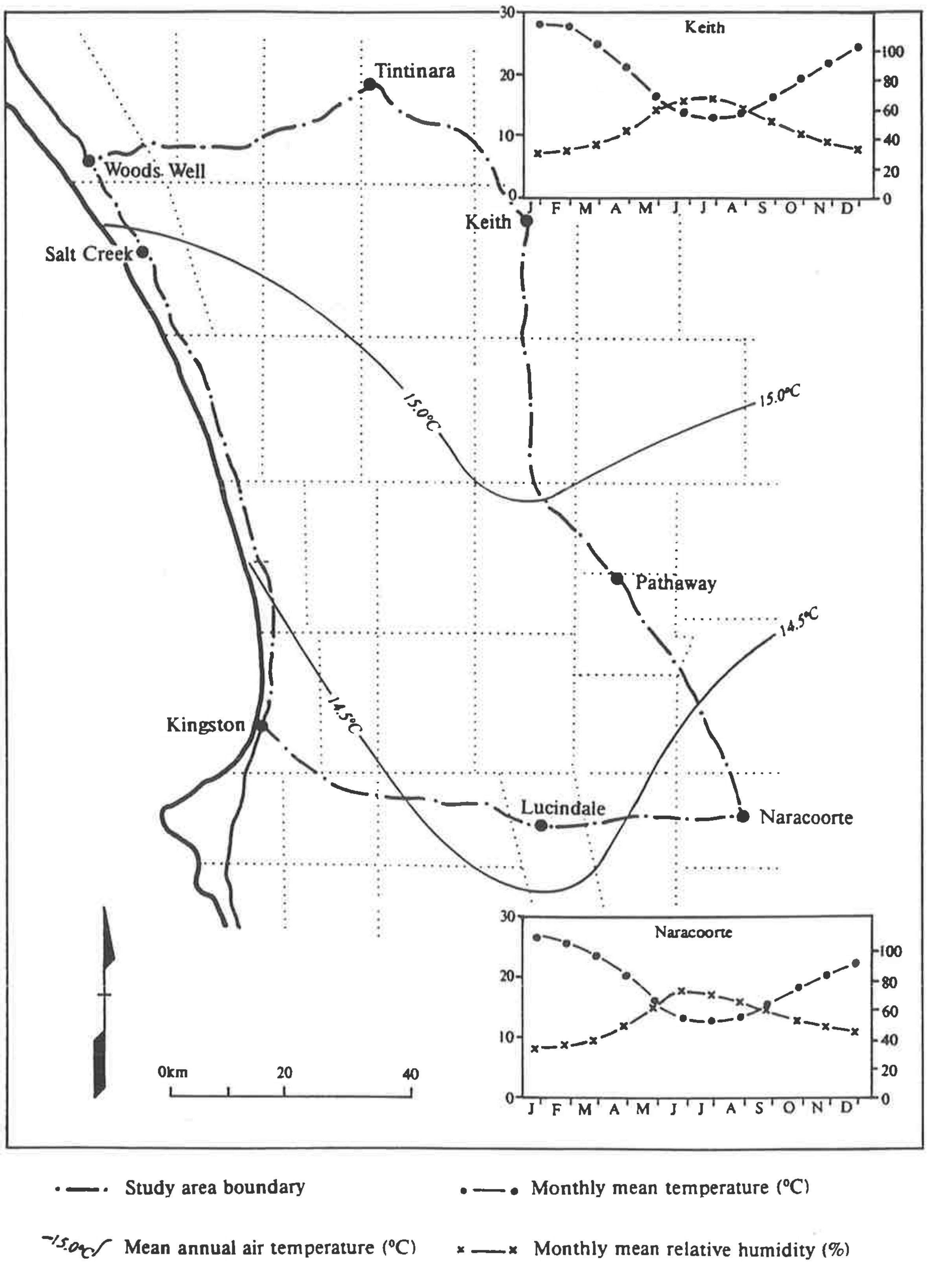
The Upper South East is part of the Murray Drainage Basin and is separated from the Otway Drainage Basin of the Lower South East by a fault system in the Cainozoic sequences known as the Padthaway Ridge (Cook *et al.*, 1977). Since the Cainozoic, the two drainage basins have become geologically distinct. Figure 3.3 illustrates the geology of the Upper South East.

Figure 3.1: Rainfall and Evaporation Isohyets of the Upper South East of South Australia



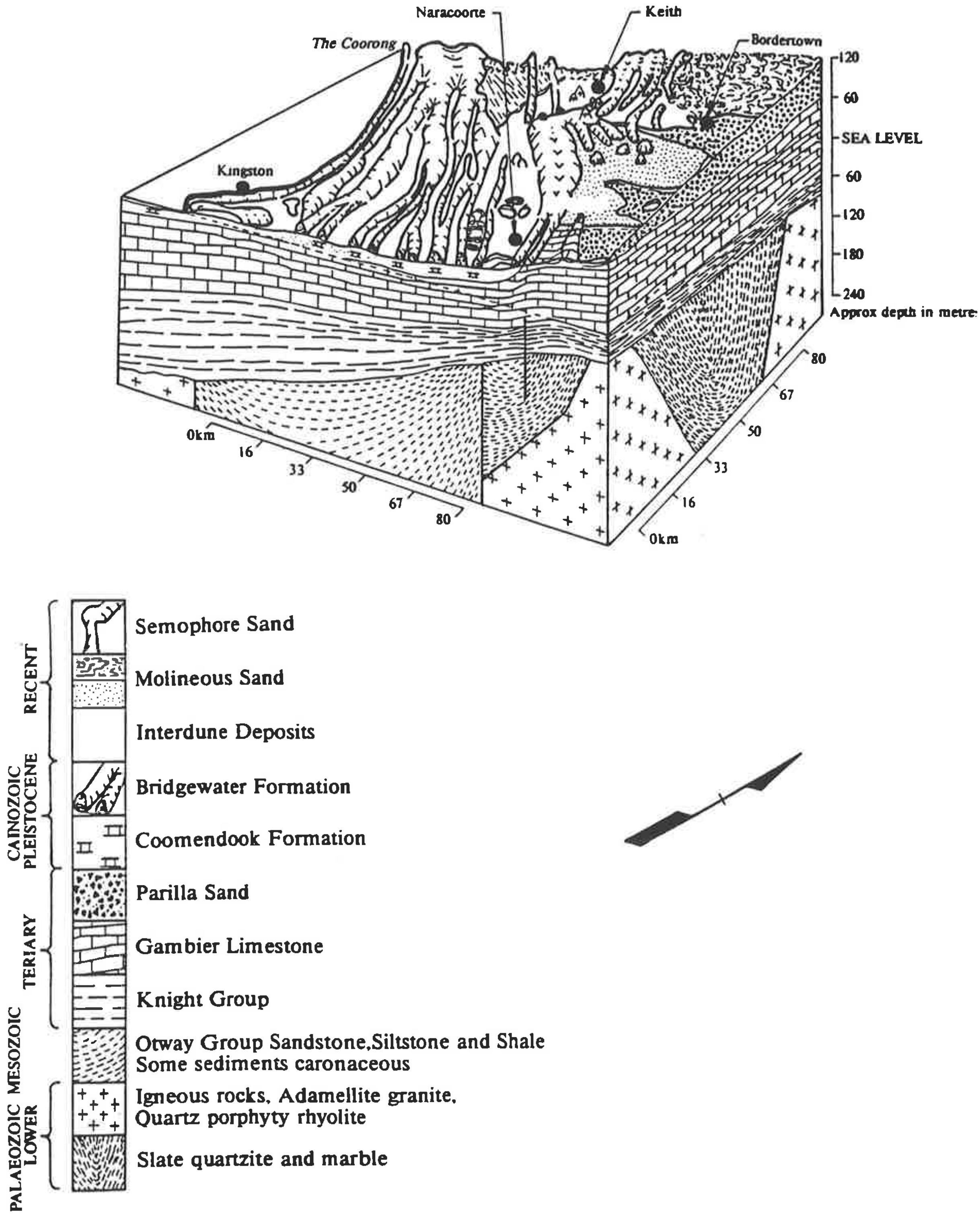
Source: Adapted from Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993.

Figure 3.2: Temperature Gradients of the Upper South East of South Australia



Source: Adapted from Penny, 1983.

Figure 3.3: Geology of the Upper South East of South Australia



Source: Firman, 1973.

Volcanic activity occurred throughout the Cainozoic in the Upper South East. Remnants of the volcanic activity exist as granite outcrops, such as Jip Jip Rocks, scattered throughout the district. During the Tertiary, Gambier limestone was laid down in the shallow marine conditions of that period. The Gambier limestone is mainly composed of bryozoan limestones varying in grain size from silt through sand to granule and pebble sized fragments (Gillieson, 1992). Overlying the Gambier limestone is a partial mantle of Parilla sand, a fluvio-lacustrine unit of Pliocene age (Cook *et al.*, 1977). This layer does not extend all the way to the modern coastline but forms a layer up to seventeen metres thick between the Naracoorte and Reedy Creek Ranges (Cook *et al.*, 1977).

The most recent sediment is the Bridgewater formation which is the series of calcareous dunes that dominate the topography. The dunes are composed of very coarse rounded and fragmentary skeletal carbonate grains with fine to medium and moderately rounded to well rounded detrital grains (Cook *et al.*, 1977). The lower part of the dunes was deposited in a beach or near beach environment whereas the upper part of the sequence was deposited under aeolian conditions (Crocker, 1941).

The interdune facies are predominantly calcareous muds with varying amounts of calcite, aragonite and dolomite (Cook *et al.*, 1977). Microcrystalline dolomite and related carbonate minerals have been forming in the interdune areas throughout the Quaternary in shallow ephemeral lakes (von der Borch and Lock, 1979). The typical sequence passes from a basal marine or lagoonal unit, through a protodolomite and magnesium-calcite lacustrine unit, to culminate in an uppermost dolomite or dolomite and magnesite unit which may be capped by a soil (von der Borch, 1976).

3.1.3 Topography

The Upper South East is composed of a series of ridges running parallel to the modern coastline. These ridges are stranded coastal dune systems formed during sea level fluctuations of the Pleistocene period. Topographic uplift of the region throughout the Quaternary has resulted in the preservation of the dune remnants. The ridges are no higher than forty metres and are situated upon a plain with an east to west gradient of 1:1600. There is a gentle topographic fall to the north west of generally less than 1:5000 (Bakers Range/Marcollat Watercourses Working Group, 1991). The innermost and oldest ridge is the East Naracoorte "Range" which has been dated at 700 000 years old (Cook *et al.*, 1977). The ridges progressively become younger westward towards the modern coastline and are approximately ten kilometres apart (Figure 2.2).

Between the ridges are extensive swampy plains or interdune corridors. These corridors were once similar to the Coorong but have developed into ephemeral lacustrine swamps. They comprise estuarine to lacustrine marls and clays which formed during their evolution from marine to lacustrine surface water channels (Schwebel, 1984).

3.1.4 Soils

Soils in the Upper South East display great variation. They are closely related to parent material, position in the landscape and drainage characteristics (Blackburn, 1983). On the dunes, soils are predominantly composed of calcareous sands. In the interdune areas humus podzols, rendzinas, solodized soils and terra rossa soils predominate. All these soils are dominated by their calcareous sand origin and are overlain by clay and organic material (Blackburn, 1983).

The characteristics of the interdune soils are dependent upon their position in the landscape, interaction with the groundwater table and the degree and frequency with which they experience surface water flooding (Foale and Smith, 1991). Quartz is the most common mineral in the Upper South East soils. Secondly, carbonate minerals which include calcite, dolomite and aragonite, predominate in the wetland areas. Clay sized particles constitute a variety of minerals including illite, chlorite and feldspar (Blackburn., 1983). The organic matter of the interdune soils is relatively low, varying from one to fifteen per cent in the majority of wetlands. The soils are alkaline recording a pH of nine or ten in all regions. The soils of the Upper South East are poor in nutrients and trace elements. Additives of super phosphate, cobalt and copper are required for agricultural use.

3.1.5 Vegetation

In the Upper South East of South Australia only fourteen per cent of the natural vegetation cover remains (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993). This vegetation is preserved in areas of Conservation Parks and in private ownership under Heritage Agreement[2] . The vegetation of the area is a reflection of the topography, soil type, salinity and water table level (Jensen *et al.*, 1983). Natural vegetation of the Upper South East is quite varied. The dryland habitats include heath vegetation, often with a mallee canopy, and at the other extreme there are permanent wetlands supporting aquatic vegetation (Jensen *et al.*, 1983).

On the ridges a dry sclerophyll forest predominates with a heath understorey primarily composed of *Eucalyptus baxteri* and *Xanthorrhoea australis*. On the low lying sands a heath vegetation dominated *by Hakea rostrata*, *Banksia marginata*, *Banksia ornata* and *Melaleuca gibbosa* dominate. Sedgeland with *Gahnia trifida* as the dominant species

[2] A Heritage Agreement is a voluntary agreement under the Native Vegetation Act to protect native vegetation on a property in perpetuity by covenant on the title (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993).

occurs on the water logged soils. *Leptospermum* spp. and *Melaleuca* spp. scrub is dominate around permanent swamps (Crocker, 1944; Jensen *et al.*, 1983; Foale and Smith, 1991).

The agricultural areas are used for grazing of both sheep and cattle. In some areas natural grasses remain but the understorey has mostly been invaded by introduced pasture species. These species include wheat grass, salt-marsh grass (*Puccinellia stricta*), strawberry clover (*Trifolium fragiferum*) or sea barley grass (*Hordeum marinum*), swamp couch (*Cynodon dactylon*) and Australian salt grass (*Distichlis distichiphylla*) on more saline areas. The vegetation of the study sites is described in section 3.3.

3.1.6 Hydrology

The defined boundaries of the Upper South East do not relate to the natural hydrological catchment area of the Murray drainage basin. The eastern boundary of the study area is arbitrary as it interacts with the Victorian portion of the Murray Basin where groundwater of the Upper South East originates. The surface water hydrology of the Upper South East interacts with the Lower South East of South Australia which is part of the Otway drainage basin. Thus the impacts of vegetation clearance and agriculture in Victoria and the Lower South East have ramifications on the hydrology of the Upper South East.

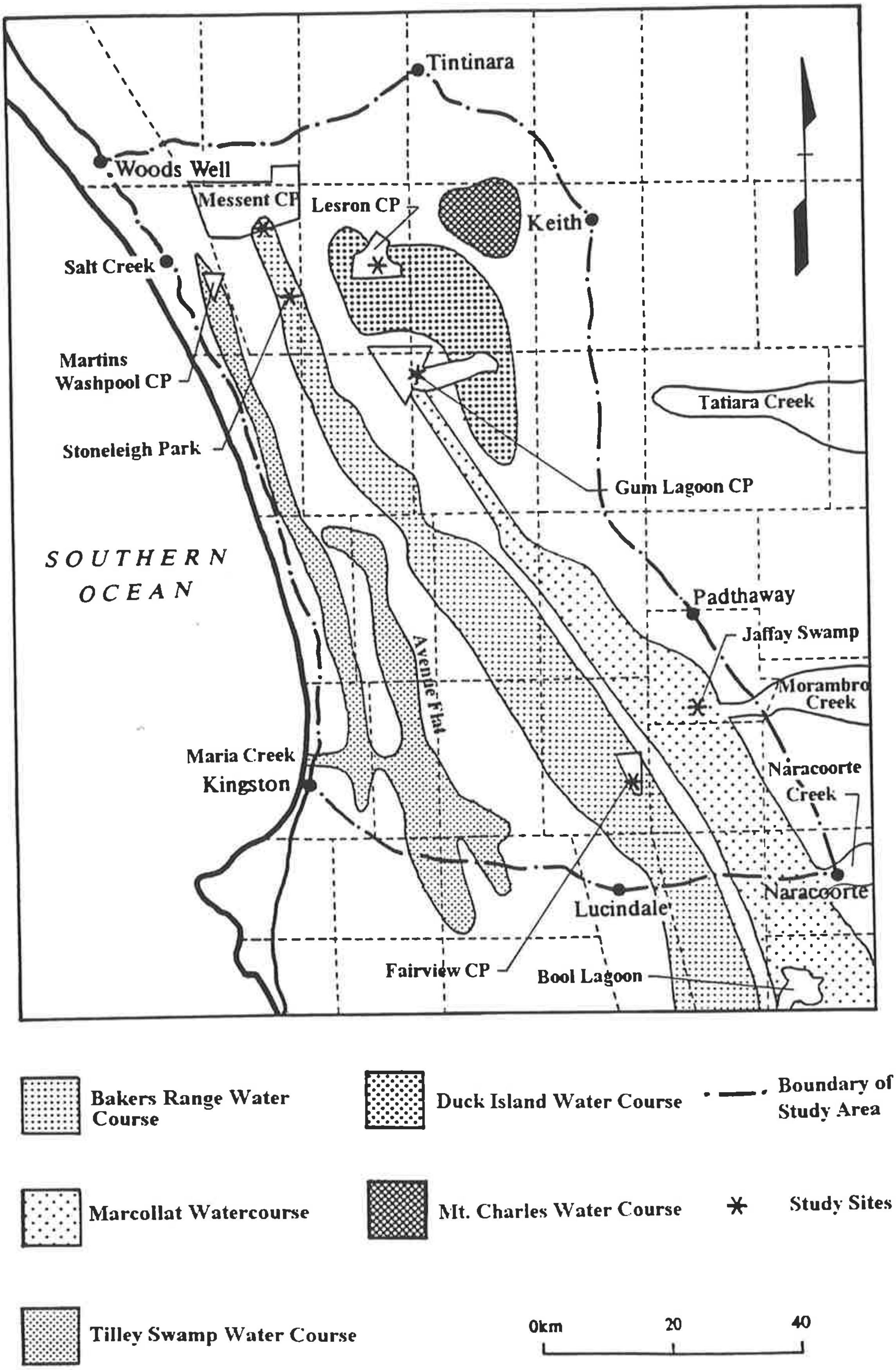
The groundwater resources of the Upper South East of South Australia are essentially contained within two major aquifer systems - an upper aquifer or water table aquifer, and a deeper confined aquifer (MacKenzie and Stadter, 1992). The groundwater of the unconfined aquifer is contained within the Gambier Limestone. The groundwater stores for this aquifer are recharged in western Victoria and regional groundwater movement is in a west, north-westerly direction (Bakers Range/Marcollat Watercourses Working Group, 1991). The unconfined aquifer is recharged from rainfall between May and September when rainfall exceeds evaporation (Figure 3.1). Water is discharged from this aquifer by either evaporative loss of groundwater in areas where the water table is within two metres of the surface or outflow to the sea or Coorong (McKenzie and Stadter, 1992).

Depth to the water table varies considerably throughout the region and is related to topographic elevation. The groundwater is shallowest in the interdune areas but varies both temporally and spatially. The general temporal trend in the Upper South East is for rising groundwater which has contributed to flooding and dryland salinisation (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993).

The Upper South East of South Australia often experiences an excess of surface water because it has a relatively high effective annual rainfall and a shallow but extensive groundwater system. Surface water drainage has been unable to develop along the east to west gradient because the dune systems hamper the path of water towards the sea. Surface water is instead diverted to the north-west along the interdune corridors. During winter, when an excess of surface water is experienced, surface water flows westward on each flat until it ponds against the dune range. Water then flows north-west along the topographic gradient forming large linear wetlands (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993).

There are five natural catchment areas in the Upper South East (Figure 3.4). The catchment closest to the Coorong is the Tilley Swamp catchment, which originates in the Lower South East, in Reedy Creek, and discharges to the Coorong through Salt Creek during periods of flood. The Bakers Range catchment originates in the Lower South East. When in flood, surface water moves northward towards Messent Conservation Park which is the terminal area for this watercourse. The Marcollat catchment is fed by the Naracoorte and Morambro Creeks in western Victoria. Surface water in this catchment usually moves northward through a chain of swamps until it merges with the Bakers Range watercourse

Figure 3.4: Hydrological Catchment Areas of the Upper South East of South Australia



Source: Adapted from Bakers Range/Marcollat Watercourses Working Group, 1991.

north of Jip Jip or continues northward to its terminal lagoon in Gum Lagoon Conservation Park. The Duck Island catchment is a very complex catchment area north of the previous three. A majority of its surface water is from local runoff but is also supplemented by an upwelling of groundwater (Foale and Smith, 1991). The Mount Charles catchment is also located to the north of the region and is a land locked area. It is bounded by the Black Range on the west and unnamed ranges on the east, north and south. Water originates from the Nalang and Tatiara Creeks in the east. There is no outlet for surface water in the Duck Island and Mount Charles catchments unless it is evaporated or seeps into the ground.

3.1.7 The Present Environmental Dilemmas

The combination of the above physical parameters has produced a remarkable environment in the Upper South East, especially the hydrology, due to its marine origin and inherent salinity problems. The shallow unconfined aquifer system and poor surface water drainage has enhanced the development of dryland salinisation following native vegetation clearance. In the last decade, dryland salinisation has manifested itself to the point where the agricultural productivity of the region is being seriously hampered. In addition the sustainability of the remaining natural wetlands is being threatened.

The increasing salinity in the region is a result of a number of interacting factors. Removal of native vegetation cover and its replacement with pasture species has caused increased groundwater recharge and a corresponding rise in water tables. Wet winters and flooding exacerbates the salinity problem. Prolonged inundation can destroy ground cover, especially pasture species. The salinisation process occurring through summer brings more salts to the surface and so further destroys the vegetation, which in turn results in more recharge and further raises groundwater levels (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993).

The problem of surface water flooding has not been solved by the widespread artificial drainage network, because the network is uncoordinated and the surface water has no ultimate outlet (this problem is discussed in section 5.2.4). Both agricultural productivity and the area available for agriculture is decreasing. Land degradation rates of four to twelve per cent per year in lost agricultural productivity are reported by the Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993).

Thus the environment of the Upper South East of South Australia is facing a large management dilemma. This problem has been addressed by the South Australian government who has recently conducted an Environmental Impact Assessment of the region. The Assessment aimed to provide management strategies to both preserve the agricultural productivity of the region and conserve the remaining natural areas.

3.2 The Environmental Impact Assessment

The South Australian Government has responded to the problems of dryland salinity and surface water flooding in the Upper South East of South Australia with an Environmental Impact Assessment of the region (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993). This report recommends large scale drainage, a wetland waterlink, on-farm measures and revegetation in order to manage the environmental problems of both agricultural and natural areas.

3.2.1 Legislative and public opinion background

Two legislative changes led the way for the current Environmental Impact Assessment (EIA). Firstly, a Cabinet directive was issued on the 14 April 1976, which prevented further drainage to be undertaken prior to the investigation of the environmental impacts of the Lower South East drainage schemes (South Australian Department for the Environment, 1980). Secondly, in 1983, the South Australian State Government endorsed the National Conservation Strategy. This strategy required projects conducted by Government Agencies, which had implications for the management of natural resources, to indicate prior to approval, their compatibility with the strategy. The result of these two pieces of legislation for the South East of South Australia was a number of environmental profile studies conducted to provide essential information that would assist environmental management and the assessment of development activities in the area (Morris, 1984).

The first study conducted under the 1976 directive was an Environmental Impact Statement (EIS) to determine the impact of drainage upon the environment of the Lower South East. The report found that the greatest impact of drainage was the subsequent clearance of large amounts of native vegetation to develop more area for agriculture. The recommendation of this report was that all future Government schemes should be subject to individual environmental impact statements and should have due regard to the importance of retaining natural vegetation and swamp habitat (South Eastern Drainage Board, 1980).

At the same time, public opinion in the South East shifted from a concern over insufficient surface water to maintain wetlands in the region which had been evident in the 1970s, to concern over excess quantities of surface water (Barkers Range/Marcollat Watercourses Working Group, 1991). Thus, in addition to the legislative changes, public concern over excess surface water brought pressure on the South Australian government to investigate environmental degradation in the Upper South East. The results of both the public pressure and legislative changes was the commission of a number of studies aimed to develop an understanding of groundwater and surface water processes in the Upper South East.

3.2.2 Previous Studies

Although some information was available on the wetlands of the Lower South East prior to the 1980s there was no recorded interest in the wetlands of the Upper South East. This changed in 1983 when Jensen *et al.* reported on the impact of drainage works on both groundwater levels and the Coorong. This report concluded that there were insufficient information upon which to base any recommendations, and that environmental monitoring programs should be initiated in the Upper South East to provide data on the ecology of the region (Jensen *et al.*, 1983).

In 1980 an inter-departmental South Eastern Wetlands Committee was formed. The purpose of the committee was to examine wetland habitat requirements for water fowl in the South East. The South Eastern Wetlands Committee (1984) prepared a detailed report on the wetlands of the South East including environmental profiles on major wetlands and their management recommendations. Focusing on the Upper South East wetlands they recommended the following four future objectives (South Eastern Wetlands Committee, 1984):

1. to assess and describe the environmental characteristics of the wetlands of the Bakers Range and Marcollat watercourses;
2. to rank the areas in terms of conservation significance;
3. to assess in general terms the water regimes of the wetlands and to predict those areas which could be significantly improved through water diversions; and,
4. to prepare management guide lines for the wetlands.

In 1988, studies on the Bakers Range and Marcollat watercourses were initiated by a company called Ecologic Associates, who were contracted by the South Eastern Wetlands Committee to collate information on the area. Three studies were published. The first study by Ecologic Associates (Atkins, 1988) which met the first objective, determined the environmental characteristics of the watercourses through field sampling and a literature review. Characteristics of hydrology, vegetation, flora and fauna were described for each wetland.

The second report (Atkins and Brendon, 1988) fulfilled the third objective of the South Eastern Wetlands Committee (1984) by investigating the feasibility of re-establishing natural surface water regimes in key wetland areas. The impact of diverting surface water to the Coorong was assessed and preliminary estimates of the range of flows that could be expected at a number of key locations was provided. The report emphasised that if the natural surface water flow patterns were to be restored in the Bakers Range/Marcollat watercourses, then an outlet would be required at the northern end of the system to prevent frequent flooding in Alf's Flat and Messent Conservation Park (Atkins and Brendon, 1988).

The third study (Atkins and Gray, 1988) fulfilled both the second and fourth objectives of the South Eastern Wetlands Committee. Firstly, the wetlands were ranked in terms of their conservation significance using the method of Lloyd and Balla (1986) and secondly, management guide lines were prepared for the wetlands. It was suggested that the management objectives should (Atkins and Gray, 1988):

1. minimise adverse impacts on pastoral activities from wetland management actions;
2. improve the conservation significance of wetlands by addressing major impacts;
3. reinstate or retain flooding regimes of appropriate size and frequency; and,
4. conserve the greatest possible diversity and abundance of wetland types with as much surrounding native vegetation as possible.

To fulfil these objectives, policy changes, innovative capital works and new maintenance procedures were required. Atkins and Gray (1988) summarised the actions required by the

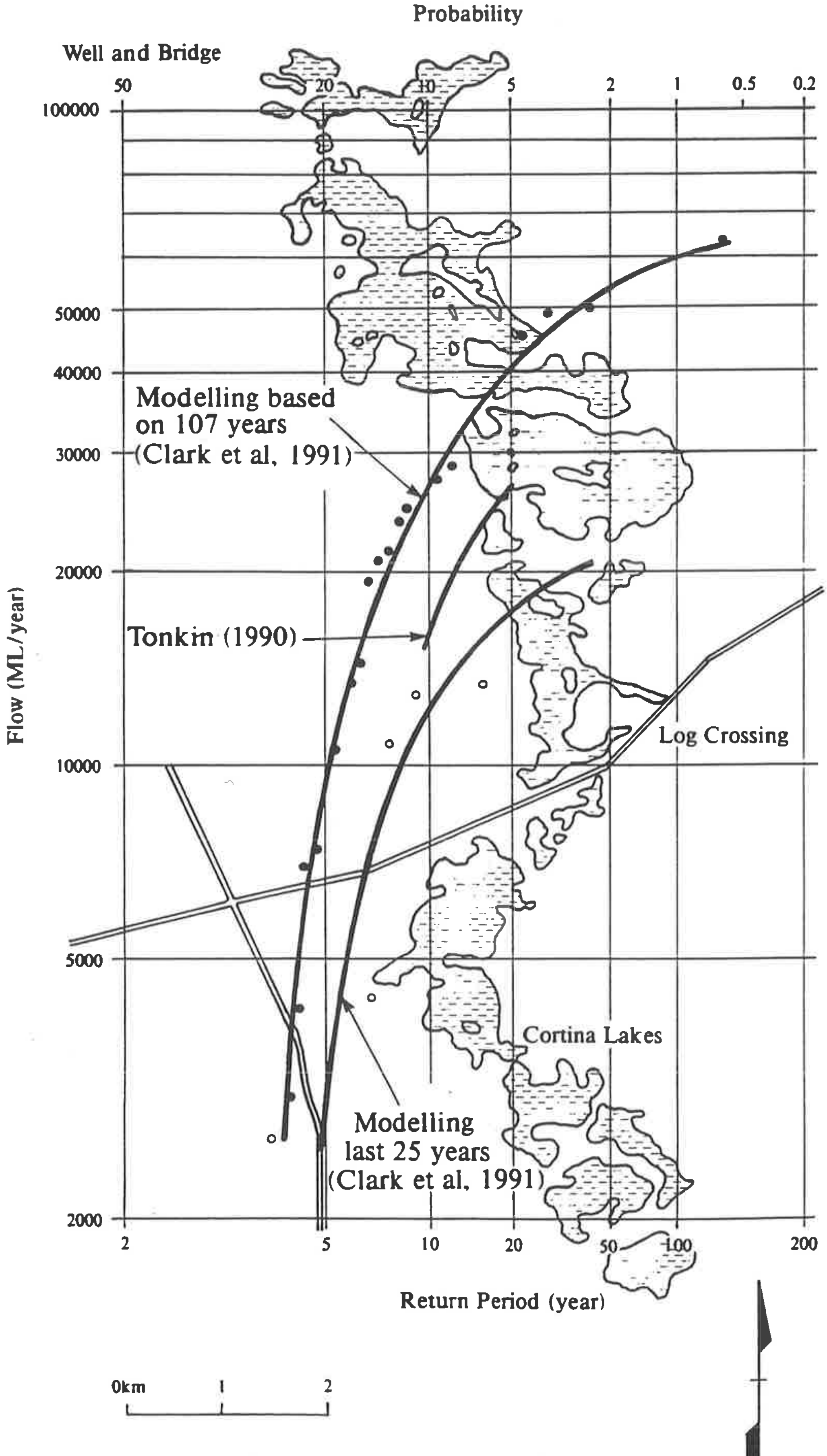
Department of Environment and Planning, the Engineering and Water Supply, the South Eastern Drainage Board and individual landholders for the implementation of the above management objectives. It is unclear in the literature whether any of their recommendations eventuated. It is likely that they were simply absorbed into the more recent EIA.

In 1990, Tonkin and Associates conducted a study on the Bakers Range/Marcollat watercourses that aimed to estimate the size and frequency of flows likely to arrive at their terminal depressions under the presently emerging post-clearance and post-drainage hydrological regimes. Based on twenty years of data Tonkin and Associates (1990) constructed a model that predicted a return period of ten to twenty years for flows of 20 000 ML/year. This model was based on measured stream flow records for the last seventeen years and although useful, required a great deal of generalisation to construct the model.

In 1991, Clark *et al.* published a similar model but included additional stream flow, rainfall and salinity data. The model was run on two sets of data to predict the return period of flood events: one based on 107 years of data and the other twenty five years of data. Analysis of the 107 years of historical data revealed that the past twenty five years had been drier than average with the exception of 1988, 1989 and 1990 (Clark *et al.*, 1991). The Tonkin and Associates (1990) results lay midway between the two estimates (Figure 3.5). It is anticipated that historical information in the form of palaeohydrological evidence of previous flood events will lead to a further improvement of the Clark *et al.* (1991) model.

Also in 1991, a report by the Bakers Range/Marcollat Watercourses Working Group was conducted for the Land Resource Management Standing Committee. This report provided

Figure 3.5: Flood Return Period Model Results



Source: Clark *et al.*, 1991 and Tonkin and Associates, 1990 an assessment of surface and groundwater processes operating in the Bakers Range and Marcollat watercourses and management options to address the problems of dryland salinity and flooding. The report recommended the construction of drainage systems in conjunction with revegetation and wetland management. The drainage scheme was strongly recommended because it was the only method that would immediately increase groundwater discharge and thereby reduce groundwater levels. The options of groundwater and surface water drains and their possible locations and outlets were outlined in the report along with approximate costing. The revegetation and wetland management strategies were briefly described.

In response to the Bakers Range/Marcollat Watercourses Working Group (1991) report, the South Australian Minister for Water Resources announced that the State Government would provide an assessment of the proposed management schemes in an EIA. The Upper South East Dryland Salinity and Flood Management Plan Steering Committee was formed to provide background information on the Upper South East in order to construct the EIA.

3.2.3 Background Reports

In 1991, there was insufficient information available on the Upper South East environment to construct an EIS. A large number of studies were initiated in 1992/93 in order to provide the required background information on the region's environment. These studies (twenty of them) all became known as "background reports" and were commissioned by the Upper South East Dryland Salinity and Flood Management Plan Steering Committee. The following is a review of the background papers pertaining to the surface water hydrology of the Upper South East.

In 1992 Clark and Kotwicki extended the Clark *et al.* (1991) surface water study in order to comply with the more rigorous requirements of the Upper South East Dryland Salinity and

Flood Management Plan Steering Committee. To do so they included a larger study area, more rainfall data, more recent flow records and additional data on the volumes of water stored in wetlands. This study focused on the past twenty years due to a wider coverage of rainfall data being available within this period which improved the estimation of spatial rainfall. Results showed that the model approximated past flows quite satisfactorily, and that the only discrepancy occurred in 1981. Clark and Kotwicki (1992) found that the estimates of Clark *et al.* (1991) needed to be increased, especially for infrequent return periods, to take account of the oversimplification due to the model assumptions. Thus they found that larger floods were likely to occur within similar return periods (Clark and Kotwicki, 1992).

Continuing the surface water theme, Eco Management Services (1992) examined the surface water quality in the Upper South East. They investigated the quality of water draining to wetland areas and collected surface water quality data at a number of sites over a two year period. Eco Management Services also assessed the efficiency of wetlands for removing metals and nutrients. The conclusions were that the wetlands were effective at intercepting drainage waters and removing pollutants. However, Eco Management Services (1992) stated that the quantity and quality of drainage waters that could be diverted with minimum effect upon the wetlands was uncertain, and required further investigation (Eco Management Services, 1992).

Also in 1992, MacKenzie and Stadter researched the impacts of various land management practices on the groundwater resources of the Upper South East. One objective of this study was to determine the impact of wetlands on water table levels. It was found that wetlands cause a local mound in water table levels by providing an additional source of recharge to the aquifer. MacKenzie and Stadter (1992) noted that although this effect did occur historically, the mound effect is now superimposed on a rising and generally higher water table elevation. They therefore suggested that the potential for increased land degradation in the vicinity of the wetlands was greater than elsewhere. However, they concluded that strategic placement of drains and appropriate wetland management practices should minimise adverse impacts from wetlands and afford protection to the wetlands in the longer term.

In 1993, Jensen attempted to assign values to the wetlands and natural resources in the Upper South East of South Australia for the benefit of the Steering Committee's use. Jensen (1993) found that although a range of dollar values could be calculated for native vegetation and wetlands, based on land sales figures, that these estimates were significantly under the true value of the natural resource, because they did not include additional values such as habitat value, tourism attraction, nutrient removal, biodiversity and gene pool maintenance. Jensen (1993) argued that these values of wetlands need to be taken into consideration in any cost/benefit analysis of management proposals to address dryland salinity and flooding problems in the region.

The last of the background reports investigating wetlands was conducted by Nicolson (1993a), who provided an assessment of the impacts associated with rising groundwater levels upon wetlands, conservation parks and areas of remnant native vegetation in the Upper South East. The objectives of this paper were to provide detailed, site specific, water management guidelines for all wetlands, conservation parks and areas of remnant native vegetation in the Upper South East and then to formulate protection strategies and assess the long term sustainability for conservation parks and remnant native vegetation under the influence of rising saline groundwater (Nicolson, 1993a). In order to achieve these objectives an inventory of each site was provided using information collected from previous studies, which was then used as an environmental baseline upon which to formulate management guidelines for each site. Nicolson (1993a) concluded that surface water management is the primary strategy that should be adopted in the Upper South East to ensure long term protection of wetland habitat and associated terrestrial vegetation. Nicolson constructed management suggestions for each wetland and suggests that specific hydrological management plans should be developed for each watercourse and catchment.

3.2.4 The Environmental Impact Assessment

The product of these and other background studies was the *Upper South East Dryland Salinity and Flood Management Plan: Draft Environmental Impact Statement - for public comment*. This report was prepared by the Upper South East Dryland Salinity and Flood Management Plan Steering Committee for the Natural Resources Council of South Australia (1993). The report was released for public comment on 20 September 1993. The primary objectives of this plan were to (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993, p. xvi):

1. reverse current trends of economic decline caused by salinity and flooding;
2. coordinate drainage and flood management;
3. protect native vegetation;
4. manage and reinstate wetlands and to provide habitat and drought refuge for waterbirds; and,
5. provide for community needs, in particular a sustainable agricultural base.

The EIS proposed the following four measures to fulfil the above objectives: firstly, a series of drainage options; secondly, a wetland waterlink scheme; thirdly, a revegetation strategy; and lastly improved on-farm measures. The suggested on-farm measures aimed to enable appropriate and sustainable agricultural productivity. Revegetation was proposed to help balance the excess surface water in the long term, and the wetland waterlink aimed to provide conservation and amenity value to the wetlands and ensure natural resource values were retained. However, drainage was the central theme to the proposal. It aimed to rid the region of excess surface water and lower the regional water table in the immediate future (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993). The details of the management strategies suggested are described in the next section.

After the draft was released, there was a period of time for public submissions. One hundred and eighty eight submissions were made expressing many and varied concerns over the draft management plans[3]. Many submissions were concerned with the placement of drainage lines, revegetation goals and achievement dates, the impact of the proposed diversion of water to the Coorong, funding of the project, and the direction of surface water flow in the wetlands waterlink concept (Upper South East Dryland Salinity and Flood Management Plan Supplement Working Group, 1994).

A supplement to the draft EIS responded to the public submissions in addition to updating and refining information that was provided in the draft EIS. This was conducted by the Upper South East Dryland Salinity and Flood Management Plan Supplement Working Group and was released in October 1994. Recommendations were made to further monitor flora and fauna, to construct management strategies for the wetlands, and to increase information programs to land holders on the proposed on farm measures. A revegetation target of twenty percent cover of native vegetation by the year 2005 was set and it was recommended that appropriate surveys of Aboriginal Heritage should be conducted prior to any further alteration of the landscape. The EIS Supplement recommended one of the

[3] A summary of the public submissions is contained within the EIS supplement pages 147-284 (Upper South East Dryland Salinity and Flood Management Plan Supplement Working Group, 1994).

twenty eight suggested drainage options as the preferred scheme. This scheme consisted of a major groundwater drainage scheme in the southern and central catchments of the region and a major surface water drain in the northern catchment. Drainage was to be constructed in combination with the wetland waterlink, on farm measures and revegetation. The approximate cost of this option was $36 million (Upper South East Dryland Salinity and Flood Management Plan Supplement Working Group, 1994).

In January 1995 an Assessment Report produced by the Environmental Impact Assessments Branch of the Department of Housing and Urban Development was completed. This report was the final component of the EIS and, together with the draft and supplement EIS, is the officially recognised Environmental Impact Statement (Environmental Impact Assessments Branch, 1995). The Assessment Report discussed the final recommended management options and discussed biological, social and funding issues of the Management Plan. It also warned that baseline information collection and monitoring is essential throughout all stages of the construction of such a scheme.

The three reports officially recognised as the EIS were then forwarded to the Minister for Housing, Urban Development and Local Government Relations. The Minister deemed the report adequate and officially recognised it. The document was then forwarded to the South Australian Cabinet for approval. On 20 June 1995, the South Australian Government pledged $800 000 to launch the program (*Advertiser*, July 1, 1995) and approved a phased scheme incorporating a groundwater trial area to a total of $24 million over six years, contingent on a twenty five per cent local funding contribution. The South Eastern Drainage Board recommended that the first construction work and incorporation of the groundwater trial begin in the southern area utilising the Blackford drain outlet early in 1996. This trial has begun but no detailed reports are as yet available on the scheme.

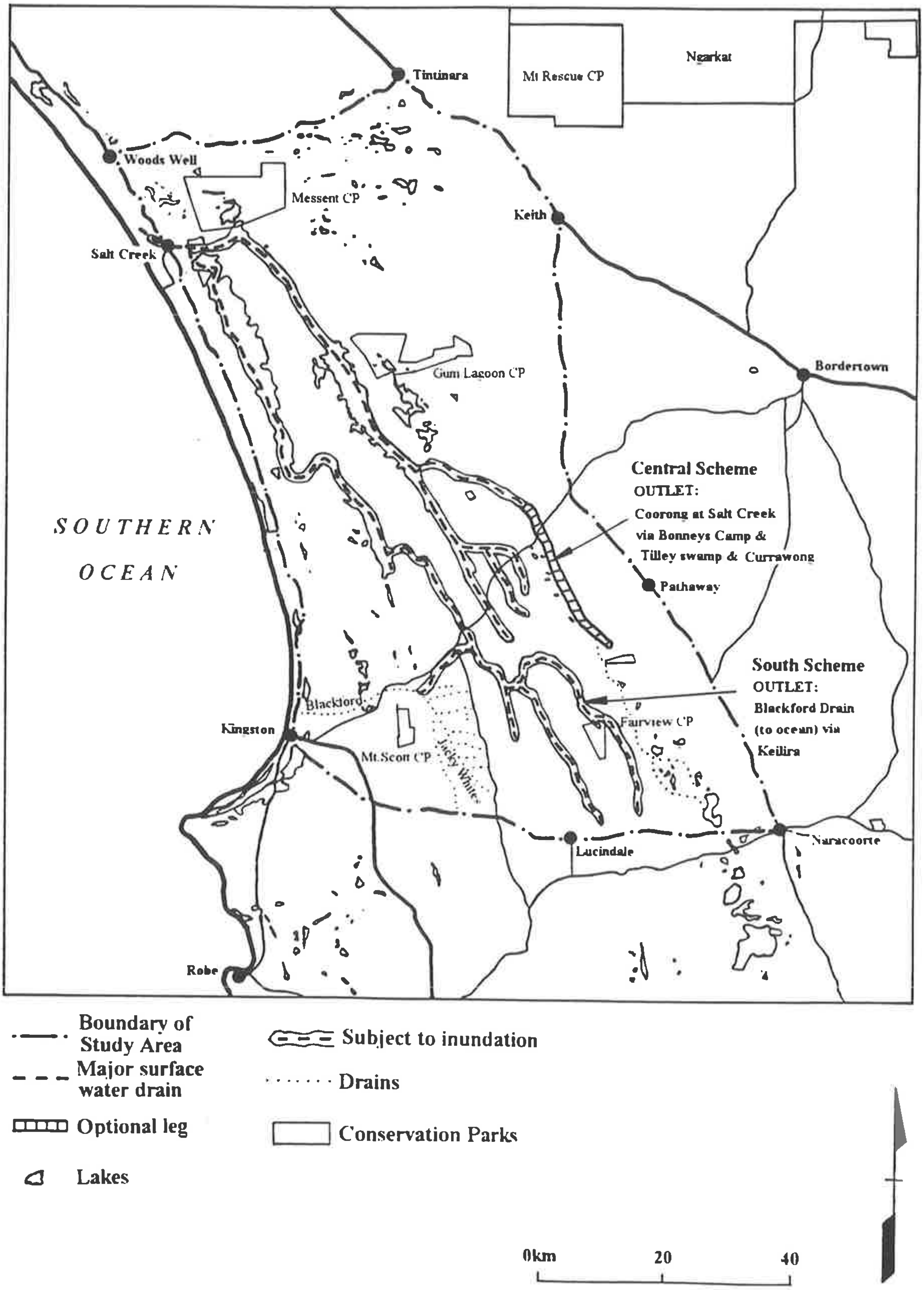
3.2.5 The Management Plan

As mentioned, the management plan consisted of four components, the first of which was the drainage network. The drainage option proposed a coordinated drainage scheme to ensure the alleviation of waterlogging whilst encouraging adequate surface water for the management of the wetlands. The proposed network incorporated major surface water and groundwater drains. Proposed groundwater drains were expected to be two metres deep and two metres wide at the origin and four metres deep and eight metres wide at the terminal ends. The surface water drains were expected to be one to two metres deep and ten metres wide, although their exact measurements were to be dependent upon the local substrate (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993).

The preferred drainage network recommended by the Environmental Impact Assessments Branch (1995) consisted of three separate drainage schemes. The first scheme was to drain groundwater in the southern catchment to Blackford Drain. The second scheme also drains groundwater from the central catchment to a new ocean outlet at Henry Creek. Figure 3.6 shows the southern and central drainage schemes. The third scheme aims to drain surface water in the northern catchment to the Coorong. The exact details for the northern scheme are yet to be determined. The three options for the northern surface water drain are shown in Figure 3.7 a, b and c. It is expected that a decision between the options will be made after preliminary results of the other management strategies are obtained (Environmental Impact Assessments Branch, 1995).

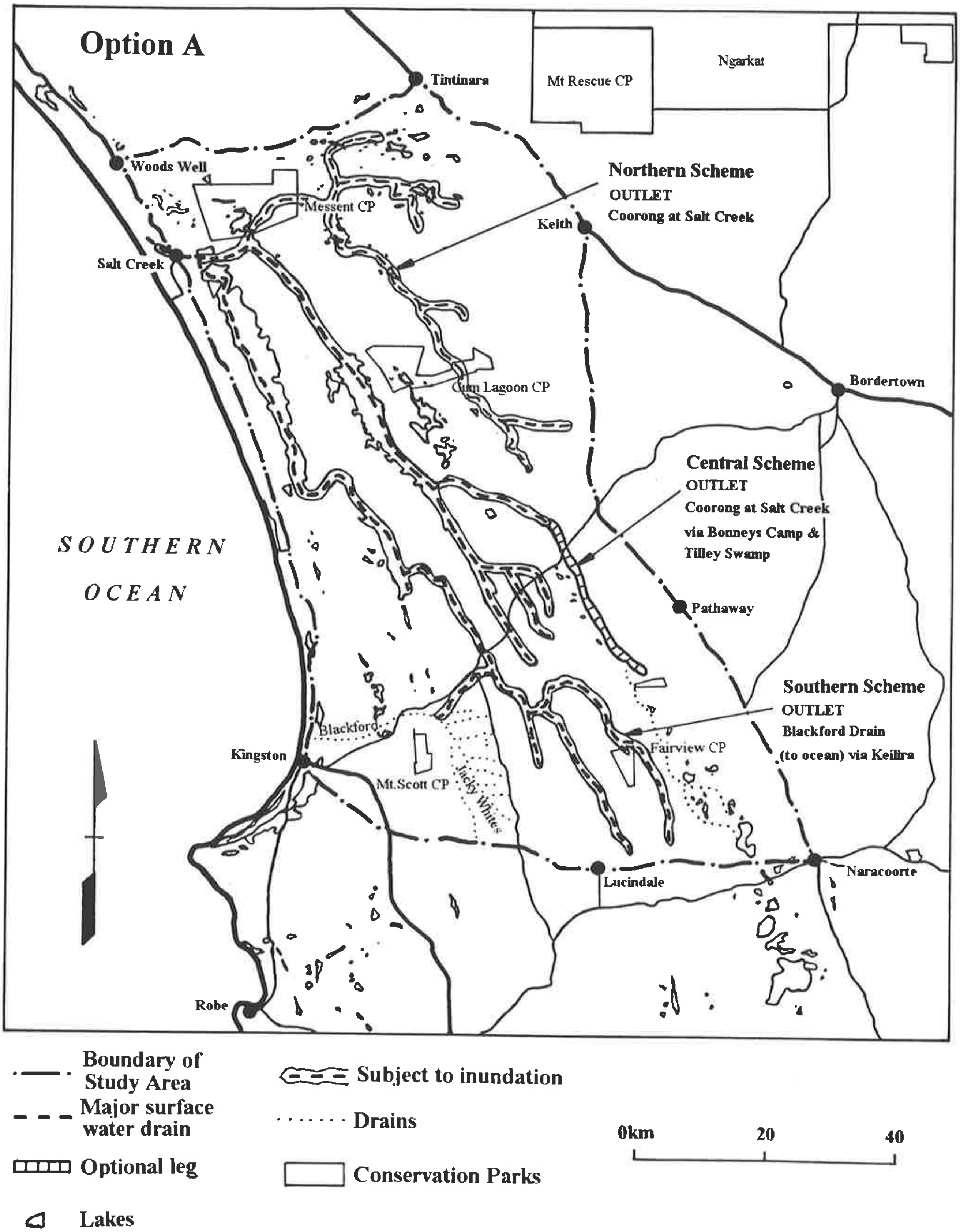
The second component of the management strategy was the wetland waterlink. The wetland waterlink is a conservation measure aimed at restoring some of the traditional wetlands in the Upper South East, and recognises the important role wetlands play in

Figure 3.6: Proposed Drainage Schemes in the Southern and Central areas of the Upper South East



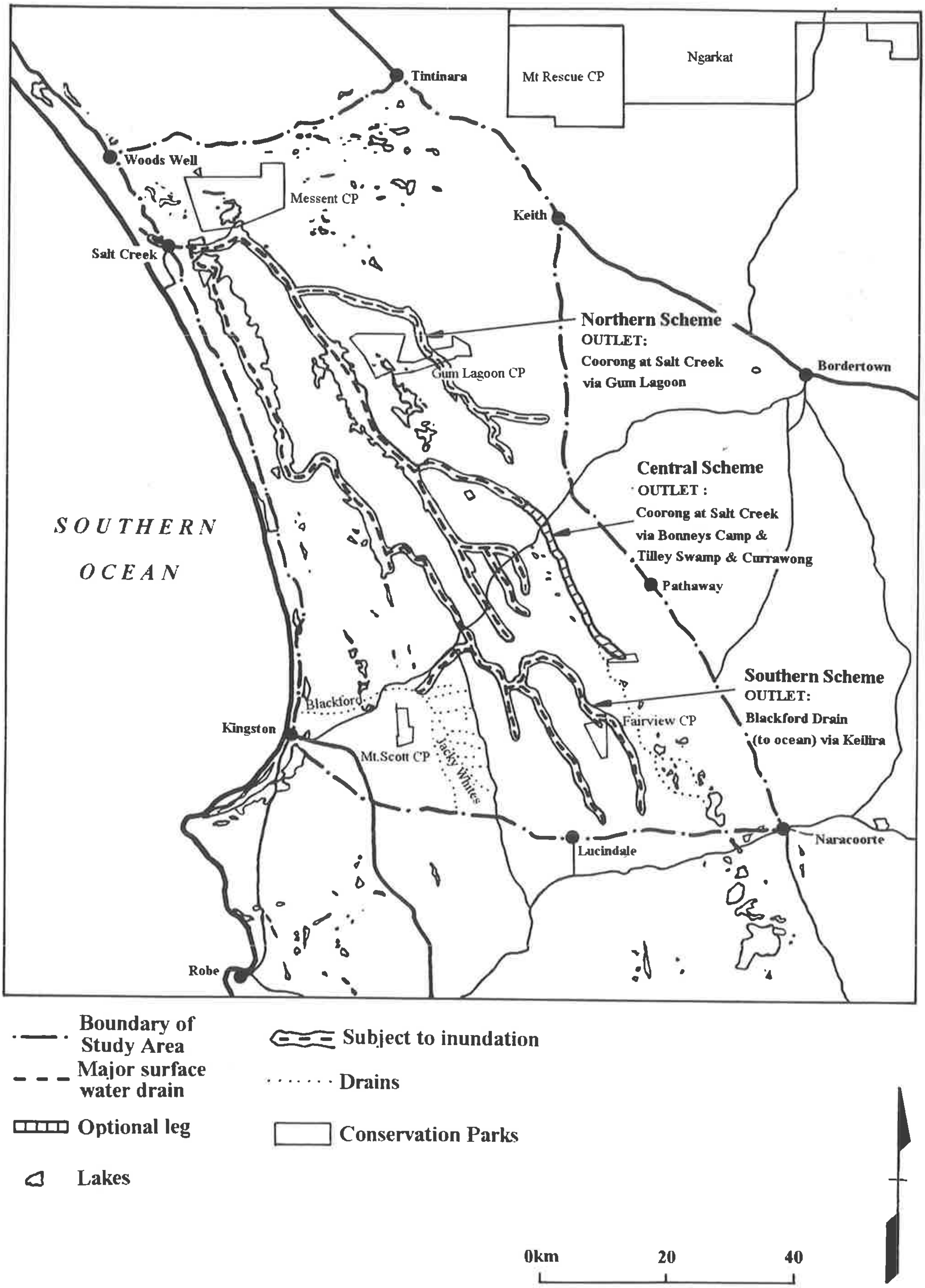
Source: Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993.

Figure 3.7: Options for Drainage in the Northern Area of the Upper South East

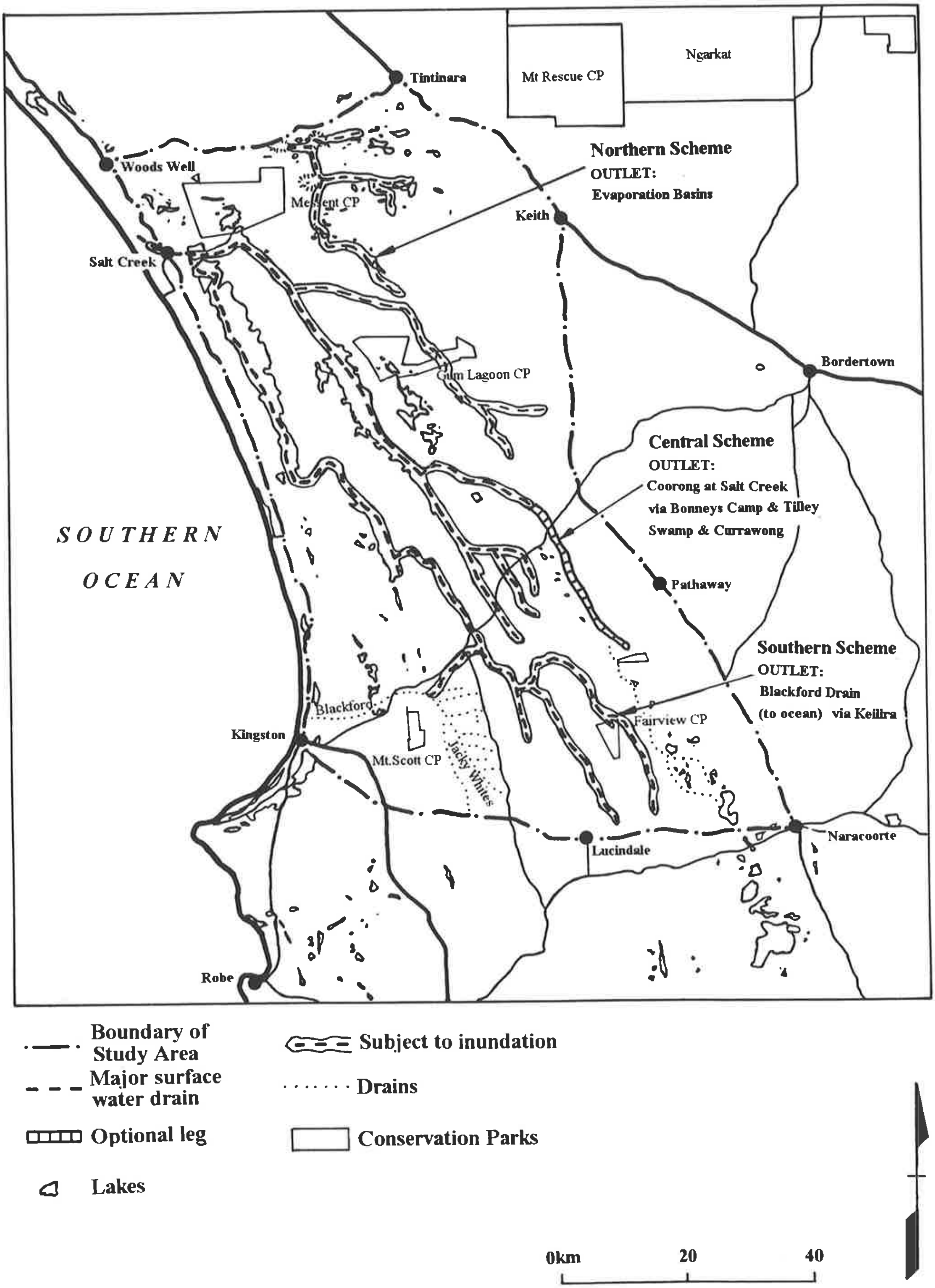


Source: Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993.

Option B


Tintinara
Mt Rescue CP
Ngarkat
Woods Well
Messent CP
Keith
Salt Creek
Northern Scheme
OUTLET:
Coorong at Salt Creek
via Gum Lagoon
Gum Lagoon CP
Bordertown
Central Scheme
OUTLET :
Coorong at Salt Creek
via Bonneys Camp &
Tilley Swamp & Currawong
SOUTHERN
OCEAN
Pathaway
Southern Scheme
OUTLET:
Blackford Drain
(to ocean) via Keilira
Blackford
Kingston
Fairview CP
Mt.Scott CP
Jacky Whites
Lucindale
Naracoorte
Robe
Boundary of
Study Area
Major surface
water drain
Optional leg
Lakes
Subject to inundation
Drains
Conservation Parks
0km
20
40

Option C

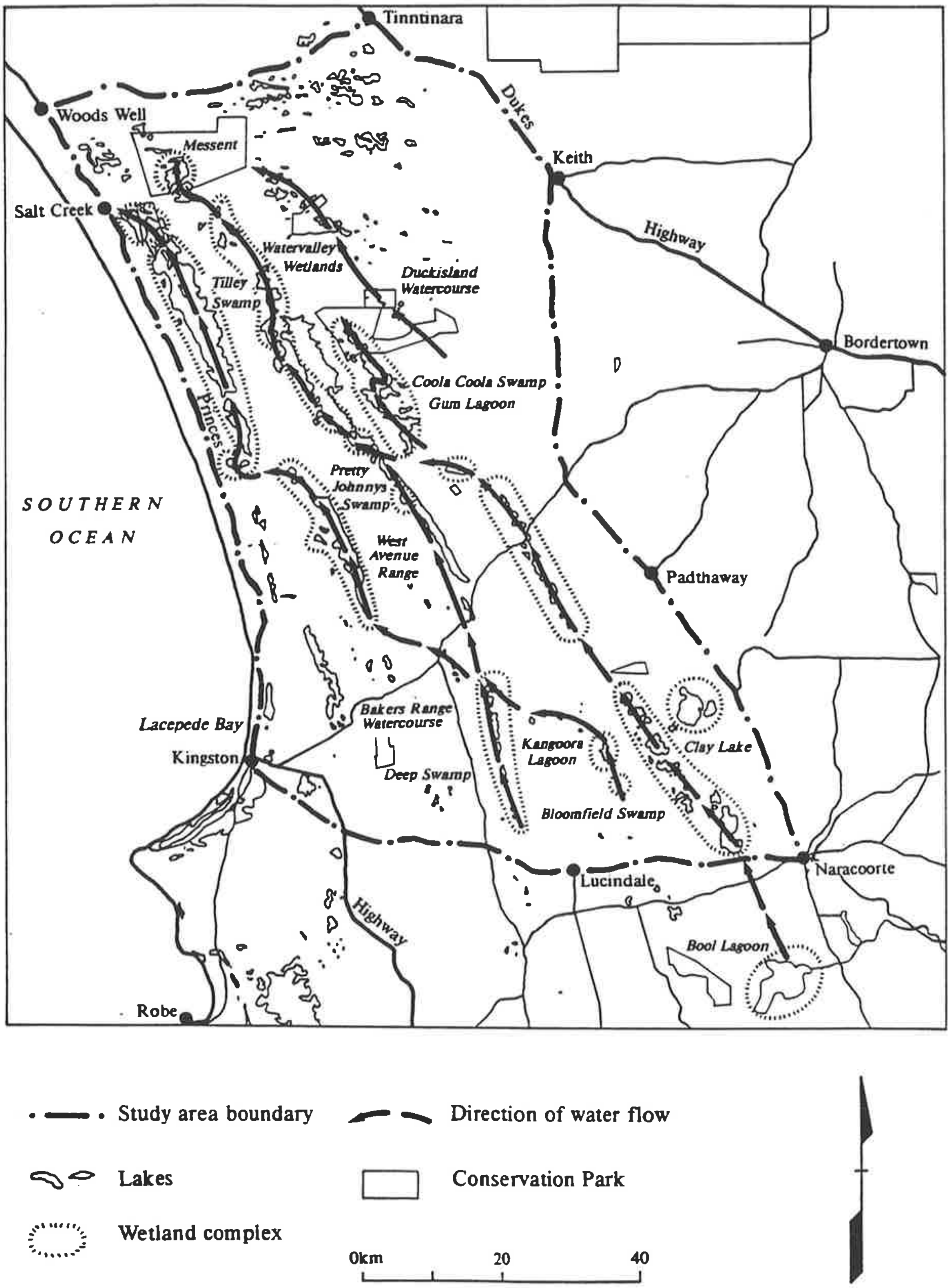


Tintinara
Mt Rescue CP
Ngarkat
Woods Well
Northern Scheme
OUTLET:
Evaporation Basins
Keith
Salt Creek
Gum Lagoon CP
Bordertown
Central Scheme
OUTLET:
Coorong at Salt Creek
via Bonneys Camp & Tilley
Swamp & Currawong
SOUTHERN
OCEAN
Pathaway
Southern Scheme
OUTLET:
Blackford Drain
(to ocean) via Keilira
Blackford
Fairview CP
Kingston
Mt.Scott CP
Jacky Whites
Naracoorte
Lucindale
Robe
Boundary of Study Area
Major surface water drain
Optional leg
Lakes
Subject to inundation
Drains
Conservation Parks
0km
20
40

maintaining and regulating an environmental balance (Upper South East Dryland Salinity and Flood Management Plan Supplement Working Group, 1994). The wetland waterlink addresses both the problem of excess surface water and the problem of declining wetland health. It incorporates revegetation as a means of regenerating wetlands in addition to drainage structures controlling the surface water flow in order to fulfil the water requirements of each wetland. The wetlands involved in the wetland waterlink stretch from Bool Lagoon near Naracoorte to the northern end of the Coorong (Figure 3.8). Surface water is to be fed into the wetlands via feeder channels (with small control structures) from either privately owned or a main surface water drain. Intersections between the surface water system and the groundwater drainage system would allow for management of water quality. The wetlands waterlink would require various regulating structures, drainage improvements and small associated works to be constructed. Management plans are to be developed for both individual wetlands as well as the wetlands waterlink itself (Upper South East Dryland Salinity and Flood Management Plan Supplement Working Group, 1994).

The third component of the management strategy, revegetation, is hoped to provide a long term solution to excess surface water and rising water tables. The revegetation target of the EIS is a minimum of fifty five per cent of perennial plant cover plus a minimum of twenty per cent native vegetation cover to be achieved by the year 2005. As native vegetation currently covers fourteen per cent of the Upper South East region an increase of six per cent is required to meet the goal. However, the fourteen per cent of existing native vegetation is included within areas of Conservation Parks and it is considered that a twenty per cent native vegetation cover outside of the National Parks and Wildlife reserve system

Figure 3. 8: The Wetland Waterlink



Source: Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993.

would be required to alleviate the adverse effects of salinisation on the region (Environmental Impact Assessments Branch, 1995).

Lastly, on farm measures are proposed as a long term solution to the problems of surface water flooding and dryland salinisation. The suggested on-farm measures include: pasture renovation with salt tolerant species; revegetation with native species on the less productive areas of farms; and perennial crops that will boost the farm income on the more productive areas of farms. The saltland agronomy is expected to be successful only if surface water drains prevent land being inundated longer than a two to four week period (Upper South East Dryland Salinity and Flood Management Plan Supplement Working Group, 1994).

The funding of the Management Plans is expected to be shared between the Commonwealth Government (37.5 %), the State Government (37.5 %) and the local community (25 %) (Environmental Impacts Assessment Branch, 1995). The capital work of the regional drainage schemes are estimated to be in the order of $25 million to $36 million. The drainage schemes are expected to be constructed over a five year period and would require funding from all levels of the government. The on-farm costs are estimated to be $18 million for the re-establishment of salt affected land with salt tolerant pastures and $7 million for lucerne re-establishment. This cost is expected to be covered by landholders alone. The Environmental Impact Assessments Branch (1995) recommended further economic assessment to detail costs and to better assess the affordability to land owners of the on-farm measures to ensure its effectiveness. The re-vegetation plan is expected to cost $13 million and this money is expected to come from landholders and community groups such as Landcare groups, Greening Australia, Save the Bush and the South East Revegetation Officer. The cost of the wetlands waterlink has not been assessed.

The costs of the associated drainage structures and regeneration of degraded wetlands have been estimated but funds required to pay for the management of the scheme have not been assessed. In addition to construction costs for the four main strategies, maintenance costs will be incurred. The Environmental Impact Assessments Branch (1995) estimated a cost of $1.4 million per annum could be expected to maintain the management strategies and that this cost would be incurred by the three levels of government.

The Environmental Impact Assessments Branch (1995) highlighted a number of areas that require further investigation and monitoring. There are many concerns over management conflicts between wetland and agricultural needs, the source of money for maintenance, and the social ramifications of the cost to the local community. Whilst this plan has been approved by the South Australian Government, much more work is required to ensure the successful implementation of the management schemes.

3.2.6 Conclusion

The Management Plan has been welcomed by land holders as a scheme to provide immediate relief from the effects of surface water flooding and dryland salinity. The planned drainage structures should reduce the water table immediately, and on farm measures should contribute as well. In the longer term the land holders recognise that re-vegetation and the wetlands waterlink in combination with suitable farming techniques will provide a sustainable future for their land (Environmental Impacts Assessment Branch, 1995).

However, while welcomed by farmers, the Management Plan has not been welcomed by conservationists for a number of reasons. One of the major concerns of the conservationists is that the surface water drain in the northern catchment may cut through the south eastern corner of Messent Conservation Park. This would pose problems for flora and fauna through the disturbance of the park. Also, the wetland waterlink leaves questions of ownership, management and access unanswered. The wetland waterlink does not follow the natural surface water flow path as constructed by Foale and Smith (1991). Conservationists have questioned whether a drainage network is necessary or whether on-farm measures and re-vegetation can control dryland salinity and surface water flooding on their own.

3.3 Field Study Sites

The EIS highlighted that little information of the hydrological history of the Upper South East wetlands is known, and that information of that nature was required to construct an effective and acceptable management strategy for the wetlands. Information is required on the previous hydrological history of the wetlands. This history is researched in this study by selecting certain sites and investigating their historical and palaeoecological records. This section describes the study site selection criteria and then the location and characteristics of the study sites selected for palaeoecological analysis.

3.3.1 Study Site Selection

A number of criteria were applied to the selection of field study sites in the Upper South East. Sites were selected within a variety of watercourses to provide a regional overview of environmental change in the Upper South East. In addition, sites were selected at a variety of locations along the length of the watercourses to illustrate latitudinal changes of surface water hydrology that may be occurring. Of necessity sites had to be within the interdune corridors, in areas of surface water flow or surface water storage, and within areas of native vegetation, because agricultural activities have disturbed recent sediment deposition. In addition, sites could not contain deep water as available coring equipment was limited to shallow lake bodies. Sites fulfilling the above criteria were examined during field reconnaissance and preliminary field sampling. Study sites were finally selected within three of the major watercourses: Bakers Range watercourse, Marcollat watercourse and Duck Island watercourse. Sites vary in location from the southern end of the Upper South East to the terminal wetlands in the north. Suitable sites could not be located in the Tilley Swamp and Mount Charles watercourses due to the lack of suitable palaeoenvironmental sites. Figure 3.9 shows the location of sample sites finally selected. At the time of sampling (June 1995) the water level of most sites was very low or dry as the 1994 winter rainfall had been less than average.

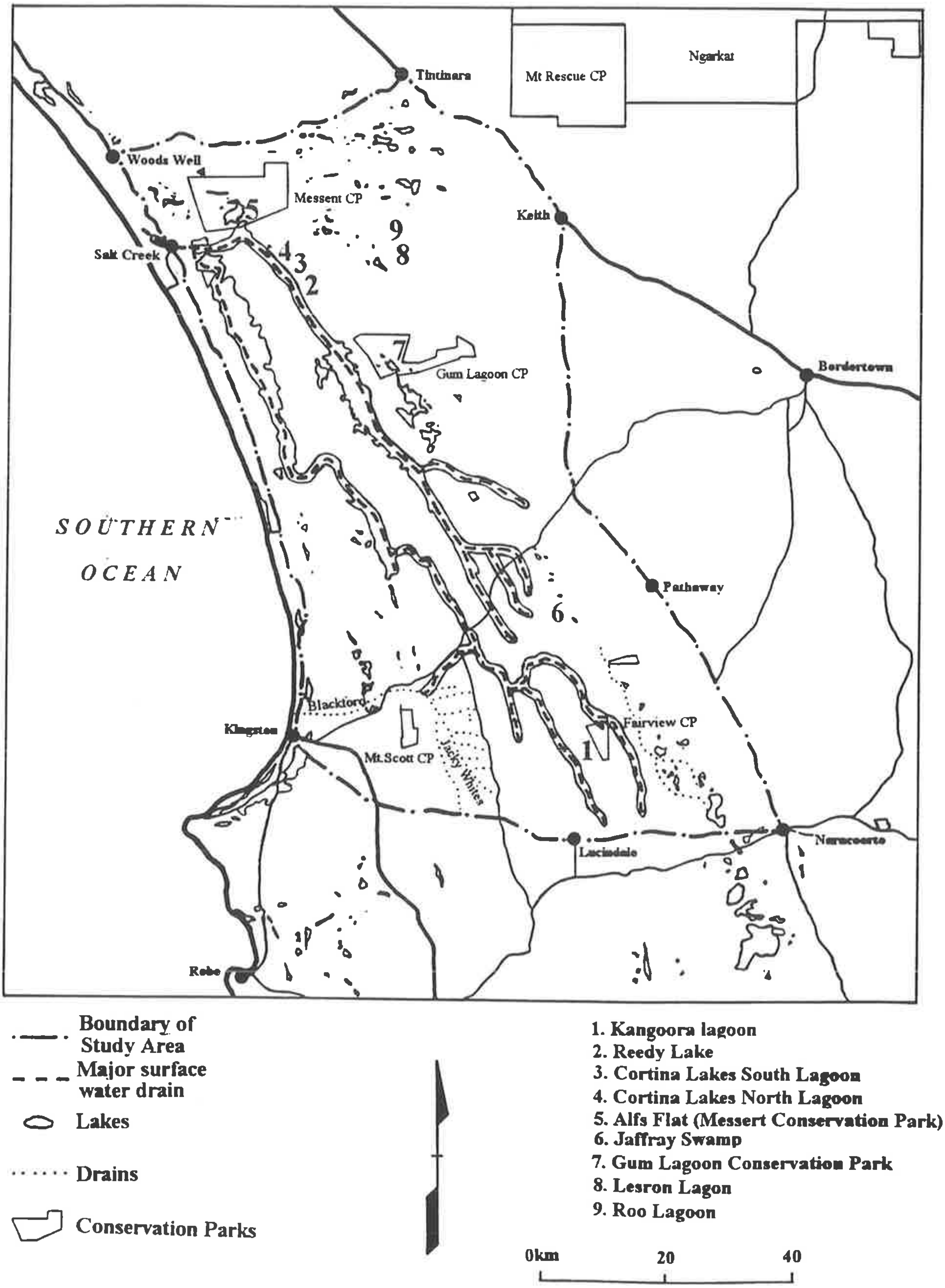
3.3.2 Sites within the Bakers Range Watercourse

The Bakers Range watercourse is the second most westerly interdune corridor in the Upper South East. It receives surface water from the Lower South East from the interdune corridor of the same name, in addition to local runoff. The watercourse flows in a north westerly direction, over two hundred kilometres, along the Bakers, Ardune and East Avenue interdune corridors through numerous swamps and waterholes (Atkins and Gray, 1988). Naturally, surface water moved northward infilling swamps along a circuitous route, often with sandbars interrupting its flow. The movement of surface water is presently controlled by a combination of government and private drains, and areas inundated by flood water are minimal. Wetland areas are well preserved within this watercourse which contains a large amount of remnant native vegetation. The hydrology of the Bakers Range watercourse is well documented by Atkins (1988), Atkins and Brendan (1988) and Bakers Range/Marcollat Watercourses Working Group (1991).

3.3.2.1 Kangoora Lagoon

Kangoora Lagoon is in the southern portion of the Bakers Range watercourse, within an area of native vegetation known as the Fairview Conservation Park. Kangoora Lagoon is

Figure 3.9: Field Study Sites of the Upper South East of South Australia



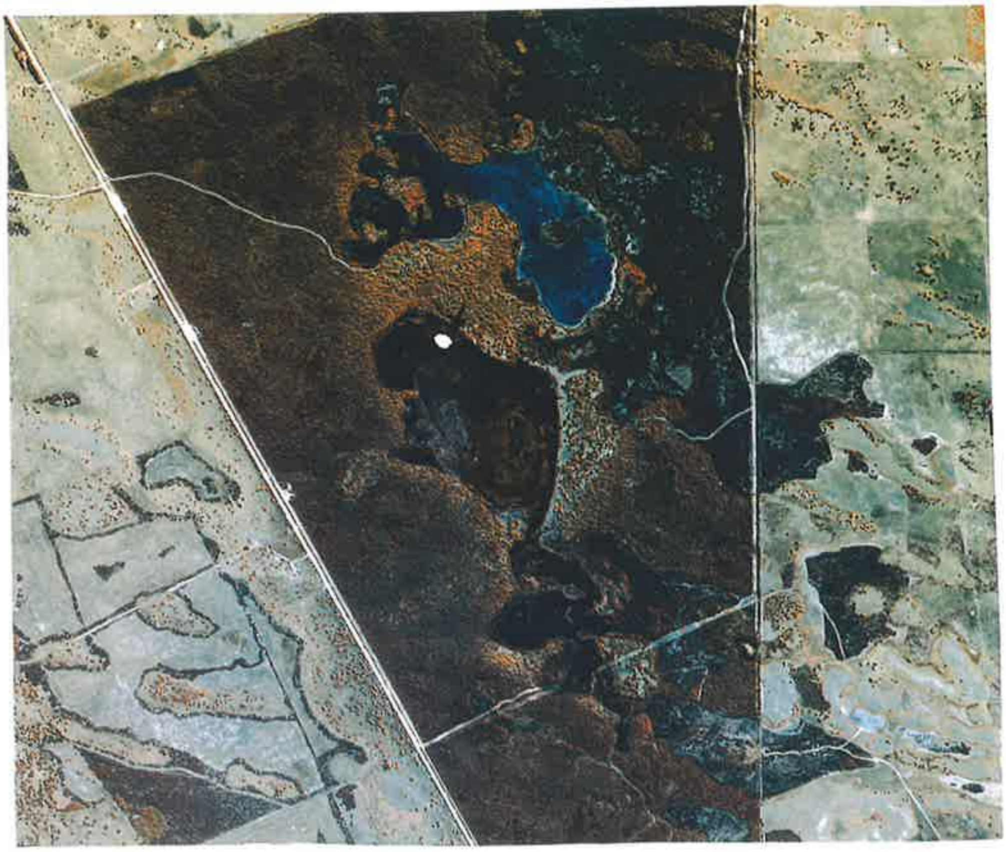
the most southern and largest of two lakes within the Conservation Park (Plate 3.1). In normal years Kangoora Lagoon receives local runoff from areas within Fairview Conservation Park, but in wet years local runoff is supplemented by surface water from Stewarts Range via Bloomfield Swamp south of Kangoora Lagoon (South Eastern Wetlands Committee, 1984). Surface water flows into the park have increased significantly since 1986 due to rising groundwater in the vicinity of Bloomfield Swamp, thus reducing surface water seepage (Nicolson, 1993a).

Kangoora Lagoon is very large and shallow. It contains approximately fifty hectares of permanent swamp and 250 hectares of semi permanent swamp. the water was only twenty centimetres deep at the time of sampling (10/6/95) (Plate 3.2). Waterbirds are known to breed in the lagoon and feed there extensively. The vegetation at the edges of the lagoon above the sandy beaches is composed of *Melaleuca* sp. and sedges. Open heath and tussock grassland cover the seasonally inundated flats, and low open woodland of *Eucalyptus leucoxylon* (blue gum) occupies the sandy limestone ridges surrounding the lagoon.

3.3.2.2 Cortina Lakes

Three sites were selected within the wetland region known as Cortina Lakes (Plate 3.3). The entire area (350 hectares) consists of native vegetation which is preserved under a Heritage Agreement between the landholder (Mr. T. Brinkworth) and the South Australian government. Cortina Lakes receives water via the Bakers Range watercourse after its confluence with the Marcollat watercourse. Under natural conditions the area was a semi-permanent wetland with deep basins retaining water for several years after inundation. However, it is now permanently inundated (Nicolson, 1993). Cortina Lakes is an important area for flora and fauna. Notable flora and fauna species were identified by Harper (1992).

Plate 3.1: Aerial Photograph of Fairview Conservation Park (Kangoora Lagoon)



North

1: 40 000

o Sampling Location

Plate 3. 2: Kangoora Lagoon

Photographer: Author.

Plate 3.3: Aerial Photograph of Cortina Lakes

North

1. Reedy Lake
2. Cortina Lakes South Lagoon
3. Cortina Lakes North Lagoon

(Refer to Plate 3.1 for key)

Plate 3.4 Reedy Lake

Photographer: Author

The first site within this complex is known as Reedy Lake* (Plate 3.4). Reedy Lake is located on the edge of the Bakers Range watercourse and is situated on a perched water table. It does not receive water from the Bakers Range watercourse, except in the most exceptional flood years, and input to this lake is predominantly from local runoff only. The lake covered half a hectare and was approximately two metres deep at the center at the time of sampling (11/6/95). Vegetation of the lake shows distinct concentric zones of vegetation. The outer zone is composed of Eucalyptus spp. with a heath understorey, which then gives way to various types of sedges: *Leptospermum juiperinum*, *Machaerina juncea* and *Gahnia filum*. The rooted aquatic plants which grow within the lake are: *Juncus procerus* and *Myriophyllum propinquum*. Only the deepest centre of the lake is free of vegetation.

The second site in Cortina Lakes is known as Cortina Lakes South Lagoon*. This lagoon is approximately five hundred metres north of Reedy Lake but is in the centre of the Bakers Range watercourse. It receives all its surface water flow from areas to the south. The lagoon is a huge expanse of shallow water with an extensive beach system, approximately fifty centimetres deep at the time of sampling (11/6/95) (Plate 3.5). Vegetation surrounding the lakes include *Melaleuca halmaturorum* and *Leptospermum* juiperinum. In many places along the lagoon beach, dead tea tree bushes that have been calcified after a long period of inundation remain.

The third site in this watercourse is called Cortina Lakes North Lagoon*. This lagoon is approximately one kilometre north of Cortina Lakes South Lagoon. It is also in the centre of the Bakers Range watercourse depression, and receives surface water from areas south of the same watercourse. This lagoon is located in the middle of a grassland dominated by

* Author's own terminology. Lake is unnamed in previous literature.

Gahnia trifida with isolated bushes of *Melaleuca neglecta* (Plate 3.6). The lagoon was very small and shallow at the time of sampling, with a diameter of twenty five metres and with water only twenty centimetres deep.

The hydrology of Cortina Lakes has been altered by drainage construction. In late 1983 drains were built in the Watervalley and Pretty Johnneys Swamp wetlands that channel water into Cortina Lakes from the south. In addition, drainage banks that have been constructed at the northern end of the wetland prevent surface water moving northward into Alf's Flat until Cortina Lakes is full. Hence Cortina Lakes is now a series of permanent lakes rather than a natural ephemeral wetland.

3.3.2.3 Messent Conservation Park

The terminal wetland of the Bakers Range watercourse is Alf's Flat, located within Messent Conservation Park (Plate 3.7). There is no further outlet for surface water from this point, so surface water will pool here in times of flood until it is either evaporated or infiltrated. Under natural conditions, a flood frequency of one in every fifteen to twenty years was experienced at Alf's Flat (Nicolson, 1993a), but the park was last inundated in 1963 and has not flooded since due to the construction of drainage lines diverting surface water to other parts of the watercourse in the southern reaches (Foale and Smith, 1991).

The vegetation of Alf's Flat is changing due to the long period of water deprivation (Plate 3.8). The centre of the depression is composed of sedgeland dominated by *Gahnia trifida* and *Baumea juncea*. *Banksia ornata* is invading the grassland area, and is advancing from the surrounding *Eucalyptus* spp. scrub located on the surrounding sand hills. The wetland area is currently dry and is an indistinct windy channel with many sand bars forming a barrier to surface water flow. Flora species found in the locality were identified by Taffs (1992).

Plate 3.5: Cortina Lakes South Lagoon

Photographer: Author.

Plate 3.6: Cortina Lakes North Lagoon

Photographer: Author.

Plate 3.7: Aerial Photograph of Alf's Flat

North

(Refer to Plate 3.1 for key).

Plate 3.8: Alf's Flat

Photographer: Author.

3.3.3 Sites within the Marcollat Watercourse

The Marcollat watercourse receives water originating in western Victoria flowing down the Naracoorte and Morambro Creeks. Surface water moves northward through the wetlands until it merges with Bakers Range watercourse at the Jip Jip wetlands, or continues north and terminates at wetlands within Gum Lagoon Conservation Park (Atkins and Brendan, 1988). This watercourse has been greatly modified by drainage activities, and many of the wetlands within it have subsequently been severely degraded. The Marcollat watercourse has been well studied by the Bakers Range/Marcollat Watercourse Working Group (1991), Atkins (1988) and Atkins and Brendan (1988).

3.3.3.1 Jaffray Swamp

Jaffray Swamp is contained within the Marcollat watercourse, and receives water directly from the Morambro Creek and from the Naracoorte Creek via Bool Lagoon. It is a large single lagoon but is connected to surrounding swamps by drains constructed by the local land owner in the early 1980s to form the Jaffray-Lever wetland complex (Plate 3.9). Regulating structures were built between 1987 and 1989 to retain water in the lagoon (Nicolson, 1993), and Jaffray Swamp is now a permanent lagoon. The area was recently purchased by the South Australian National Parks and Wildlife Service for its preservation.

The southern side of Jaffray Swamp is surrounded by a previously cleared area with scattered *Eucalyptus camaldulensis* (red gums) which are demonstrating good regeneration (South East Wetlands Committee, 1984). On the northern side, the vegetation is composed of *Leptospermum juniperinum* (tea tree) scrub. The lake water contains some *Triglochin sp.* (water ribbon). Jaffray Swamp occupies approximately five hectares and was sixty centimetres deep when sampled (10/6/96), which was well below average water levels

(10/6/96) (Plate 3.10). The species of flora and fauna located at Jaffray Swamp are listed in the South Eastern Wetlands Committee (1984).

3.3.3.2 Gum Lagoon Conservation Park

The terminal end of the Marcollat watercourse is the Coola Coola Swamp. The last three lagoons of this swamp are within the Gum Lagoon Conservation Park (Plate 3.11). Originally the lagoons within the Gum Lagoon Conservation Park filled during wet winters to a depth of 3.5 metres every 15 to 20 years and retained water for several years (Nicolson, 1993). Since the Didicoolum diversion was constructed at Jip Jip in the 1950s, which directed water from the Marcollat watercourse into Bakers Range watercourse, it now rarely fills. Even in exceptional years, the volume of flow under the present drainage system is insufficient to fill all these lagoons (South East Wetlands Committee, 1984). Only once in documented history has water exceeded the capacity of these terminal depressions: that was in the 1955/56 flood when surface water flowed through the centre of Gum Lagoon Conservation Park towards Gum Well (Foale and Smith, 1991).

The most northward depression in the surface water flow was selected as a sampling site (Plate 3.12). Within that depression the vegetation is composed of mossy grass species. *Eucalyptus camuldulensis* (red gum) dominates scrub surrounding the depressions on the sandy dunes. Within some of the basins, dead *Acacia brachybotrya* skeletons remain. These bushes died in 1955/56 which was the last long period of inundation.

3.3.4 Sites within the Duck Island Watercourse

The Duck Island watercourse is a landlocked catchment that has been severely degraded by the regional rise of the water table. Surface water flows to the area are increasing due to the rising groundwater table. Surface water in this catchment moves from the Duck Island property northward towards Naen Naen Swamp. This swamp is shaped like a horse shoe

Plate 3.9: Aerial Photograph of Jaffray Swamp

North

(Refer to Plate 3.1 for key).

Plate 3.10: Jaffray Swamp

Photographer: Author.

Plate 3.10: Aerial Photograph of Gum Lagoon Conservation Park

North
1: 40 000
● Sampling Location
(Refer to Plate 3.1 for key).

Plate 3.11: Terminal Depression of Marcollat Watercourse (Gum Lagoon Conservation Park)

Photographer: Author.

and surface water fills the deeper basins first before gradually infilling the swamp. When this swamp is full, surface water overflows the Keith-Cantara Road and moves towards the Lesron depression contained within Lesron Conservation Park (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1992).

3.3.4.1 Lesron Conservation Park

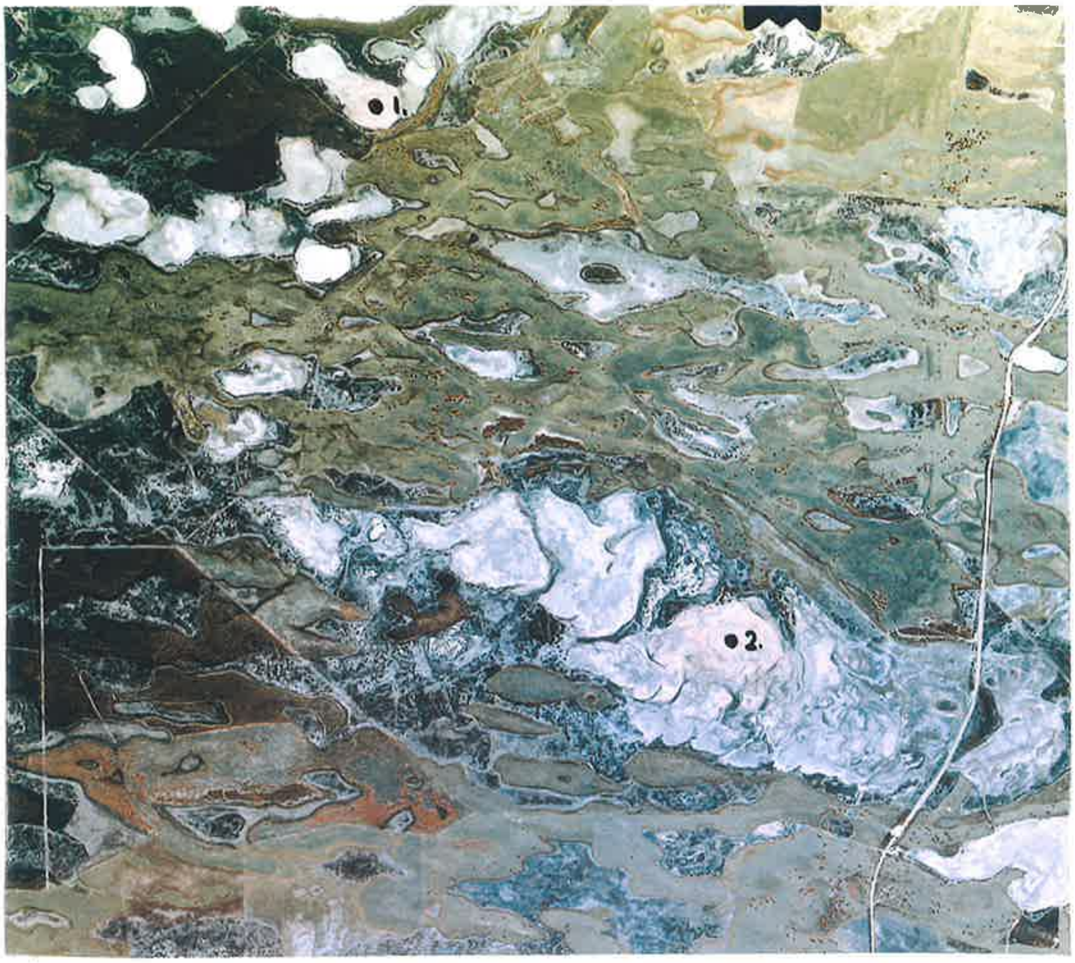
Both Lesron* and Roo Lagoons* are within the proposed Lesron Conservation Park. The area has been severely degraded by salinity and flooding. Even the dominant *Leptospermum* sp., which is resistant to saline soils and flood waters, is being degraded.

Plate 3.13 shows the location of the lagoons within Lesron Conservation Park. The Lesron Lagoon is a one of a series of lakes. It is surrounded by samphire that is inundated in periods of flood (Plate 3.14). Lesron is a very shallow but extensive lagoon. The level of water in the lagoon fluctuates widely on a seasonal basis and especially in times of flood. The lagoon is approximately 0.6 hectares in area and water was twenty centimetres deep when sampled (10/6/95). The lagoon would cover a very extensive area when in flood.

The Roo Lagoon is a distinct shallow lake that would only be linked to the surrounding lakes in times of flood (Plate 3.15). This lake was so saline that it appeared sterile. It is surrounded by *Leptospermum* spp. The lagoon was approximately twenty five hectares and twenty centimetres deep at the time of sampling (10/6/95).

* Author's own terminology. Lake is unnamed in previous literature.

Plate 3.12: Aerial Photograph of Lesron Conservation Park



1. Roo Lagoon
2. Lesron Lagoon

North
1: 40 000
● Sampling Location

(Refer to Plate 3.1 for key).

Plate 3.13: Lesron Lagoon

Photographer: Author.

Plate 3.14: Roo Lagoon

Photographer: Author.

4.0 METHODS

Two methodologies were utilised to reconstruct the environmental history of the Upper South East of South Australia (Figure 4.1). Firstly, the impact of human activities upon the Upper South East environment were investigated and reconstructed through the use of historical records. Secondly, the palaeoecological record of the Upper South East was investigated to examine environmental changes that occurred both prior to and during the periods of written documentation.

4.1 Historical Reconstruction

The aim of the historical reconstruction was to research all written and instrumental records available on the environment of the Upper South East of South Australia. Historical information enabled identification of the nature of environmental change that had occurred in the environment of the region during the period of human settlement.

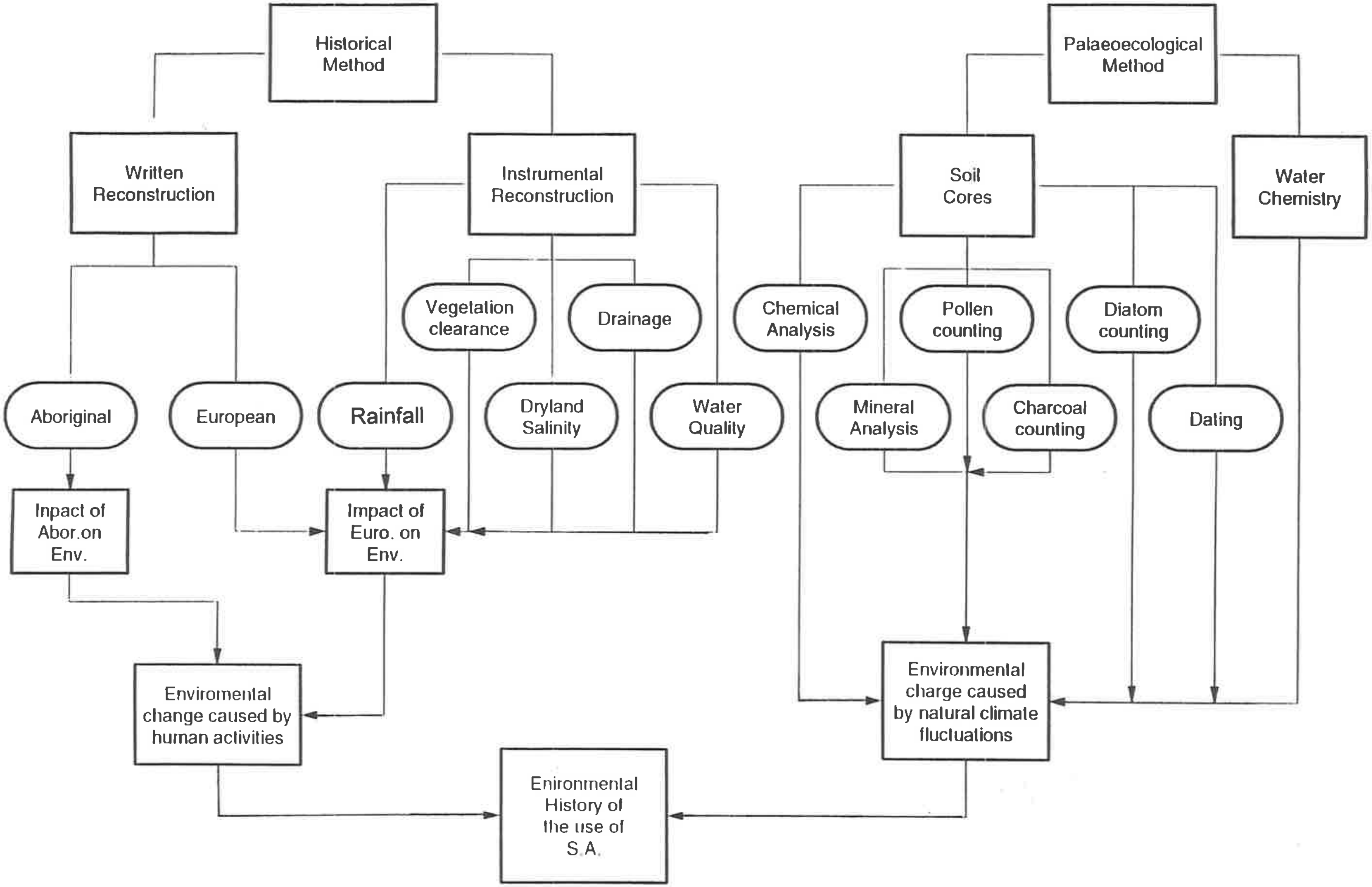
4.1.1 Written Records

The activities of both Aborigines and Europeans in the Upper South East were investigated. It was necessary to determine the impact of Aborigines on the hydrology of the Upper South East as a basis for fully understanding the nature of hydrological changes caused by European activities.

4.1.1.1 Aboriginal History

Aboriginal activities in the Upper South East environment were researched through a variety of reference material. Several early settlers to the South East took an interest in the Aborigines of the region and investigated their culture and history. They recorded their observations in diaries which were later published in entirety or in part in the journal of the Royal Geographical Society of South Australia. Useful information also came from

Figure 4.1: Method used to Ascertain the Environmental History of the Upper South East of South Australia



missionaries who ran Aboriginal missions in the region. However, their observations were biased as they tended to describe the 'civilisation' of the Aborigines rather than recording their natural lifestyle. Of greater use was information recorded by ethnographers, especially Tindale (1935, 1937, 1959, 1974, 1976). Another source of information on Aborigines of the Upper South East was archaeological studies such as those by Ross (1981) and Cann *et al.* (1991).

The problem with the above reference material is that the data post-dated the modification of the Aboriginal culture by European diseases, ideas and artefacts. For example, the Aboriginal population was decimated by the spread of small pox along the River Murray prior to physical contact with Europeans (May and Fullager, undated). Some reports may therefore be unreliable and cannot always be verified.

All sources of information were collated and described in chapter 5. Unfortunately, very little historical information was available for the Aboriginal groups of the Upper South East. Thus records of the impact of Aborigines from other parts of Australia were utilised to describe the likely impact of Aborigines upon the Upper South East of South Australia's environment.

4.1.1.2 European History

Information on European activities in the Upper South East was researched from explorer diaries, surveyor reports, newspapers and government reports. Government reports were obtained from either the relevant government department or the South Australian Parliamentary Papers. Information on activities of more recent years was collected from the annual reports of the South Eastern Drainage Board and independent published and unpublished research of the area. All sources of information were investigated and narrated in chapter 5 using two formats. Firstly, the exploration and agricultural development of the region are described. Secondly, a description of flooding, surface water movement and drainage activities are reported. In many cases information has been quoted from the reference material in order to present it in its original format.

The problems of utilising descriptive evidence were encountered in this section. Information obtained was rarely quantitative and varied spatially and temporally. Many events must have gone unreported due to the sparsity of settlers in the region. Events that were reported were described by people of different backgrounds, and often years after the event. The descriptive evidence provides a useful account of events occurring in the Upper South East but the accuracy of the timing and magnitude of these events must be viewed with caution.

4.1.2 Instrumental Records

Instrumental records were investigated to aid determination of the nature and direction of hydrological change occurring in the Upper South East. Most instrumental records, excepting the rainfall record, have only recently begun to be collected. Therefore, only recent hydrological changes could be ascertained.

4.1.2.1 Native Vegetation Clearance

The area of native vegetation cleared over the past fifty years in the Upper South East was examined from four sources of data. The rate of vegetation clearance was illustrated using maps showing areas cleared for selected years. All maps were reproduced at the same scale to allow for easier comparison.

The natural vegetation remaining in 1936 was mapped from the Melville and Martin (1936) survey. Melville and Martin did not mark cleared areas of land on their survey but only areas that had been sectioned and leased. It was presumed that these areas were either cleared in 1936 or soon after, meaning that an overestimation of cleared land was possible.

Young's (1976) study of vegetation clearance in South Australia was utilised to examine the land cleared in 1945, 1954, 1958, and 1967. Young mapped the area of native vegetation cleared from aerial photographs. Since Young's maps only encompassed the Tintinara region, the rate of clearance in the entire Upper South East remains unclear for this time period.

Mowling and Barritt (1980) produced a detailed map of the vegetation remaining in 1980. Their map encompassed the whole South East and was mapped from recent aerial photography. They also discriminated between areas of Conservation Parks and areas of native vegetation remaining on privately owned land, as well as cleared and uncleared areas.

The vegetation remaining in 1993 was mapped by the Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993). This map was constructed from Landsat TM imagery. It was reproduced to illustrate the amount of native vegetation remaining in the early 1990s. Comparison of the above sources of information provides an indication of the rate of vegetation clearance through the period of European settlement in the Upper South East.

4.1.2.2 Agricultural Development

The rate of agricultural development within the Upper South East was investigated through the use of data on production area and livestock populations obtained from the Australian Bureau of Statistics. The total area under production included area under wheat, barley, oat and triticale crops. Livestock numbers included cattle for meat and dairy produce, and all sheep (lambs, ewes and rams). Data were available for all Hundreds within the study region and were obtained at five yearly intervals within the period 1935 to 1995.

As agricultural activities initially focussed upon crop production and then changed to grazing activities, the production area and livestock numbers were combined to obtain an overall average of the area utilised for agricultural activities within each Hundred. In order to do so the total area under production was expressed as the percent area of each Hundred. Secondly, the livestock numbers were expressed as a percent of the maximum achieved for each Hundred. The two percentage values were combined to provide an indication of percent area developed for agricultural activities of each Hundred. Several Figures were constructed illustrating the percent area under agricultural use for each Hundred at five critical time periods.

4.1.2.3 Drainage Network

The timing and location of the construction of the South East drainage network was examined using historical maps. The drainage network in both the Lower South East and the Upper South East of South Australia were illustrated because drainage in the Lower South East greatly affected the hydrology of the Upper South East.

Information on the drainage network was obtained from two sources. The drainage lines constructed by the South Australian government were illustrated in Williams (1974) for the period prior to 1900, from 1900 to 1943 and from 1944 to 1970. These maps are reproduced. There is no data available on drainage lines constructed privately in the Upper South East until 1993. Two maps showing private drains of the Upper South East were compiled by the Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993). The first shows drainage lines constructed prior to 1981 and the second depicts private drains constructed between 1981 and 1993. These maps are integrated with those of Williams (1974) and illustrated. Comparison of all the maps allows the rate and direction of drainage network construction to be determined.

4.1.2.4 Rainfall Record

Rainfall data for the Upper South East was obtained from the South Australian Bureau of Meteorology. Data was available for a number of sites in the Upper South East and four locations were selected: Keith, Bordertown, Naracoorte and Lucindale. All records were over one hundred years long, except Keith which had a duration of ninety years. The annual rainfall total was graphed using Microsoft Excel for each location. The five year moving average was calculated for each record and overlayed the annual rainfall record.

The cumulative percentage deviation of the mean annual rainfall was calculated for Keith, Bordertown, Naracoorte and Lucindale. This analysis was conducted to illustrate the fluctuations in mean annual rainfall over decades. The Upper South East fluctuations were then compared with those found by Pittock (1975) for south eastern Australia.

To determine if a relationship between high precipitation years and flood events existed, the years of flood, as defined by the South Eastern Drainage Board (and prior to their existence the newspaper records) were overlayed upon the Lucindale rainfall record at various resolutions. Lucindale was selected as the most representative rainfall record of the Upper South East based upon its central location. Finally, the historical flood event record was compared with the Southern Oscillation Index (SOI) by overlaying the flood events upon the SOI (1940 to 1987) which had been constructed by Nicholls (1991).

4.1.2.5 Dryland Salinisation

Changes in salinity of both the soils and groundwater in the Upper South East were examined. Firstly, soil salinity was studied utilising data from two sources. The Melville and Martin (1936) field survey and Taylor's (1933) report were used in conjunction with the Environmental Impact Statement (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993) salinity map that utilised remotely sensed images and a supervised classification technique to categorise the severity of soil salinity.

The field sampling sites of this thesis were located within both the Melville and Martin (1936) and the Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993) study areas. The salinity classification of each site was noted. A table was constructed illustrating the salinity classification of each site and the change in salinity at each site was identified[4].

Recent changes in groundwater salinity were examined from bore well data provided by the Department of Mines and Energy. Bores located near each field study site were selected. The salinity of the groundwater was measured and plotted for each sampling date. Trends of salinity change were then identified for each field site.

4.1.2.6 Water Quality

The quality of surface water in the Upper South East was examined using data obtained by Eco Management Services (1992), who collected data on surface water nutrients, heavy metals and anions and cations for several sites along the Bakers Range watercourse over a two year period. The data was utilised to determine if seasonal changes in water quality existed and whether a gradient in water quality existed along a watercourse.

[4] A similar, more exhaustive, study is currently being conducted by Mr. M. Foale and Mr. D. Smith of the University of Adelaide Department of Geography. Results were unavailable at the time of printing.

Data at the Well & Bridge crossing over a period of two years was graphed to determine seasonal changes in water quality. The Well & Bridge site was selected for this purpose as this site had the most extensive and frequent sampling regime. Secondly, data collected on 21/7/92 (the most common sampling time) was mapped for a number of sites ranging from the south towards the north of Bakers Range watercourse to examine any existing gradients of water quality along the watercourse.

4.2 Palaeoecological Reconstruction

A variety of techniques were used to reconstruct the palaeoecological history of the Upper South East of South Australia. Techniques concentrated on sedimentological evidence because biological evidence was rarely preserved in the very alkaline (pH ~10) soils and because the water table fluctuates widely. A brief outline of the purpose and procedure of each method is given in this section.

4.2.1 Coring Procedure

Cores were obtained from Gum Lagoon Conservation Park and Messent Conservation Park in August 1994 using the piston corer drill rig of the Division of Soils, University of Adelaide. One core was obtained from Messent Conservation Park that was 260 cm in length. Several preliminary short cores were obtained from Gum Lagoon Conservation Park. Long cores were taken at Gum Lagoon Conservation Park in October 1994 using the piston corer of the Australian National University, Division of Archaeology and Natural History drill rig. Three cores were obtained: 350 cm, 360 cm and 140 cm deep. These wetland sites were dry at the time of sampling thus allowing for the utilisation of the piston corers. The remaining field sites contained water and therefore could not be sampled using the drill rigs.

Sites containing water (Kangoora Lagoon, Cortina Lakes, Jaffray Swamp and Lesron Conservation Park) were sampled using pvc piping which was hammered into the ground and extracted using winches in June 1995. Although compaction was more likely to occur using this method the lake sediments were very soft and the cores short in length (all less than one metre). Once sampled, all cores were sealed in plastic and clearly labelled. Cores were transported to the laboratory where they were further examined.

4.2.2 Logging Cores

The initial logging of the cores included classification of the material according to Northcote's (1965) system of soil classification. Northcote (1965) utilises texture, colour, structure, fabric and pH to classify soils. Colour was ascertained using the Munsell Soil Colour Chart. The pH was measured using a pH field testing kit. Texture, structure and fabric were ascertained using Northcote's procedure and classification system. This process was repeated for each soil horizon of each soil core.

The core was then sliced at one centimetre intervals. Any compaction that may have occurred was mathematically corrected at this stage by dividing the length of each section of the core by the depth of the core hole, measured after removal of each core section. This method assumes linear compaction. As the cores were composed of relatively homogeneous substrate within each section this was a reasonable assumption. Each slice was stored in an airtight vial or plastic bag.

4.2.3 Pinus Pollen Extraction

The occurrence of pine pollen in sediment cores has been widely associated with the timing of European settlement. The pine pollen in the Upper South East cores was extracted in order to determine the timing of European settlement to aid dating results. Pine was planted in South Australia in the late 1800s (Wegener, 1995). The occurrence of pine grains in sediment of the Upper South East of South Australia would therefore indicate sediment deposited during the past one hundred years or so.

The method of Ogden (1996) was followed to extract the pine pollen. One millilitre of sediment was placed in a 250 ml flask with 100 ml of 10 % potassium hydroxide and ten drops of saffranin stain. With a magnetic flea the flask was heated at 100 degrees for 15-30 minutes on a hot plate to disperse the sediment. The dispersed sediment was poured through a 65 μm sieve, before thoroughly washing the sieve contents and saving the remainder in the base. The sieve contents were inspected for pine grains and then discarded. The content of the base was then poured through a 35 μm sieve and the sieve contents washed. The contents of the sieve were retained and the base discarded.

To separate the pine from the silt fraction, the contents of the 35 μm sieve were poured down a 120 cm column of water. After seven and a half minutes a 10 ml sample was collected from the base of the column, which was inspected and then discarded. The remainder of the column was twice rinsed with distilled water, and poured through the 35 μm sieve again. Contents of the sieve were then collected in a 10 ml centrifuge (CF) tube, centrifuged and the top 9 ml of water was discarded. The remaining sample was pipetted onto a flat microscope slide and the pollen counted using a dissecting microscope at 160 times magnification with a hatched surface underlying the slide for guidance. The whole sample was counted.

In the samples analysed for pine pollen content, the grain size of the sediment particles was very small (principally clay and loam soil types) and, as the pine pollen grains are quite large, it was anticipated that downward movement of the pine grains would not be significant. Thus, contamination of the samples below the period of European occupation of the region was not expected. Blanks were run with each set of samples to check laboratory contamination rates. In all cases contamination was no more than two grains per sample and in most cases contamination did not occur.

4.2.4 Chemical Analysis

Chemical analysis of the samples was conducted to determine the bulk density, dry weight, loss on ignition and calcium carbonate content of each sample of the core. Bulk density varies with the water content, composition and compaction of the sediment. It can be an important indicator of change in the sedimentary environment and prevailing depth of water (Bengtsson and Enell, 1986). The dry weight reflects the water content, composition and compaction of the sediment. Vertical variation in water content can be due to a variation in the rate of sedimentation and a change in the nature of the sediment deposited (Bengtsson and Enell, 1986).

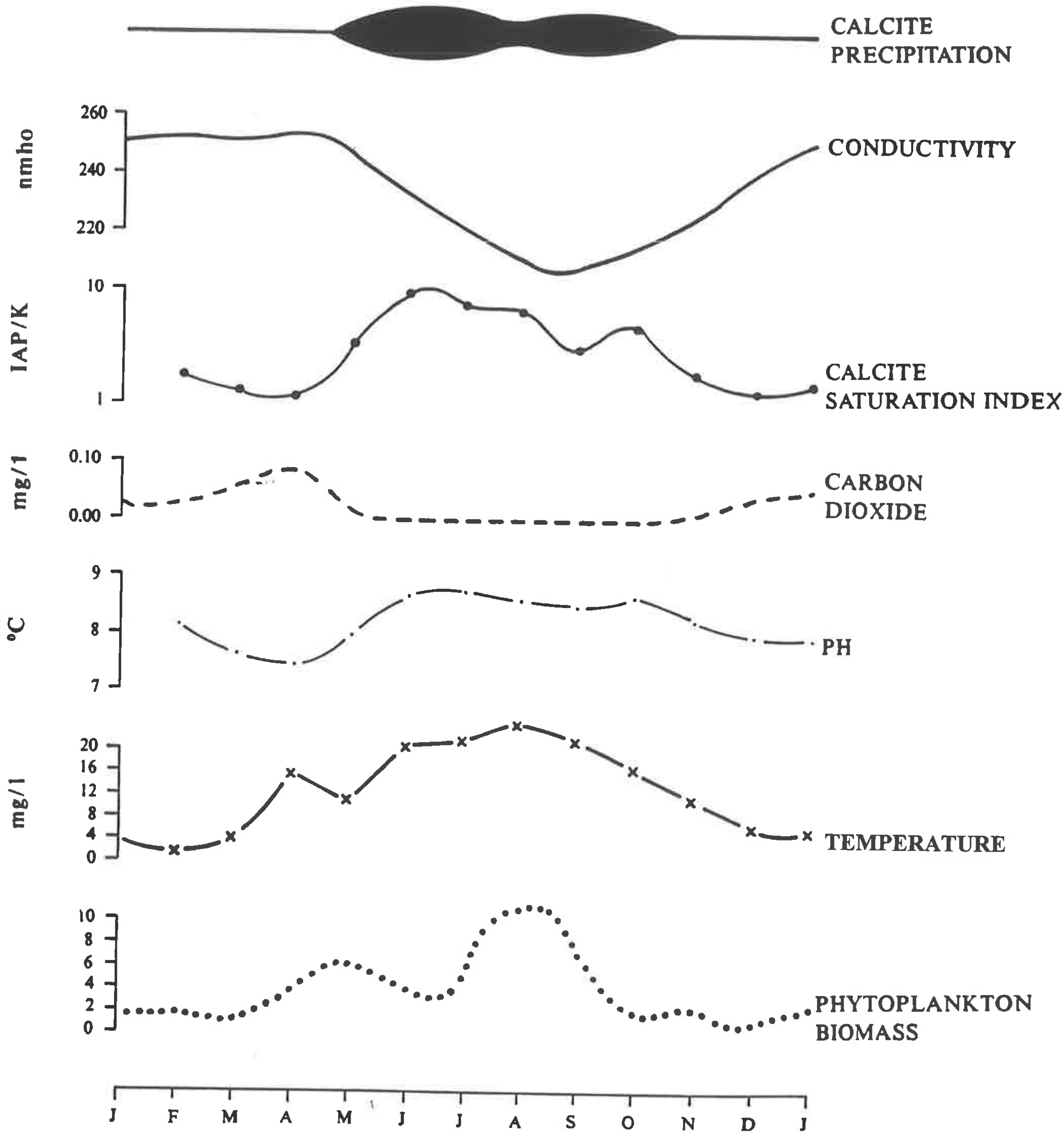
Loss on ignition was used to estimate the organic matter or organic carbon content of the sample. The organic content of a lake core increases in periods where the environment of the lake is conducive to high productivity (Mackereth: 1965, 1966). In the Upper South East the organic material was expected to primarily derive from autochthonous material, except in times of flood when material from downstream was washed into the wetland areas downstream.

The carbonate content of lake cores reflects changes which occur in the lake or depression. In general a high level of calcium carbonate is correlated with warm, ephemeral lake conditions (Wetzel, 1970; Kelts and Hsu, 1978; Engstrom and Swain, 1986). The precipitation of carbonate is reliant upon a high pH of lake water, a high water temperature (shallow lake depth), a large phytoplankton biomass and low conductivity (Dodson, 1974; Kelts and Hsu, 1878). The levels of carbonate are moderated in times of deep lake water (lowering the water temperature), high salinity, or when the calcite saturation of the lake water is low. Wetzel, (1970) and Engstrom and Swain (1986) also demonstrated that a sharp rise in the per cent carbonate content of a lake core may correspond with the cultural horizon (cultural eutrophication). Kelts and Hsu (1978) summarised the conditions conducive to carbonate precipitation, and these are demonstrated in Figure 4.2.

The relationship between organic production, carbonate precipitation and conductivity is complex, and of significance to the chemical composition of the Upper South East lakes. The organic content of the lakes is primarily derived from autochthonous production. Organic content of the cores is therefore expected to be highest when the lakes are full and non saline. Carbonate precipitation is greatest in shallow, warm waters of low conductivity and high pH. Carbonate precipitation is reduced when the water depth becomes too deep (reducing the lake water temperature) or the salinity becomes too high. There often exists conditions conducive to both high autochthonous organic production and carbonate precipitation, until the water depth becomes too great for the precipitation of carbonate minerals.

The procedure of Bengtsson and Enell (1986) was followed for the chemical analysis of duplicate samples. Three millilitres of fresh sample was transferred into a previously ignited and weighed crucible. The total weight of the crucible and fresh sediment was obtained and the sample was placed in a drying oven for a minimum of 12 hours at 105°C. The sample was then left to cool in a dessicator after which the weight of the crucible and dry material was obtained. The same sample was then ignited in a muffle furnace at 550°C for 2 hours. This process burns off organic material in the sample. After being cooled in a dessicator the weight of the ash and crucible was obtained. The same sample was then ignited in a muffle furnace a second time: this time at 925°C for 4 hours. This step burns off all carbonate contained in the sample. Once cooled, the weight of the ash and crucible

Figure 4.2: Environmental Conditions Conducive to Carbonate Production in lakes



Source: Adapted from Kelts and Hsu (1978) were obtained. The dry weight, bulk density, loss on ignition, and calcium carbonate content were then calculated according to the procedure of Bengtsson and Enell (1986) (see Table 4.1).

Table 4.1: Calculations for Chemical Analysis

Variable	Equation
Bulk Density	(B-A) / (cm^3 of fresh sample) gFW/cm^3
Dry Weight	(C-A) / (B-A) gDW/gFW
Loss on Ignition	(C-D) / (B-A) gLOI/gDW
Carbonate Content	(D-E) / (B-A) gCO3/gDW

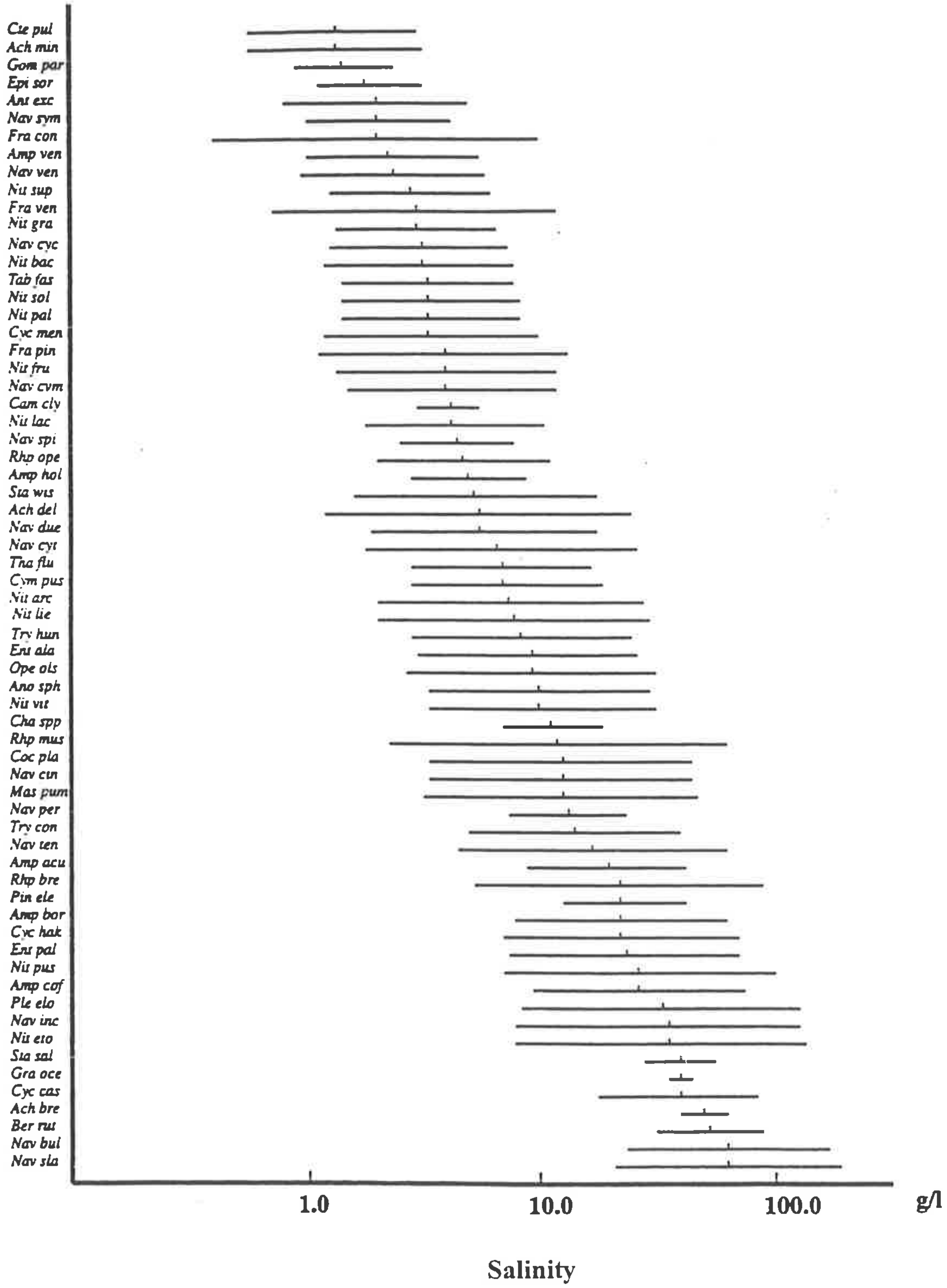
N.B. 'A' is the weight of the crucible, 'B' is the weight of fresh sample and crucible, 'C' is the weight of dry sample and crucible, 'D' is the weight of the ash remaining after being ignited at 550 °C for two hours and the crucible, and E' is the weight of the ash remaining after being ignited at 925 °C for four hours and crucible (Bengtsson and Enell, 1986). The above units were used on diagrams illustrating core chemical results (chapter 6).

4.2.5 Diatom Analysis

Diatoms are increasingly being utilised as indicators of environmental change because they are abundant in all aquatic environments and are highly sensitive to water quality changes. In particular, diatoms are very sensitive to changes in water chemistry and many taxa have well defined ecological optima and tolerances (Gasse *et al.*, 1987). Figure 4.3 illustrates the salinity tolerance levels of a number of diatom species. Preliminary processing indicated that diatoms were one of the very few biological indicators that were preserved in the Upper South East cores.

The procedure of Gell (1995) was followed to extract the diatoms from the sediment. All samples were processed using 10% hydrochloric acid to remove carbonate material, and then 10% hydrogen peroxide to oxidise organic matter. Samples were then well rinsed and mixed before application onto a coverslip (two coverslips for each sample) and allowed to

Figure 4.3: Diatom Salinity Optima and Tolerances



The above Figure shows the salinity tolerance of all diatoms found in lakes of western Victoria. Some diatoms found in the Upper South East are not included on this diagram. It does, however, illustrate that diatoms have limited ecological tolerances of salinity, and thus can be successfully utilised to reconstruct palaeoecological salinity levels.

Source: Gell (1995)

dry. Coverslips were then mounted onto slides, using Naphrax as a medium. Slides were examined using an Olympus BH / 2 microscope.

A minimum of 300 diatom valves or frustules were counted per slide. If less than 300 frustules were found under two cover slips the sample was discarded. In these cases dissolution must be occurring and would bias results towards the more robust specimens. The diatoms were identified from information and photographic plates in Krammer and Lange-Bertalot (1986, 1988, 1991a and 1991b), Czarnecki and Blinn (1977) and Foged (1978). Ordination analyses were then undertaken to determine if the measured environmental variables could detect the principal patterns of variation in the diatom assemblages. All ordinations were performed using the computer program CANOCO (version 3.12). Canonical correspondence analysis (CCA), a method of constrained ordination, was used to identify the environmental variables that could account for the variations in diatom taxa. CCA is based on correspondence analysis but constrains the relationships between the species and the samples by considering a further dimension, the environmental variables. It simultaneously represents diatom species, samples and environmental parameters in two dimensional space (Gasse *et al.*, 1987).

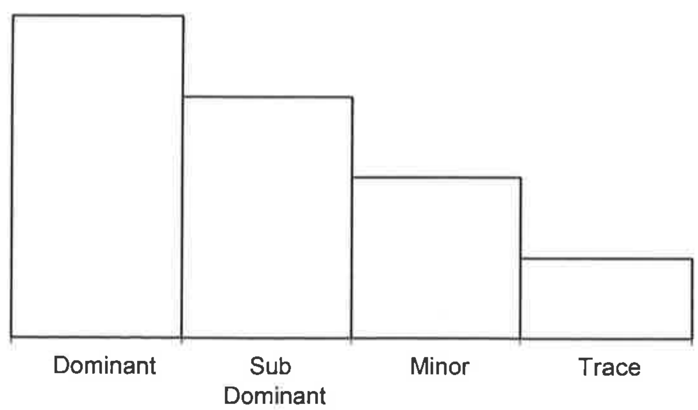
Only in three cores were diatoms sufficiently preserved to conduct diatom analysis. Diatoms were photographed during the identification procedure and are illustrated in Appendix 9.1.

4.2.6 Mineral Analysis

X-Ray diffraction (XRD) analysis was conducted to determine the mineralogy of sediments. Knowledge of the mineralogical composition of the sample aids determination of the evolution of the landscape. Mineralogical composition was determined using the facilities of the Department of Geology, University of Adelaide. The procedure of Hardy and Tucker (1988) was followed.

Samples were selected from each carbonate peak of each core. Samples were first ground using a mortar and pestle, then mixed with three drops of distilled water and combined into a paste. The paste was placed on a slide and allowed to dry. This slide was then placed through the spectrometer which utilises X-rays, produced by a bombardment of a metal anode by high energy electrons, to produce a beam directed at the sample. The sample diffracts the X-rays according to Bragg's law. The diffracted signal is amplified and then passed onto the electronic recording equipment (Hardy and Tucker, 1988). From the computer output semi-quantitative results were obtained and these were graphed for each core. Figure 4.4 illustrates the manner in which results were interpreted and represented in a graphical format. Mineralogical results were checked and examined in more detail as smear slides under a petrographic microscope to determine the likely origin of some of the carbonate minerals.

Figure 4.4: Representation of Mineralogical Results



4.2.7 Charcoal Counting

The relationship between charcoal and fire frequency has led to valuable insights into the dynamics of vegetation and human interaction with the environment (Clark, 1982). Charcoal was counted to aid determination of the chronology of the cores. It was expected that charcoal would increase in frequency during both dry periods and in the period of European settlement.

Clarke's (1982) point counting method was utilised. Using the slides processed for pollen counting (Appendix 9.2) one or more charcoal transects were counted. Charcoal was counted if it fell upon one of the cross hairs of the eye reticule for each field of view. A number of transects were counted for a 10 % relative error. The area of charcoal on each slide was then calculated after measuring the area of sample on the slide. The total area of charcoal per unit volume of sediment was the final estimate. A charcoal count was only obtained for Tea tree depression Core A of Gum Lagoon Conservation Park.

4.2.8 Dating

Fifteen samples were processed for Accelerated Mass Spectrometry (AMS) dates. Ten samples were from the Gum Lagoon Conservation Park central core, three samples were from the Jaffray Swamp core and the remaining two samples from the Cortina Lakes North Lagoon core. Processing was conducted by the Quaternary Dating Centre at Australian National University and then dated at the Australian Institute of Nuclear Science and Engineering who provided funding for the dates under grants 94/171 and 95/064 (sample numbers OZC248-OZC256, OZC466-OZC471).

Detail of the required processing steps is outlined in Slota *et al.* (1987). Initial experimentation of the Gum Lagoon Conservation Park samples indicated that virtually all of the organic component was associated with the 60-80 μm size fraction so this fraction was separated from the bulk sample for conversion to elemental carbon. The Jaffray Swamp and Cortina Lakes North Lagoon consisted of organic vegetation in a sediment matrix. In these samples the organic vegetation was separated from the inorganic matrix and then converted to elemental carbon (Head, pers. com. 1997).

Lead-210 dating was conducted on sixteen samples from the Jaffray Swamp, Cortina Lakes North Lagoon, Kangoora Lagoon and Lesron Lagoon sites. Dating was conducted at the Department of Chemistry, University of Melbourne. The method utilised was outlined by Smith and Hamilton (1985). Lead-210 is a member of the ^{238}U natural radioactive series, with a half life of 22.26 years (Koide *et al.*, 1972; Oldfield and Appleby, 1984) and is a useful chronological measure of geological processes in the order of a century. The method assumes a constant flux of unsupported lead-210 from the atmosphere to the lake waters and sediment. The fall out of lead-210 was measured by Bonnyman *et al.* (1972) for the Adelaide area, the closest measured lead fallout record to the Upper South East. This measure (2.5 picoCuries/litre) was utilised to estimate ages of sediment horizons of the cores obtained.

4.2.9 Water Chemistry

Where the study sites contained water (Kangoora Lagoon, Cortina Lakes sites, Jaffray Swamp and Lesron Conservation Park sites), duplicate samples were taken and analysed either in the field or upon return to the laboratory. The chemistry of the water was determined to give an indication of the different aquatic habitats and quality of water across the study area. The pH, conductivity, total phosphorus and nitrite content were analysed.

The pH and conductivity of water samples collected from the lakes were conducted in the field using hand held spectrometers. The phosphorus content was analysed using the Molybdate Blue method of Murphy and Riley (1962). This method measures mostly phosphate - phosphorus but some organic phosphorus also. When placed in acid the phosphate forms a yellow complex with molybdate which is reduced to blue by ascorbate. The absorbence value at 705 nm gave a measure of phosphorus content.

The nitrite content of the water samples was measured using the method of Wood *et al.* (1967). This method converts nitrate to nitrite via a column of copper coated cadmium. Nitrite content was determined by spectrometer after diazotization with sulfanilimide and coupling with N-(1-napthyl)-ethylenediamine hydrochloride formed a pink dye. Water quality results were tabled to compare results within and between watercourses.

4.2.10 Other Methods

Several other palaeoecological methods were attempted, including an examination of other biological indicators such as non-pine pollen, cladocera, ostracods and chironomids, and also the heavy metal content. However, results from these methods were unsuccessful because of the nature of the study sites. It was found from the Gum Lagoon Conservation Park core that pollen existed in the top few centimetres of soil but rapidly disintegrated in the samples thereafter. Degradation of the pollen is due to the alkaline soils and fluctuating water table. Results were not deemed to be reliable as the more robust grains were preferentially preserved. Samples from other cores were processed to determine if that was the case at other sites, especially those that still contained water. It was found that even in the cores extracted under standing water that pollen grains were severely degraded, and therefore pollen was not counted.

Ostracods, cladocera and chironomids were examined in the reconnaissance cores, giving similar results to that of the pollen. It is again believed that these fossils were not preserved because of the alkaline soils. Whilst fossils may be found in the surface soils, indicating their presence in modern times, their lack of preservation to any depth makes them an unreliable indicator of environmental changes within the Upper South East.

Analysis of copper and cadmium content through the soil column was also attempted. Results indicated that the fluctuating water column was moving these compounds through the sediment column, and so no peak associated with European settlement could be identified. Instead, both the copper and phosphorus content gradually diminished with depth through the soil column.

Particle size analysis of the core samples were also performed, but preliminary results did not provide any further information about the characteristics of deposition. Utilising both dry sieving and the hydrometer method (Lewis, 1984) reconnaissance cores were analysed but the sampling interval was too coarse relative to the slow sedimentation rate to provide information about flood events. The stratigraphy of the cores provided more information than the size analysis.

This study area was selected for its unique ecology and controversial management future. It was always expected that conventional techniques may not provide the detailed information that they might in other study areas. Therefore a range of techniques had to be utilised to provide a variety of complementary evidence of environmental change to reveal the hydrological changes that have occurred in the Upper South East. The procedure for the above attempted methods are all described in Appendix 9.2.

5.0 HISTORICAL EVIDENCE OF ENVIRONMENTAL CHANGE

Historical records provide valuable information on rural practices and associated human activities in the past. In this chapter historical documents have been utilised to provide information on the nature of the environment and of environmental change in the Upper South East of South Australia. Through the use of a variety of written and instrumental records the impact of humans upon the environment, and the changes they have produced within the environment are reported.

5.1 The Aboriginal History

The pattern and timing of Aboriginal settlement of Australia is a contentious issue, no less so in the Upper South East of South Australia. There are three opinions on the Aboriginal settlement of the Upper South East: two are based on archaeological evidence and one on an Aboriginal dream time song.

The first is that of late Aboriginal settlement of the region, and is described by Ross (1981) based on Victorian archaeological evidence. Ross believed that Aboriginal occupation of the Victorian mallee did not occur until the Pleistocene/Holocene boundary, when more favourable climatic conditions enabled Aborigines of the Murray to explore into the mallee country. More widespread occupation did not occur until long after the favourable conditions of the Holocene ended (Ross, 1981). This theory is based on dated prehistoric sites relating to high lake levels in western Victoria in the early Holocene. For example, the Raak Plains archaeological site was dated at 7650±110 years BP (Ross, 1981). The spread of Aborigines into the Murray mallee eventually occurred due to population pressure, and Ross argued that Aborigines moved into the southern mallee of the Upper South East after 7000 years BP. This theory is supported by Campbell's (1939) ethnographic reports, which state that the Aborigines of the Upper South East were outcasts of the Murray Groups that had migrated across the mallee.

The second theory of Aboriginal occupation of the Upper South East is that of continuous occupation of the region since the Pleistocene. Evidence of such was described by Cann *et al.* (1991) who conducted an archaeological study at Little Dip Conservation Park in the Robe Ranges. They dated two buried middens using radiocarbon dating at a site near Kingston. The lower midden revealed dates of 8270±80 and 7910±140 years BP from charcoal and shell respectively (Cann *et al.*, 1991). The upper midden gave a date of 470±160 years BP. From these results Cann *et al.* developed the theory that there were two stages of Aboriginal occupation on the Robe Range, each separated by a period of marine inundation corresponding to sea level high during the Holocene at 7000 years BP (Cann *et al.*, 1991).

The third source of information is from an old Tanganekald song about ancient times (Tindale, 1937, p. 110):

> When natives arrived in their country in dream times they came from the north out of the inland scrub country. They heard a great noise, which was so terrible that it brought them abruptly to a standstill. Some were unable to move with fear, while others began to rush about in panic. One man asked the people, for there were many of them:-
>
> "What will you do now?" They replied, "Let us go back". Word went around saying, " We must stay here; we are cut off all around; let us make the best of this country" The noise was made in order to tell people they must stop, and not travel any further. The noise was just like the sound of the great waves beating against the Coorong beach.

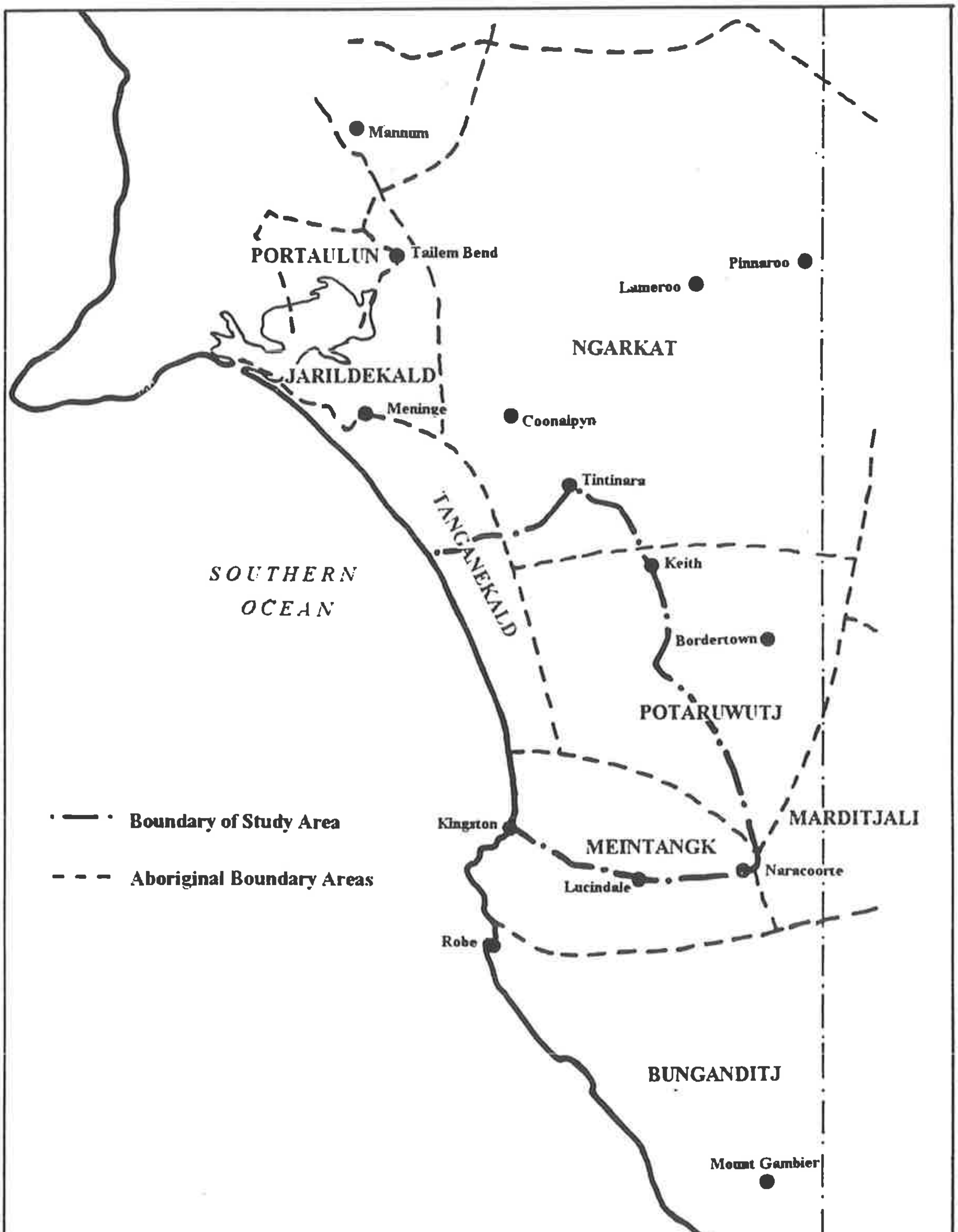
This song provides support to the above theory. That is, the Upper South East Aborigines migrating from the Murray mallee region, hence they were unused to the sound of the ocean.

The vegetation history of the Upper South East, identified by Dodson *et al.* (1992), gives no reason to suggest anything but continuous Holocene occupation as well as probable Pleistocene occupation of the Upper South East by Aborigines. Thus, excepting periods of marine inundation, it could be presumed that Aborigines have occupied the Upper South East throughout the Holocene.

Before European settlement of the Upper South East, several Aboriginal groups occupied the area. There are three differing schools of thought on the Aboriginal groups that occupied the Upper South East. Howitt (1904) claimed that the Upper South East was occupied by one group called the Narrinyeri. Campbell (1934) also believed that the Upper South East was composed of one group but that this group was composed of several different hordes. Tindale (1974) claimed that four groups occupied the Upper South East, and because he conducted an exhaustive study of Aboriginal groups across Australia, his ideas on the Aboriginal groups of the Upper South East will be discussed in this thesis.

According to Tindale (1974), four Aboriginal groups inhabited the defined area of the Upper South East of South Australia (Figure 5.1). These are the Ngarkat, Tananekald, Potaruwutj and the Meintank (Tindale, 1974). The Ngarkat group was located in the Murray mallee region of what is now known as the Little Desert. Only the south west corner of their territory overlaps with the area of the Upper South East. The Tanganekald group were a coastal group primarily living on the Young Husband Peninsula and moving inland during the winter months. The Meintank covered the very southern portion of the Upper South East. This group had a close relationship with the Boandik group of the Lower South East. The Aboriginal group inhabiting the greatest area within the Upper South East was the Potaruwutj. The area of the Potaruwutj covered the ancient dune systems, although the eastern boundary is a little vague. 'Potaruwutj' means 'wandering' or

Figure 5.1: Aboriginal Groups of The Upper South East of South Australia



Source: Adapted from Tindale (1974).

'travelling' men and is based on their constantly shifting camps (Tindale, 1974). Tindale (1976) believed that the boundaries of the Aboriginal groups were quite stable and were strictly adhered to. The location of the boundaries were influenced by local changes in the environment (Tindale, 1974).

The different Aboriginal groups of the Upper South East were very hostile towards each other. Smith (1880, p. ix), in her description of the Boandik group of the Lower South East, stated that "the tribes were in continual dread of each other". Although the groups met occasionally on friendly terms for a corroboree, these often ended in a fight resulting in someone's death. This is supported by two Aboriginal songs outlined by Tindale (1937), which indicate that relations between Aboriginal groups of the Upper South East were simply maintained to fulfil marriage and trade traditions. For other purposes there was very little contact of friendly nature.

The actual population of Aborigines in the Upper South East is even more difficult to discern. Haynes (1887, p. 456) wrote "there are still in the Tatiara country remnants of the several tribes whose numbers in the aggregate are thought to have reached 500". Woolmer (1986) argued that in 1848 the Aboriginal population of south east Australia was reduced to ten per cent of its pre 1788 level. Actual numbers are very difficult to estimate for the Upper South East because the local Aboriginal mortality rate must have rapidly increased prior to European contact through the spread of small pox down the River Murray (Angas, 1847). It is presumed that the Aboriginal population was decimated by this occurrence, and therefore there are no means of determining population numbers prior to 1788. In 1935, Tindale estimated that there existed fewer than thirty full blooded Aborigines living in the whole of the area east and south of Port Augusta (Tindale, 1935). It is doubtful that any of these individuals were from the Upper South East, and there are currently no full blood Aborigines of the Upper South East surviving.

The available information suggests that Aboriginals exploited the resources of the mallee over a wide area and probably over at least the last 7000 to 8000 years. Evidence of Aboriginal modification of the Upper South East environment is very scant. Hawdon (cited in Turner and Carter, 1989, p. 2), in his expedition in July 1939 through the region, described relicts of dams, constructed by Aborigines in the interdune corridors, to catch fish in the wet seasons. The Aboriginal use of the land in the lower Murray and Lower South East were studied by Clarke (1994) and Leubbers (1978) respectively. Clarke stressed that Aborigines of the Lower Murray actively utilised the environment, and Leubbers wrote of the way Aboriginal activities were influenced by natural climate changes. Clarke (1994) described the hunting and gathering procedures of Aborigines in the Lower Murray. It is apparent that these Aborigines actively used fire in a wide range of circumstances and hunted and trapped animals with spear, net and club. It is unlikely that hunting and gathering activities significantly altered the natural environment. The use of fire, however, may have altered species composition of flora and fauna favouring those adapted to an increase in fire frequency (Clarke, 1994). The likely activities of Aborigines in the Upper South East are summarised in Table 5.1.

Table 5.1: Aboriginal Activities in the Upper South East of South Australia

Activity	Impact
Date of occupation	Post 7000 years BP (Ross, 1981)
	Pre 7000 years BP and post 7000 years BP (Cann et al., 1991)
Size of population	Unable to be accurately determined, possibly around 500 (Haynes, 1887)
Likely environmental impacts	Use of fire, hunting animals, plant and animal husbandry

5.2 European Exploration and Agricultural History

Europeans began to occupy the South East of South Australia in the 1860s. Settlement was concentrated in the Lower South East which had far greater agricultural potential. For many years the Upper South East was considered a "wasteland", and settlement did not occur until after World War Two. A chronology of exploration and development for agriculture in the Upper South East is described below, followed by a discussion of changes caused by European activities to the surface water hydrology in section 5.3. The exploration and agricultural development of the Upper South East occurred in four distinct time phases, as reflected by differing perceptions of the Upper South East environment.

5.2.1 Pre 1900: A Marshy Plain

The only descriptions that provide an indication of the natural environment of the Upper South East is that of several exploration parties which travelled through the region. The first recorded expedition through the Upper South East was undertaken by Charles Bonney in 1839, who was in search of a new overland route for stock from the Port Phillip district (now Victoria) to Adelaide (Harris, 1969). Bonney was followed in the same year by Joseph Hawdon and Lieutenant A. Mundy. Hawdon wrote (cited in Turner and Carter, 1989, p. 2):

> ...we entered upon a marshy plain, which continued for 9 miles [14 km]. There were a few very large trees on the plain, the soil so soft that we were obliged to lead our horses for the last 2 miles [3 km] through water about half a foot in depth. We now entered a wretched sandy scrub of stunted Eucalypts bushes and grass trees which continued for 4 miles [6 km], when again a small belt of sheoak trees with good grass succeeded. After feeding our horses and leaving the forest we entered upon a marsh which extended as far as the eye could see in a north west direction, but we crossed in about four miles. ... passing alternately over thinly timbered forest of sheoak and sandy land and marshes which we were frequently obliged to outflank. The

> remainder of our day's journey was over plains evidently at times under water.

In July 1847, police commissioner Alexander Tolmer, when investigating a new mail route from Adelaide to Mount Gambier wrote (cited in Turner and Carter, 1989, p. 3):

> ... my course from the Salt Creek to Lake Mundy was south east; and, as the whole distance consists of alternate flats intersected by well timbered ridges running north and south, he [the reader] will at once perceive that to keep the said course necessitated travelling obliquely across the flats, which were all submerged, and the water so deep in many places that our horses had to swim. At night our camping places were the ridges or slight elevations forming islands in the midst of these vast waters.

The condition of the country, however, depended a lot on the seasons as noted by W. Hanson, Engineer and Architect, following a journey undertaken by him in the South East in 1863 (South Australian Parliamentary Papers, 1863):

> The time of my visit to the district (January), coupled with an exceedingly dry spring, did not allow of seeing much water upon the swamps; in fact, where, in winter, in some places water had to be passed through consecutively for about 7 miles [11 km] without intermission, the roads were perfectly dry in many instances, not even showing where the watercourse even had been.

The natural conditions of the Upper South East may be best summed up in Goyder's words (South Australian Parliamentary Papers, 1863):

> My opinion is that from Salt Creek southward, the area of the south east is equal to 7600 square miles [197 000 Ha] and in every wet season half of that is under water. The depth of the water varies from 1 to 6 feet [0.3 to 1.8 metres] and some of it is never dry. Some swamps extend from 4 to 6 miles [6 to 9 km].

Due to the nature of the region, development of the Upper South East in the nineteenth century was limited. The region was not of interest to settlers and Government officials except as the most direct transport route between Adelaide and the Lower South East. As a result, the area was left almost untouched except for the construction of some bridges aimed at improving access through the region. When questioned about development of the area by the South Australian Parliament W. Hanson (Engineer and Architect) recommended "only go on at present as we have done hitherto, improving the boggy pieces of road, so as to make them passable, leaving the sand and limestone for the present" (South Australian Parliamentary Papers, 1863).

The only agricultural activity which occurred in the Upper South East in this period was of pastoral squatting. Pastoral squatters utilised the sandhill country to run sheep on their holdings for a number of months. However, after three to nine months they were forced to withdraw their flocks to the improved pastures of the Keith district for a period of recuperation due to the frequent occurrence of coastal disease[5]. Their impacts upon the environment included grazing and the use of fire. Every fifth year, or whenever there was sufficient growth to carry a fire, they burnt the heath and tea tree country. The resultant new growth supplied rough feed, but the country inevitably had a low carrying capacity (Taylor, 1933).

The first recorded drainage constructed in the Upper South East occurred within this period. A small drainage scheme was constructed privately by Mr Seymour on Kercoonda Station, and was inspected by Government officials in 1863 (South Eastern Drainage Board, 1980). The Government officials admired the scheme and recommended to the South Australian Parliament that similar drainage schemes be constructed where excess surface water limited agricultural activities.

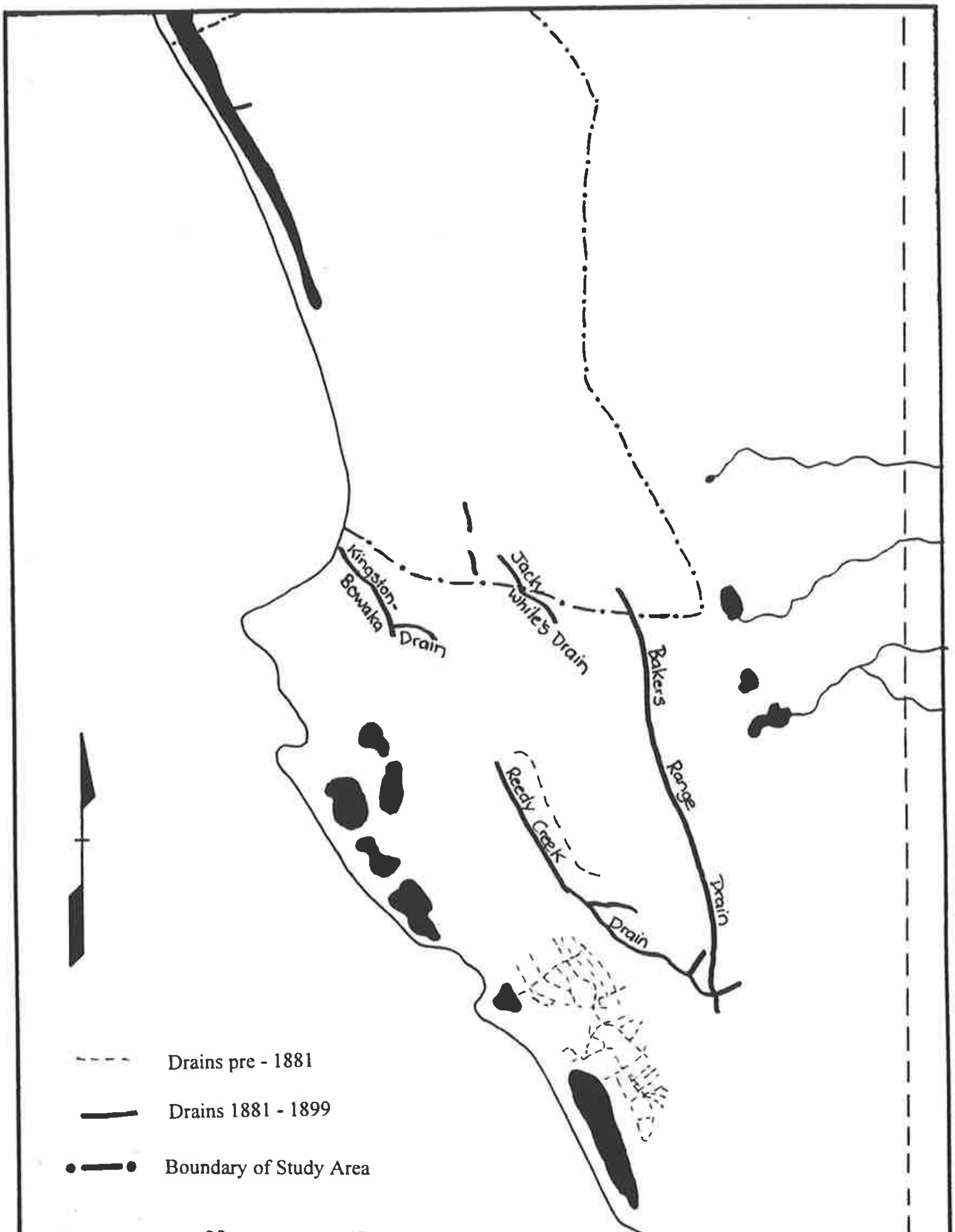
[5] Coastal Disease is a decline in sheep health due to the deficiency of trace elements in their diet.

In 1864 the Salt Creek cutting was constructed (South Australian Parliamentary Papers, 181/1864). The aim of this cutting was to remove excess surface water that built up in the northern reaches of Tilley Swamp watercourse and drain it into the Coorong. As a result of the cutting, crossing the Salt Creek to access the Lower South East became much easier. The second drain to be constructed in the Upper South East was at Martin's Washpool. This waterhole acted as a storage feature, which only overflowed in very wet years to Salt Creek and the Coorong. Once the Salt Creek cutting was made, surface water north of the Martin's Washpool drained away but was still banked up to the south of the waterhole. A cutting was made in 1884 in order to increase the flow of water through this area (Foale and Smith, 1991).

During this period agricultural development proceeded rapidly in the Lower South East. Drainage proposals for the region were submitted to Cabinet in the late 1800s. In a visit to the South East in 1863, Goyder reported on the advantages of draining the country from east to west (South Australian Parliamentary Papers, 1863). He foresaw that drainage of this type would not only aid the general traffic of the country but also double the area presently available for the stockholder and place at the disposal of the Crown a large extent of rich agricultural land.

Figure 5.2 illustrates the drains constructed in this period of development in the Upper South East. The only drains constructed at this time were the afore-mentioned Salt Creek and Martin's Washpool cuttings. Prior to 1900 the Upper South East was considered a wasteland. Thus in the Lower South East excess surface water was channelled toward the Upper South East, via the Bakers Range drain and Jacky White's drain. This pattern mimicked the natural flow of surface water but increased the speed and rate at which water

Figure 5.2: Drains Constructed Prior to 1900 in the South East of South Australia



Source: Williams (1974).

reached the northern portion of the study area. Flooding must therefore have occurred more frequently and more severely.

Thus prior to 1900 the impacts upon the environment of the Upper South East were the construction of roads through the area, grazing by sheep during the summer months, and the burning of sandhill vegetation by pastoral squatters. The construction of drains at this stage did not greatly impact the hydrology nor the environment of the area. Table 5.2 summarises the nature of human impact upon the Upper South East in this period.

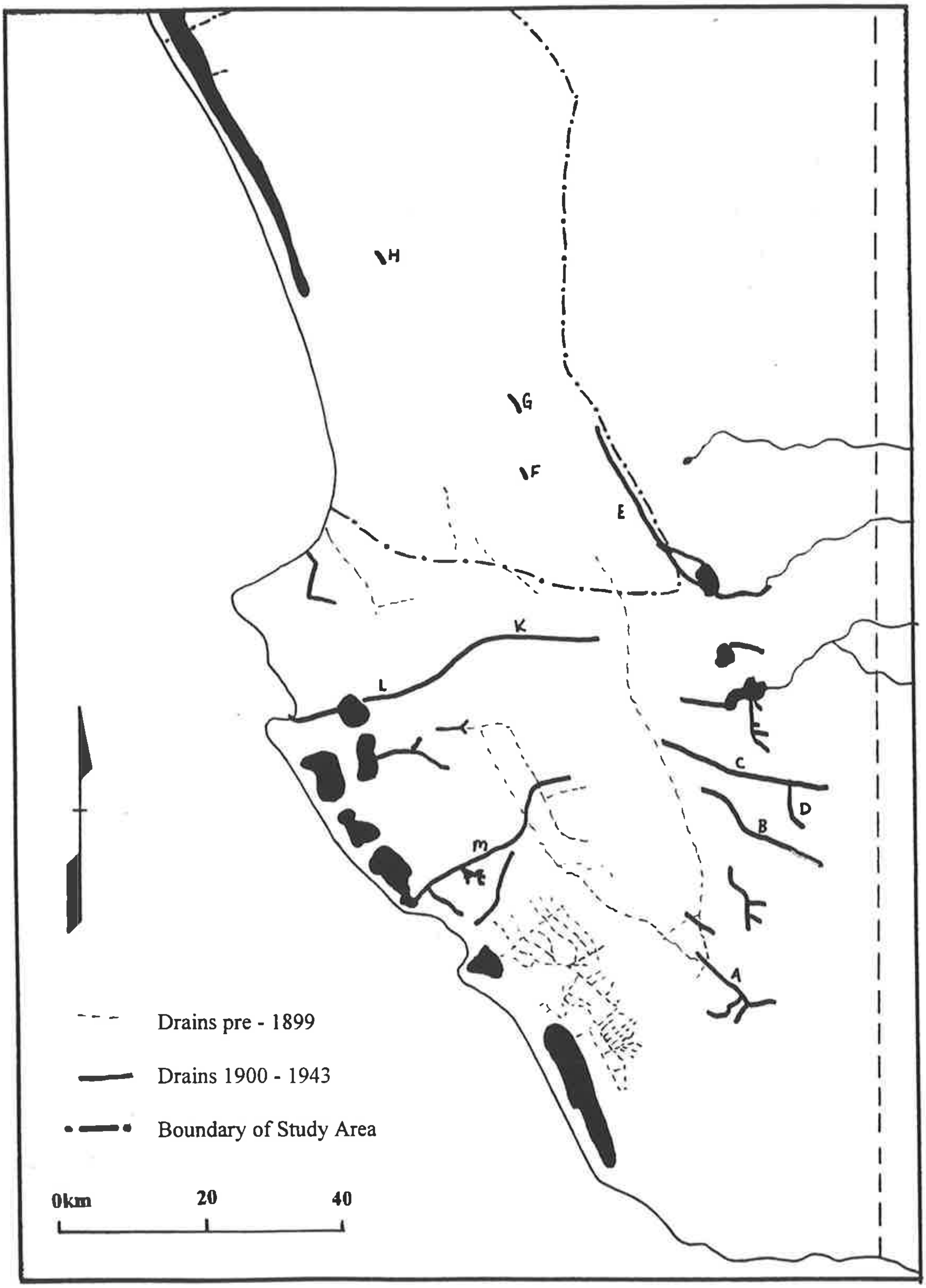
Table 5.2: Impacts upon the Upper South East environment prior to 1900

Activity	Impact
Pastoral Squatting	Summer grazing and burning favoured fire resistant vegetation.
Private Drainage in the USE	At this stage minor.
Government constructed drainage	Impact of outlet at Salt Creek upon the Coorong ecology; increased surface water flow to the USE (more frequent and greater floods)

5.2.2 Early 1900s to World War Two: The God Forsaken Country?

Low intensity grazing by the pastoral squatters continued in the Upper South East until the late 1920s and 1930s. Whilst their activities were the only impact within the Upper South East, the construction of drainage in the Lower South East rapidly continued. Drains which aimed to channel water from the Lower South East toward the Upper South East continued with the construction of Drain E. But in the 1930s, a change of drainage strategy occurred, aiming to channel excess surface water westward towards a sea outlet rather than dumping excess surface water in the Upper South East (Figure 5.3). Drains such as L, M and K

Figure 5.3: Drains constructed between 1900 and 1943 in the South East of South Australia



Source: Williams (1974)

removed surface water from the southern reaches of the Bakers Range watercourse and the Tilley Swamp watercourse (Reedy Creek), causing a period of drought. Reduced surface water flow would have resulted in less frequent and smaller floods. The Marcollat watercourse continued to receive increased amounts of surface water, as water was not allowed to store in swamps in the south. Details of these hydrological changes are discussed in more detail in section 5.3.3.

A debate began in the 1930s on the development potential of the Upper South East, which raged for the next two decades, and is evidenced in many reports of government officials. The reports were a mixture of both favourable and unfavourable opinions on the agricultural potential of the region. However, most are based on very little empirical evidence.

The first scientific report on the Upper South East was that of Taylor (1933). Taylor was a scientist at the Department of Agriculture who conducted a soil survey of the Hundreds of Laffer and Willalooka. He examined the salinity content of the soils in particular and concluded that the agricultural potential of the Upper South East was very low. The second scientific report on the Upper South East was a soil classification survey on County Cardwell conducted by Melville and Martin (1936). This survey is very detailed and is the primary historical record of the natural environment of the Upper South East. The report described in detail the pre European vegetation and soil distribution and also assessed the suitability of the region for agricultural purposes. The results of both reports are shown in Figure 5.4. Melville and Martin (1936) concluded that the agricultural potential of the Upper South East was slightly more optimistic than that reported by Taylor (1933).

Figure 5.4: Agricultural Reports of Taylor (1933) and Melville and Martin (1936).

Taylor (1933) and Melville and Martin (1936) mapped vegetation communities and geomorphological units through field surveys, and subsequently classed these communities according to their susceptibility to salinisation. Only interdunal and lowland areas were included in the classifications. The two surveys were joined by the CSIRO Division of Soils and are illustrated in this Figure. Unfortunately reproduction of this map is poor due to the deterioration of the original, thus the legends of the two authors are explained below.

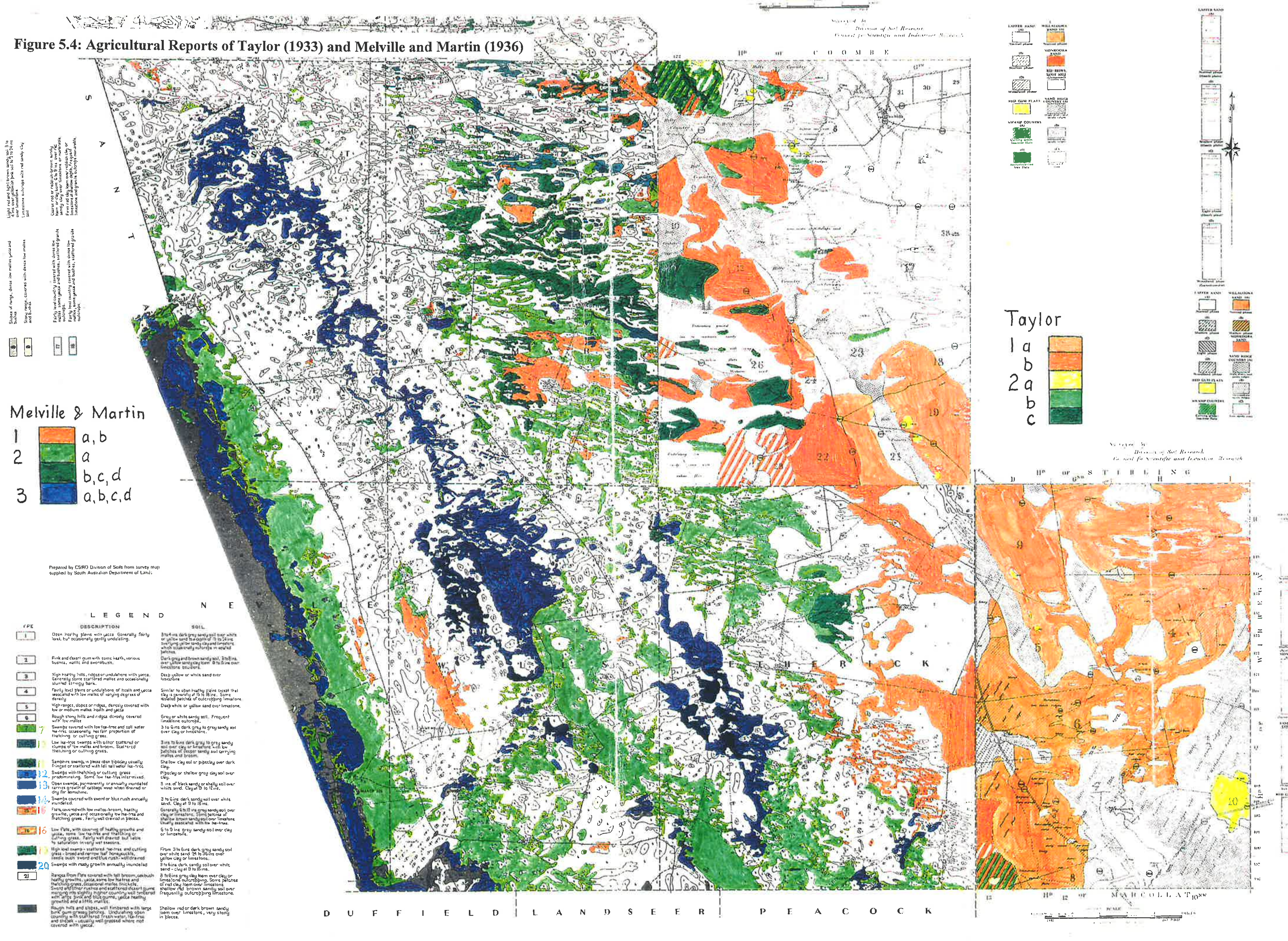
The Hundreds of Stirling and Coombe (upper right corner) are categorised by the Taylor (1933) agricultural report. The lowland areas are separated into five categories according to their susceptibility to salinisation:

Class 1a : very high : Willalooka Sand soil types;
Class 1b : high: Monkoora Sand soil types;
Class 2a : moderate: Redgum flats;
Class 2b : low : Swamp country (Cutting Grass, Tea Tree flats);
Class 2c: very low : Swamp country (Samphire, Tea Tree flats).

The remainder of the map is illustrated according to the classification scheme of Melville and Martin (1936). Meville and Martin's vegetation classification is more detailed than that of Taylor but is difficult to decipher. The salinity classes are as follows:

Class 1: very high : Flats well drained;
Class 2: low: High level Swamps;
Class 2b: very low: Swamps covered in tea tree and/or samphire;
Class 3: open water: Open swamps with annual inundation or permanent water.

Figure 5.4: Agricultural Reports of Taylor (1933) and Melville and Martin (1936)



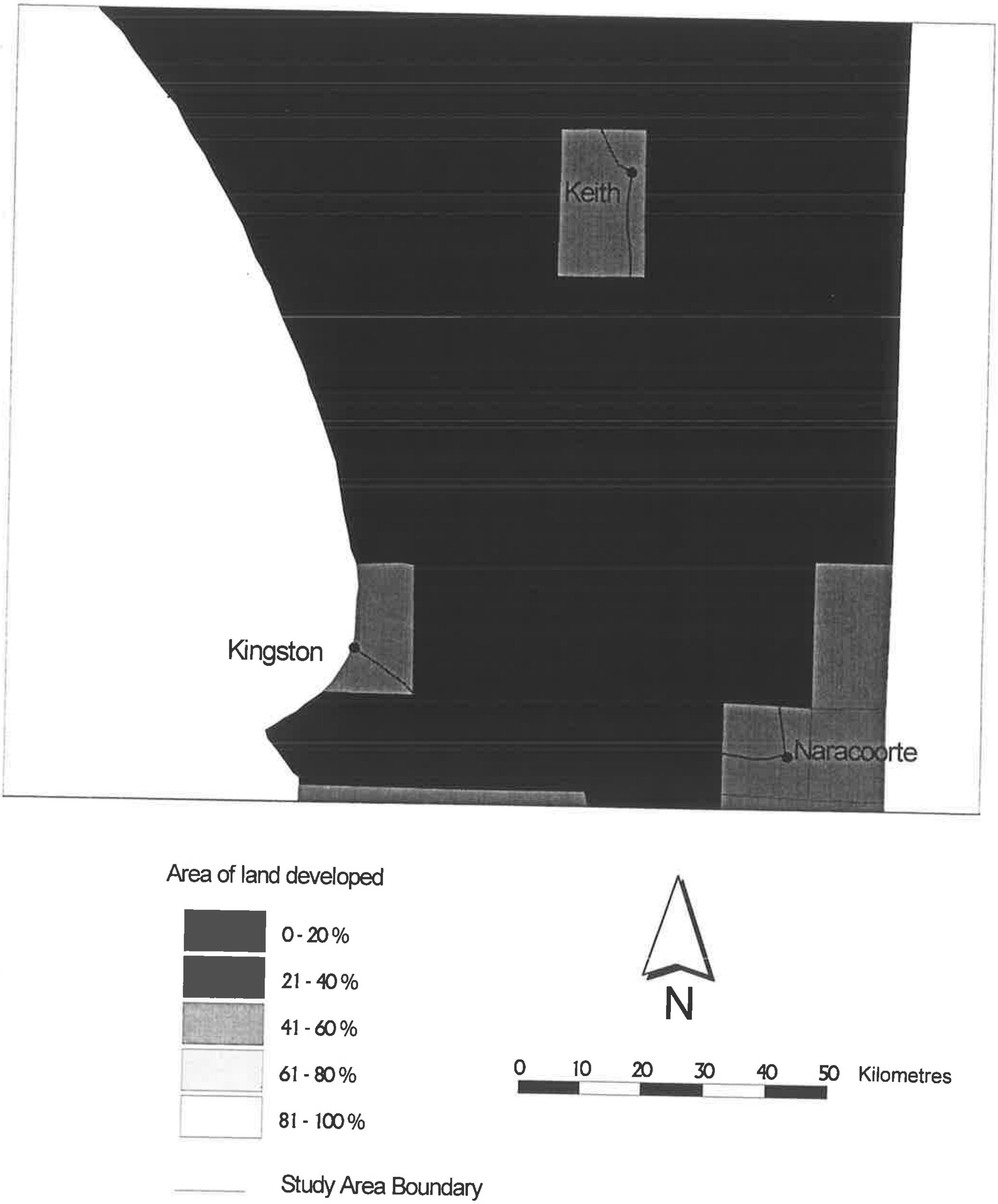
The Melville and Martin (1936) field survey provided the earliest information available for the extent of native vegetation in the Upper South East. This survey only covered the northern portion of County Cardwell and indicated that a few areas of native vegetation around Keith had been cleared, however the native vegetation of all other areas included in their survey remained intact. The agricultural development data confirms this result with only the Hundreds adjacent to the three major towns of the region (Keith, Naracoorte and Kingston) having greater than twenty percent of their area utilised for agricultural activities (Figure 5.5). In fact, approximately 97.2 % of native vegetation remained uncleared in 1936.

Discussion on the suitability of the Upper South East for agricultural development reached the newspapers in 1936. An article by Mr. R.C. Mowbray in the *South Eastern Times* (April 31 1936) stated that "excepting only the sand drifts along the sea coast and excluding the comparatively small swamp flat at Blackford, the area embraces the most god-forsaken country south of the Murray".

Despite the pessimistic reports coming from the South East, the *Adelaide Advertiser* gave the impression that agricultural development was proceeding successfully in the Upper South East. "In the Upper South East development is proceeding satisfactorily and many thousands of acres of low fertility land considered useless a few years ago is being brought into profitable production" (*Advertiser*, 12 January 1936). And again (*Advertiser*, 19 January 1936):

> There were tens of thousands of hectares that could be cleared with tractor and modern disc plough and it would be necessary to resort to the use of the scrub roller only where the mallee was heavy ...With a modern tractor and plough it would be possible to clear this land at a rate of a hundred acres or more a week.

Figure 5.5: Agricultural Development of the Upper South East in 1936



Despite the indication by the *Advertiser* that development was occurring in the Upper South East, Mr Spafford, the Director of Agriculture, who had been a strong supporter of development in the area, expressed some frustration on the lack of development occurring (Department of Lands, 1939). However, the developmental, if cautious, enthusiasm of the Mr Spafford was not shared by everyone concerned. On 9 April 1941, the Surveyor General wrote to the Chairman of the Land Board as follows (Department of Lands, 1939):

> It appears to me that it would be most unwise to attempt any general settlement of this area until such time as the results of the experiments now being conducted are known. It may even be necessary to conduct experiments on other types of soil.

The Chairman of the Land Board developed a similar opinion (Department of Lands, 1939):

> ... the Board agrees that it would be unwise to attempt any general settlement of this area at the present juncture. Observations show somewhat promising results of pasture on isolated patches, but they provide no evidence of permanency nor do they indicate that the land can be developed economically.

These last two reports are the first to indicate any doubt about the sustainability of agriculture in the Upper South East. World War Two, however, ensured that any further moves towards the development of County Cardwell were delayed. Table 5.3 summarises the impact upon the Upper South East environment from the agricultural activities of this period.

5.2.3 Post World War Two to 1980: Drought and Flood

At the end of the World War Two a demand for agricultural land to settle returned servicemen developed. The high demand for land over-rode any doubt the government may have had about the economic sustainability of agriculture in the Upper South East. At the

Table 5.3: Impacts upon the Upper South East Environment 1900 to World War Two

Activity	Impact
Pastoral Squatting	Summer grazing and burning favoured fire resistant vegetation Vegetation clearance
Lower South East drainage additions	Less surface water reaching Tilley Swamp and Bakers Range watercourses. Amount of surface water in Marcollat watercourse increased.

same time some important developments in agricultural technology occurred which facilitated closer settlement in the Upper South East.

The technological developments were mostly achieved by the Commonwealth Scientific and Industrial Research (CSIR). Through experimentation they discovered that 'coastal disease', previously a limiting factor to agricultural development in the region, occurred where the soil had a large calcium content and lacked both phosphate and small quantities of heavy metals normally found in soils, namely cobalt and copper (Jones, 1985). At the same time research into pasture growth on the coastal soil was being conducted and results showed the need for copper to be added for satisfactory pasture growth. The addition of trace elements to the soils raised the copper level of plants significantly and the intake of copper through grazing proved sufficient to overcome copper deficiency in sheep (Jones, 1985).

These results became widely known in the 1940s. Public opinion about the suitability of the Upper South East for agricultural development then changed, as was reported in the South Australian Parliamentary Papers (1949):

> Large tracts of useful country in the Upper South East are suitable for closer settlement and, in the interests of the State, they should not be permitted to remain idle indefinitely. These soils are of common origin and all of them will probably suffer the same deficiencies, namely, phosphorus, nitrogen,

> zinc and copper, though perhaps in different degrees. Their physical state has been found suitable for a number of plants that can be grown under a rainfall of eighteen inches [45 cm] or more per annum. On individual farms where an effort has been made to develop the land by recommended procedures, the results have been successful.

In addition to soil improvements, the development of agricultural technology enabled rapid development of the Upper South East through the use of new machinery. Initially scrub was cleared by pulling a log or logs attached by chains to a large crawler tractor. The chains broke some scrub down and the rest was rolled by the logs. Using this method, if all went well, about eighty or ninety acres could be cleared in a day. This changed in 1952 when anchor chains were introduced. About six hundred feet of an old ship's anchor chain was hitched between two tractors and the tractors driven through the scrub. By this method 100 acres could be cleared in an hour, more than a days work using the logs. The dislodged scrub was allowed to dry and was then burnt (Jones, 1985).

Once the native vegetation had been stripped from the area, ploughing to dig out the remaining roots was undertaken. Initially Majestic ploughs were used but these did not remove all the mallee stumps. Settlers were then faced with the problem of mallee regrowth. To overcome these problems the ripper was developed during the 1950s. Available for the last few years of development of the Upper South East, the big tynes of the ripper went below the ground surface and cut through virtually all the mallee roots. There was almost no regrowth of mallee and yacca (*Xanthorrhoea* sp.) on country which had been ripped (Jones, 1985).

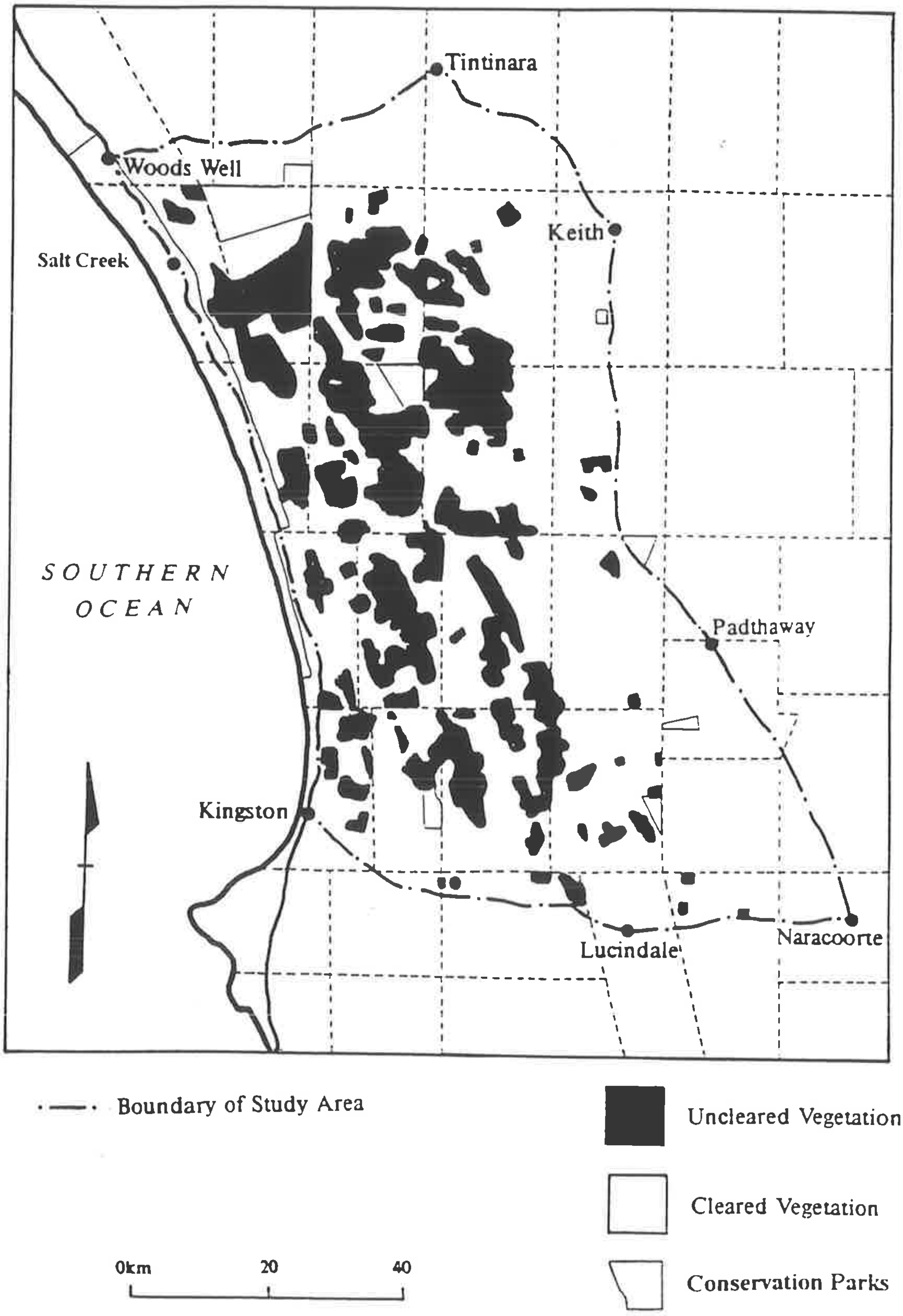
Whilst technological improvements suddenly made agriculture a productive prospect, the problem that then emerged, was financing the development of land until the pasture produced a return. The catalyst to increasing the settlement rate in the Upper South East was a scheme developed by the Australian Mutual Provident Society (AMP). The AMP scheme provided investment capital to finance land development on a large scale (Jones, 1985). By negotiating long term Development Leases from the South Australian Government and utilising employed labour the AMP developed huge tracts of the Upper South East until they were returning produce (Jones, 1985). This scheme was well received by the local community. By 1957, development of land in the Upper South East funded by the AMP was complete.

Figure 5.6 illustrates the percent area developed within each Hundred of the Upper South East during this and the following period. Figure 5.6a shows that in 1950 a majority of the region remained undeveloped for agricultural activities. However, technological improvements, the AMP scheme and soldier resettlement schemes resulted in the rapid development of the Upper South East in the 1950s (Figure 5.6b). By1970 (Figure 5.6c) most Hundreds of the Upper South East had a majority of vegetation cleared for agricultural production, excepting those in the Bakers Range watercourse which was flooded in the mid 1950s and retained water for several years (section 5.3.2). Young reported that 73 % of the native vegetation in the Upper South East had been cleared in 1976, and believed that remaining vegetation was generally contained within large areas that had potential for further clearance. This must have occurred as Figure 5.6d shows most Hundreds well developed for agricultural activities. Clearance would have been very rapid with the use of modern machinery in this latter period.

Mowling and Baritt's (1980) map of the South East vegetation (Figure 5.7) indicates the actual remaining native vegetation, in 1980, all of which is contained within formal reserves or Heritage Agreement areas. Mowling and Barritt (1980) estimated that approximately 20 % of native vegetation remained in 1980. However, most of these areas

Figure 5.6: Agricultural Development of the Upper South East in 1950, 1960, 1970 and 1980

Figure 5.7: Native Vegetation Remaining in 1980 in the Upper South East of South Australia



Source: Mowling and Barritt (1980)

of native vegetation were in the interdune corridors that were annually flooded and not worthy of agricultural use.

While the clearance of native vegetation and development for agricultural purposes was an active goal for the landholders of the Upper South East, there was no apparent concern about the resultant impacts upon the environment. In fact, the first notification of the impact of agricultural development in the Upper South East was not mentioned until 1955. At that time, the Engineer for Surveys, Mr S. Gild, and the Engineer for Irrigation and Drainage, Mr F.B. Idle, visited the Upper South East when it was in flood (Engineering and Water Supply, 1955):

> [the flooding] has been caused by the very rapid development of land where the original natural vegetation is being cleared in preparation for pasture. This causes a very marked increase in runoff particularly during the first few years of establishment and the extra quantity has raised the water table and caused flooding.

The 1955/56 flood marked a transition from optimistic enthusiasm for development of the Upper South East to concern for the environment. This is due to a change from a series of dry years to a series of wet years experienced in the mid to late 1940s (Pittock, 1975). Floods occurred in 1955/56, 1960, and 1964. This period of flooding highlighted the relationship between surface water floods and dryland salinisation, which became apparent to the landholders. This is evidenced from a letter by a Tintinara landholder to the Engineer in Chief (Engineering and Water Supply, 1958):

> I'm contacting you re the water problem of the following landholders ... In wet seasons the water flows through the above properties but in doing so it spreads over large areas, where, owing to salt content, crops and pastures are ruined leaving the affected ground useless for years afterwards.

However, the Government largely ignored the indicator signs of salinisation. The late 1960s and the 1970s were a dry period in the Upper South East (see Figure 5.12) and so concern changed back to the lack of surface water, as evidenced by a letter from the member for Albert who expressed concern of the need to convey flood waters into the region (South-Eastern Drainage Board, 1979).

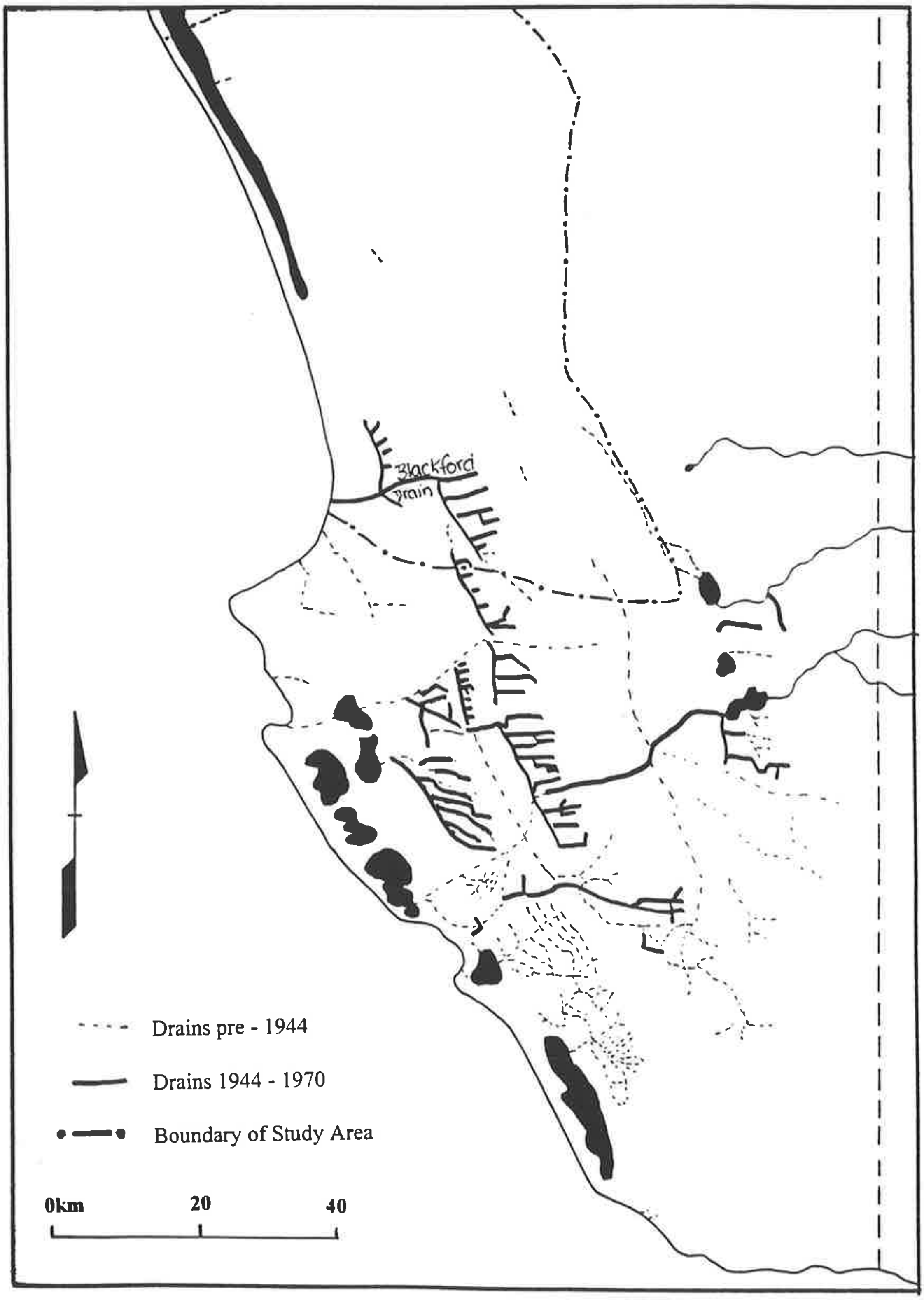
> ...While flood waters in the Upper South East may be a temporary disadvantage ... it must be remembered that the very environment which permits agricultural land use is, to some extent, dependent on its productivity on flooding.
>
> ... It is unlikely that extensive drainage, such as that existing in the Lower South East could be repeated further north, where the required net benefits would simply not accrue.

This problem was due in part to the change in drainage strategy in the Lower South East that diverted surface water to the sea rather than northward as described in section 5.2.2. Thus, during the 1960s and 1970s, the Upper South East would have been deprived of the amount of surface water it would have naturally received from the Lower South East. That problem was compounded after World War Two, as in this period the density of the drainage network rapidly increased (Figure 5.8). Thus excess surface water was removed more efficiently from all areas likely to be inundated and was channelled to the sea.

During the 1970s, the topics of salinity and private drainage became popular concerns in the Upper South East. Although it was widely known that the soils of the Upper South East were naturally saline, salinisation had never previously been mentioned in the context of limiting agricultural productivity. For example (Department of Lands, 1939):

> ... an extensive drainage system to lower the groundwater table would be necessary to reduce the salinity level in the surface soils, providing sufficient water was available to leach the salts downwards.

Figure 5.8: Drains Constructed in the Upper South East of South Australia Between 1944 and 1970



Source: Williams (1974)

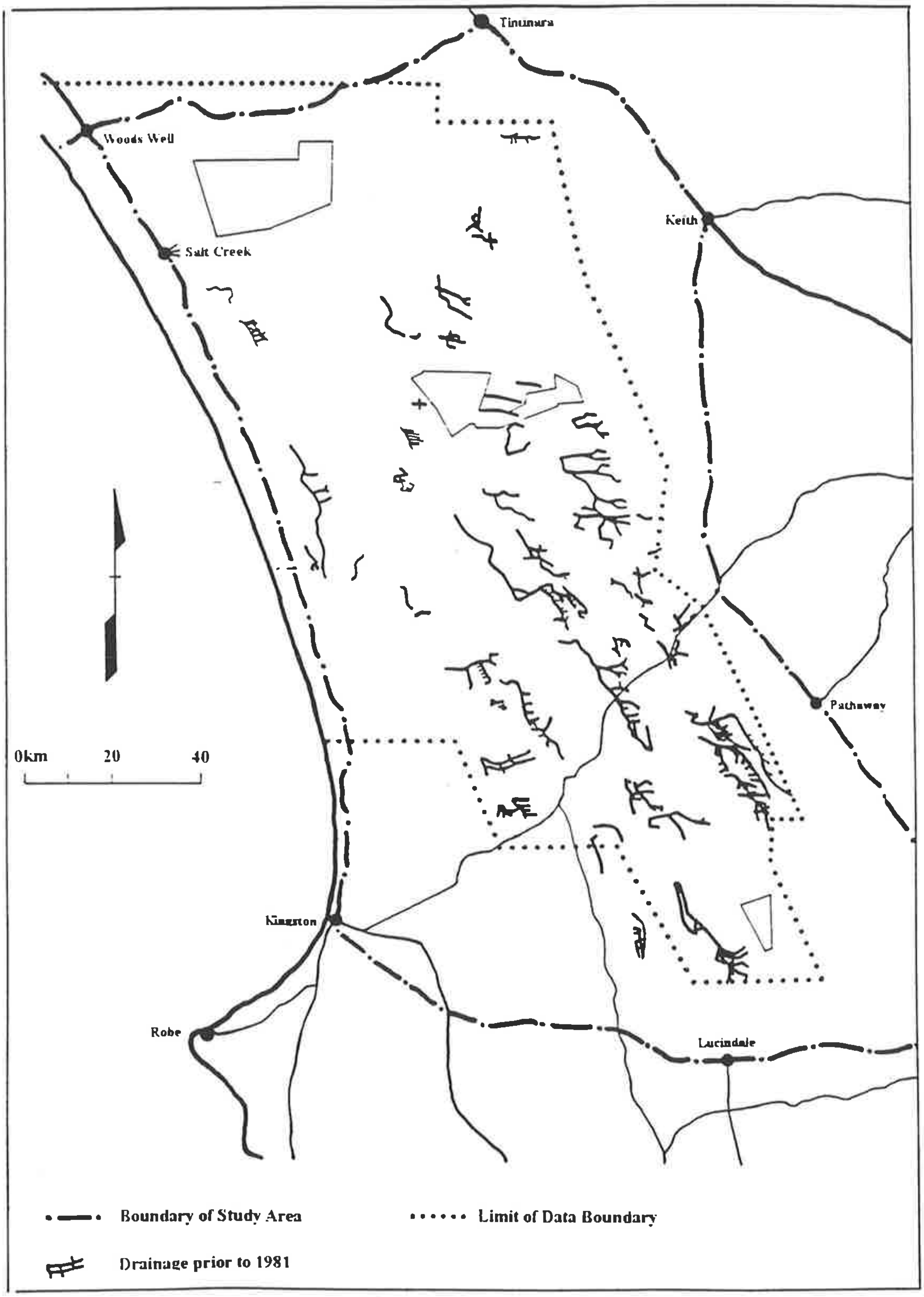
Also of concern was the vast amount of private drainage being undertaken in County Cardwell. This topic was brought up by Mr Lowe of the City Meat Co. Pty. Ltd, who held large areas of pastoral lease in the Upper South East (South Eastern Drainage Board, Number unknown):

> We appreciate that there simply has not been enough knowledge available on the movement of surface and groundwater on which to formulate drainage plans covering both the interests of those who want land drained and those who fear over draining. However we respectfully suggest that urgent consideration now be given to the effect of over draining on groundwater in the County Cardwell.

The modification of the Upper South East surface water hydrology in this period was highlighted in the EIS where the first record of private drains constructed in the Upper South East was reported (Figure 5.9). This Figure shows private drains constructed up until 1981, and excepting the Salt Creek cutting and Martin's Washpool drain all drains have been constructed by landholders. The large number of these drains indicates that private drainage occurred over a long period of time. An enormous amount of time and money has been spent by land holders in an effort to protect their land from inundation. As indicated by Mr Lowe, this drainage network developed without background ecological information and in an uncoordinated manner thus it caused unknown modifications to the hydrology of the Upper South East.

Concern continued to be expressed at a perceived lowering of the water tables in the Upper South East resulting, it was presumed, from the activities of the South Eastern Drainage Board in the Lower South East. In early 1981, Mr B. Bartlett, a long time resident of the region, complained of the lack of surface water (District Council of Coonalpyn Downs, 1981):

Figure 5.9: Private Drains Constructed up to 1981 in the Upper South East of South Australia



Source: Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993).

> One time we had a wonderful wet lands area through from the Lower South East region flowing through to Salt Creek, which was teeming with bird and animal life and very nice recreation areas. But with over drainage and over clearing I have seen the Parks slowly dying.

In reply the Board responded (South Eastern Drainage Board, 1976):

> Records of water flows in the pre drainage era for your district are very scant and unreliable, therefore it is difficult to give a conclusive answer to this question.

In this period of development of the Upper South East, public opinion oscillated from concern over excess surface water to concern of lowering water tables. The change in opinion was due to both natural fluctuations in rainfall and changes in drainage activities occurring in the Lower South East. Table 5.4 summarises the European activities altering the environment of the Upper South East between World War Two and 1980.

5.2.4 Post 1980: Salinity and Floods

In 1981 the Upper South East experienced one of the largest floods since European settlement. This event seemed to remove from local perception all preoccupation with over drainage and declining water tables (Foale and Smith, 1991). Instead, problems of annual surface water flooding and dryland salinity were highlighted. Land holders became very concerned with these issues and the resultant decline in agricultural productivity, and wrote many letters of concern to local councils and the relevant South Australian government departments. Their concern at increasing salinity and annual flooding in the area culminated in an investigation of such issues by the government in an EIS that was described in section 3.2.

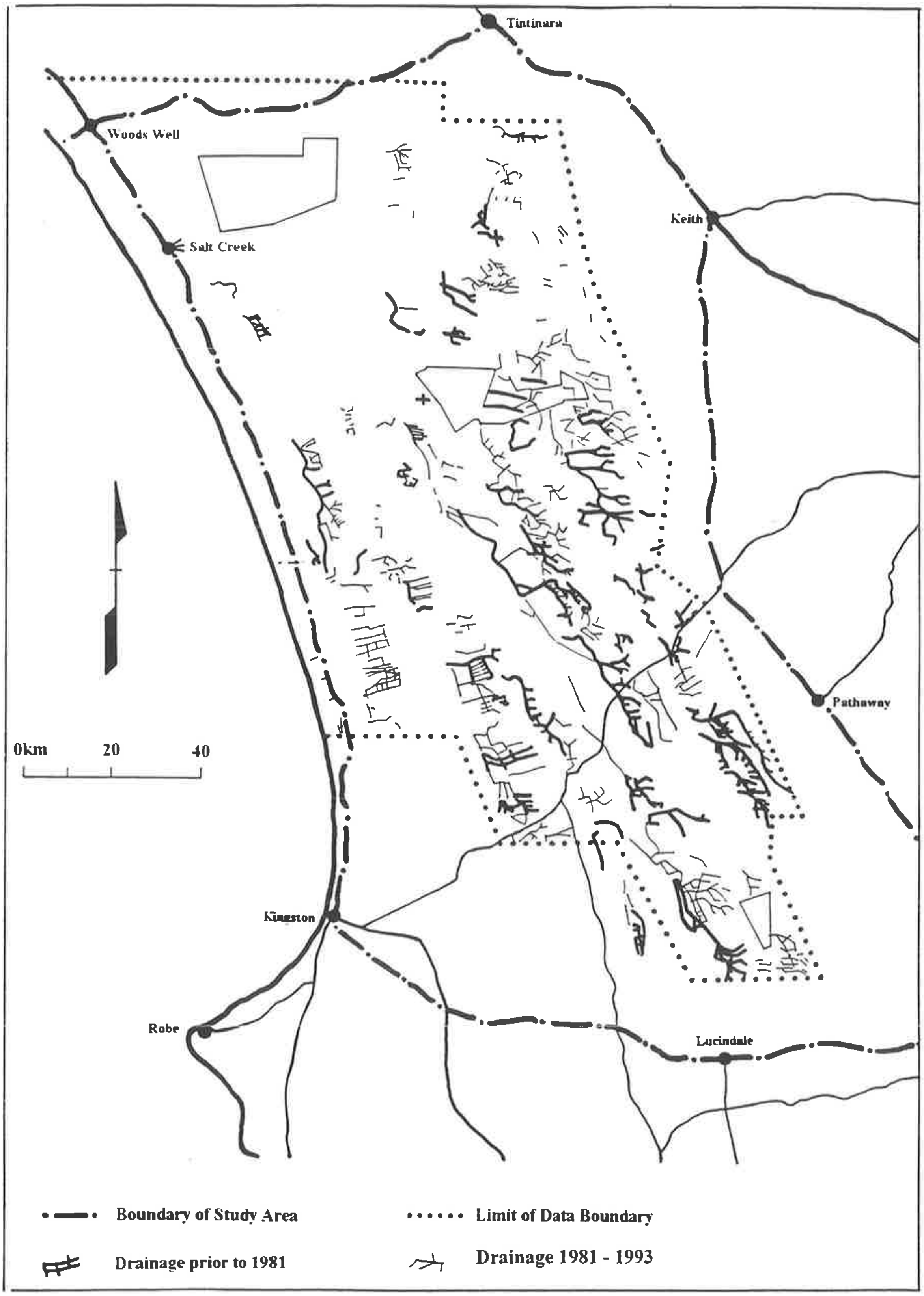
Table 5.4: Impact upon the Upper South East environment between World War Two and 1980

Activity	Impact
CSIR development of trace element additives	Facilitated closer settlement
Use of chains, tractors and the ripper	Increased rate of vegetation clearance causing rise of water table levels, increasing flooding and the rate of salinisation.
AMP Scheme	Facilitated rapid development of the region
LSE drainage outlets to the sea	Reduced amount of surface water reaching the USE
USE private drainage	Circulated excess surface water without any outlet

After the 1981 flood, the development of privately constructed drainage networks in the Upper South East rapidly increased (Figure 5.10). The aim of each network was to rid excess surface water as quickly as possible from each individual land holder's property, and stopbanks were constructed to prevent water entering the properties. However, no outlets were provided for the excess surface water. Rather than lessening the flooding problem, private drainage increased the period of inundation, as surface water was moved round in circles rather than exiting the system, or being allowed to pool in designated evaporation basins (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993). Thus private drainage construction had a pronounced impact upon the Upper South East surface water hydrology.

While excess surface water remained a problem in the Upper South East, the value of the remaining natural wetlands was recognised in the late 1980s. In August 1988, Councillor

Figure 5.10: Private Drains in the Upper South East of South Australia



Source: Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993).

Dinning of Tatiara District Council prepared a discussion paper in which he recommended a Surface Water Management Authority to be set up (Tatiara District Council Files, 1988):

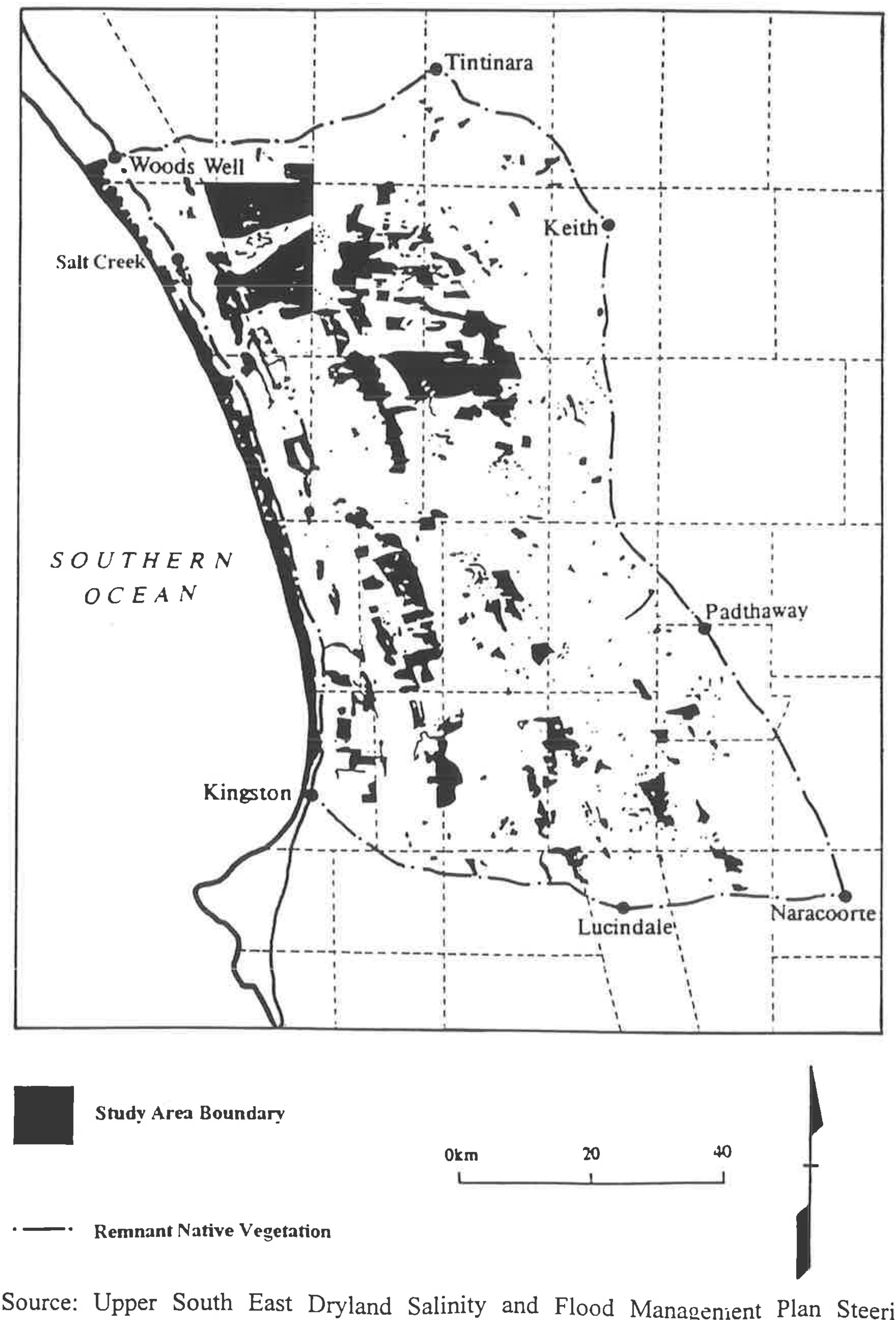
> It must be recognised that surface water is an asset and it should not be regarded as a mere liability. This water is a valuable resource and should be preserved for future use where practical to do so, a fact which takes on greater significance when we consider the extent of irrigation in our district which is draining from underground aquifers.

The City Meat Co. Pty. Ltd. also expressed concern for the conservation of surface water in a letter addressed to the District Council of Coonalpyn Downs (cited in Foale and Smith, 1991):

> We would like to see our lakes full to their natural waterline not only for aesthetic reasons and environmental reasons but also because our bores are freshened by the influx of good water in country notorious for salinity problems.

Although the problems of surface water inundation increased, vegetation clearance was halted. In 1983 legislation was passed preventing further clearance of native vegetation under the Native Vegetation Retention Act (Bakers Range and Marcollat Watercourses Working Group, 1991). Figure 5.11 illustrates the area of native vegetation remaining in 1993 (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993). The Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993) estimated that 88.4 % of the original vegetation had been cleared in 1991. The remaining native vegetation is contained within Conservation Parks or under Heritage Agreement. Comparison of the 1980 (Mowling and Barritt, 1980) map (Figure 5.7) and the 1993 (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993) map (Figure 5.11) shows that very little vegetation was cleared between these two dates. When compared with the rest of South Australia, this proportion

Figure 5.11: Area of Native Vegetation Remaining in 1993 in the Upper South East of South Australia



Source: Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993) of remnant native vegetation is a considerable amount, however, these areas of native vegetation are being threatened by flooding and soil salinisation. In addition, the water table is continually adjusting to previous clearance and continues to rise (Bakers Range/Marcollat Watercourses Working Group, 1991).

Since 1987 dryland salinity and surface water flooding have increased at a stunning rate in the Upper South East of South Australia. Over 10 000 hectares have been lost to extreme soil salinity and a further 110 000 hectares have been seriously affected (*Advertiser*, 11 August 1992). The Upper South East Dryland Salinity and Flood Management Plan Steering Committee predict that if nothing is done to lower the rising groundwater tables and to drain the districts, heavy annual surface water inundation and salinity will degrade another 100 000 hectares of agriculturally productive land within ten years. This includes 22 302 hectares of native vegetation inside Conservation Parks and on private property, where no one has yet assessed the impact of salt contamination on native fauna and migrating birds.

The outcome of landholder concern in this period has been a massive study initiated by the State Government resulting in the EIA, which was outlined in section 3.2. The Upper South East has experienced grave problems in this time period. The effects of previous activities have culminated with present activities to suddenly produce massive environmental problems. These problems are summarised in Table 5.5.

5.3 Hydrological Changes

The surface water hydrology of the Upper South East of South Australia has fluctuated throughout the past one hundred years due to both natural climatic fluctuations and the activities of Europeans. This section describes the fluctuations and alterations of the surface water hydrology in the study area.

Table 5.5: Impact upon the Upper South East Environment between 1980 and the Present

Activity	Impact
Private Drainage	Passes surface water from one property to the next with no real outlet - increasing frequency of flooding in selected areas.
Vegetation Clearance	Increasing water table level thus increasing salinity and surface water flooding

5.3.1 Rainfall Fluctuations

Rainfall records are the longest existing source of environmental monitoring in the Upper South East of South Australia. No other environmental data exist for the region to illustrate natural climatic changes that have occurred during the past one hundred years. There are a number of meteorological stations in the Upper South East, four of which were selected: Keith, Bordertown, Lucindale and Naracoorte. These stations had the longest existing rainfall records, and provided a widespread geographical representation of rainfall in the eastern and western catchments of the Upper South East.

Figure 5.12 illustrates the annual rainfall record and five year moving average for the above mentioned stations. All show a fluctuating rainfall with distinct periods of wet and dry years. Most distinct are above average rainfall periods in the late 1880s, early 1910s, mid 1940s and 1950s, early 1960s, 1970s and 1980s. Most distinct is a dry period in the 1930s. The wet years correlate with the years of flood as described section 5.3.2. However, the magnitude of the floods have been much reduced in recent years in comparison to the actual rainfall. The reduction of rainfall in the 1930s correlates with a period of rapid development in the Upper South East suggesting that Foale and Smith (1991) were correct in their assumption that dry years and agricultural development were related. Figure 5.12 also illustrates that rainfall throughout the region is not uniform. The amount of and patterns of rainfall very from station to station, even within the eastern and western parts of the catchment area.

The cumulative percentage deviation of the mean annual rainfall was graphed for the same four meteorological stations (Figure 5.13). This figure illustrates more clearly the wet and dry periods that have occurred in the Upper South East. For example, the turn of the century and the 1970s illustrate decades of higher rainfall whilst the late 1930s, early 1940s demonstrate a decade of drought. These results fit the pattern described by Pittock (1975) for meteorological stations in eastern Australia. That is, a wide spread reduction of rainfall occurred over much of Australia in the 1940s. The most modern reduction in the cumulative percentage deviation of the mean curves, indicate that the Upper South East is currently within a similar fluctuation. It may be expected that a high rainfall period will occur at the turn of the twentieth century.

To more closely examine the relationship between flood events and rainfall, the flood years (as determined from the historical record) were overlayed on the Lucindale rainfall record at various resolutions. Figure 5.14 illustrates the annual, monthly and seasonal rainfall totals for the Lucindale Post Office. Figure 5.14a illustrates the annual rainfall for the entire length of the records. This Figure indicates that a flood does not always result during an above average rainfall year. This pattern is especially prevalent post 1980s when the current drainage network was fully developed.

Figure 5.14b examines the monthly rainfall totals for the period between 1979 and 1985. During this period floods were experienced in the winter/spring of 1981 and 1983. The 1981 monthly totals illustrate high winter rainfall which resulted in a flood, but this peak is

Figure 5.12: Rainfall Record and Five-Year Moving Average of Keith, Bordertown, Lucindale and Naracoorte

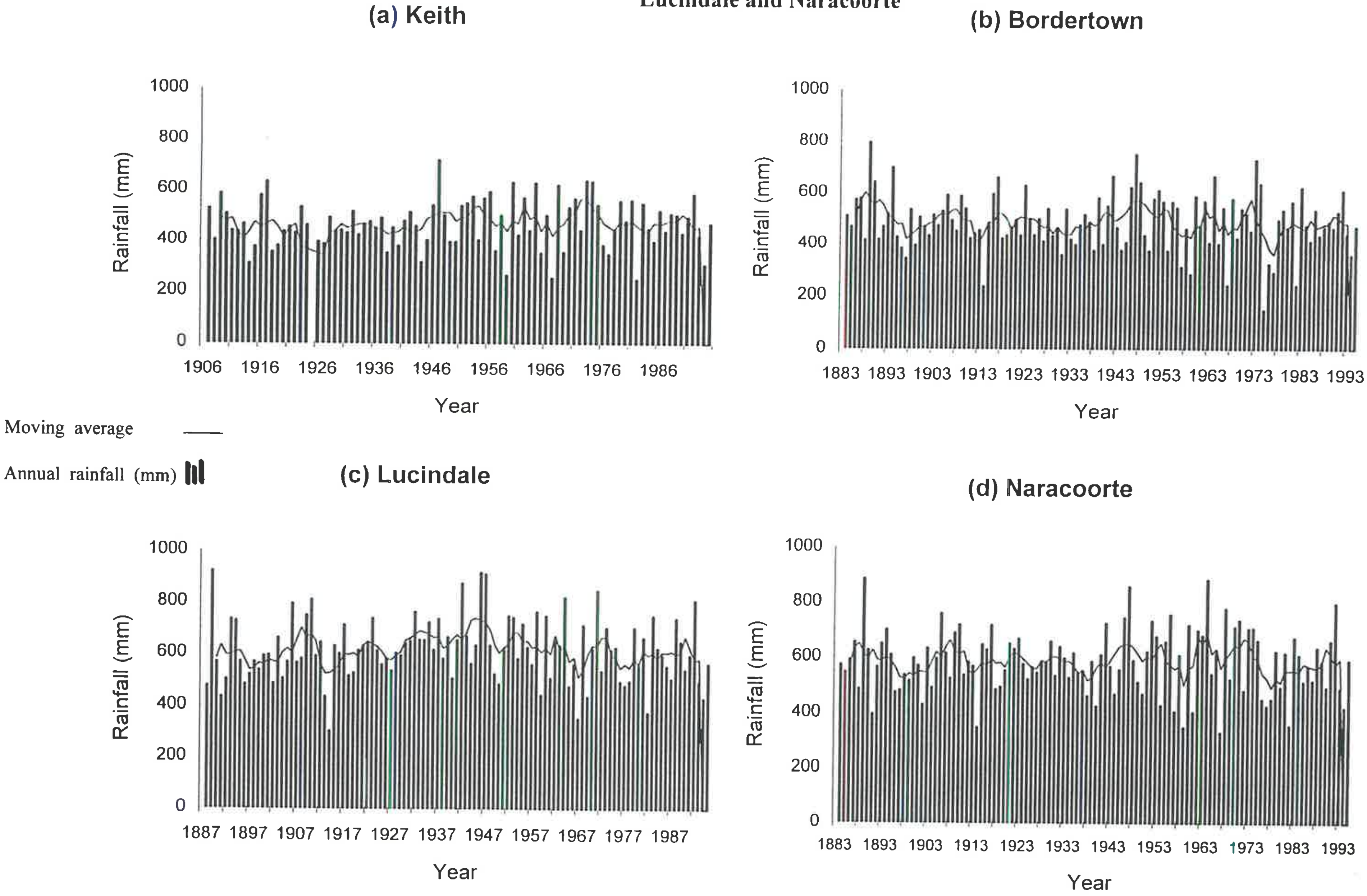


Figure 5.13: Cumulative Percentage Deviation Of Mean Annual Rainfall of Meteorological Stations in the Upper South East

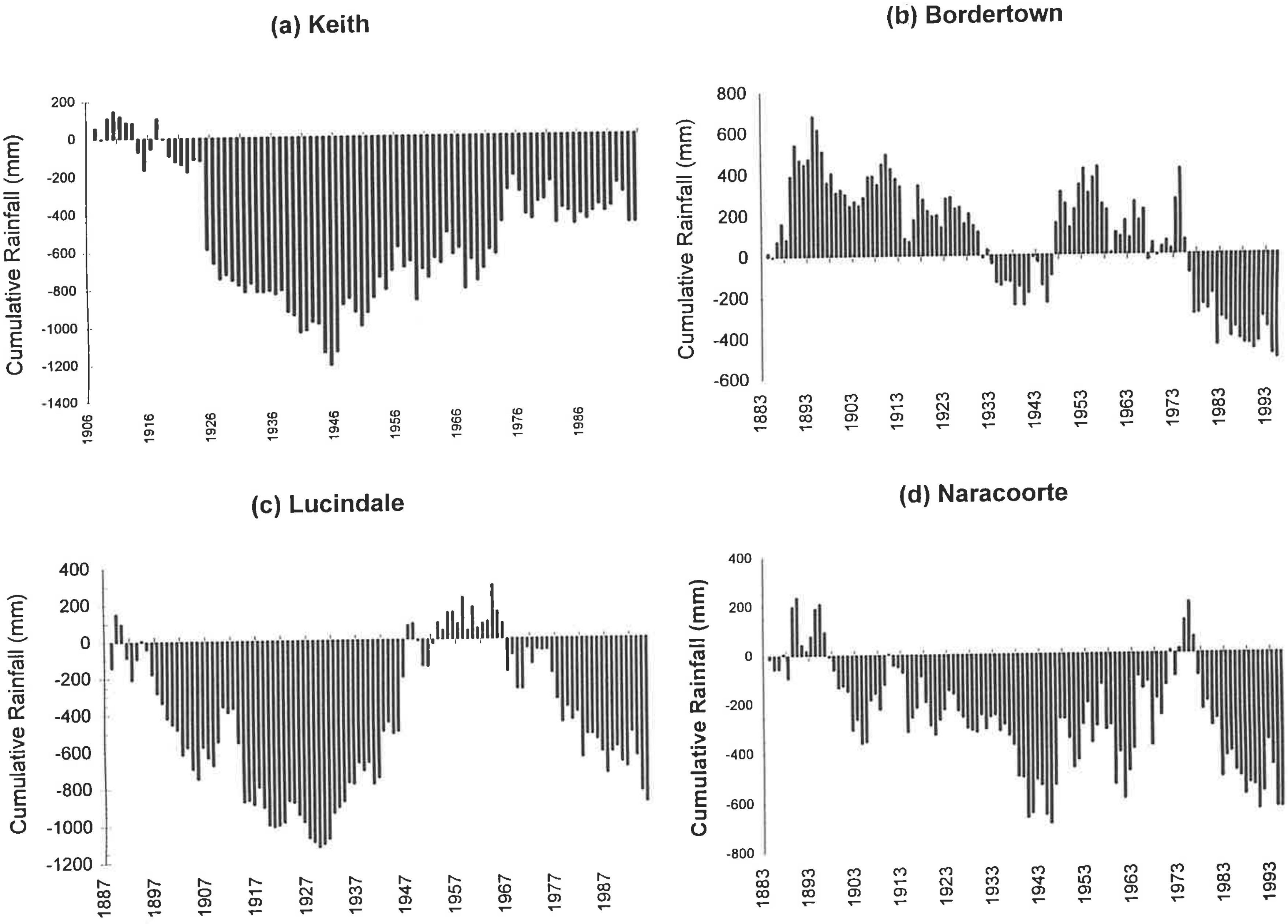
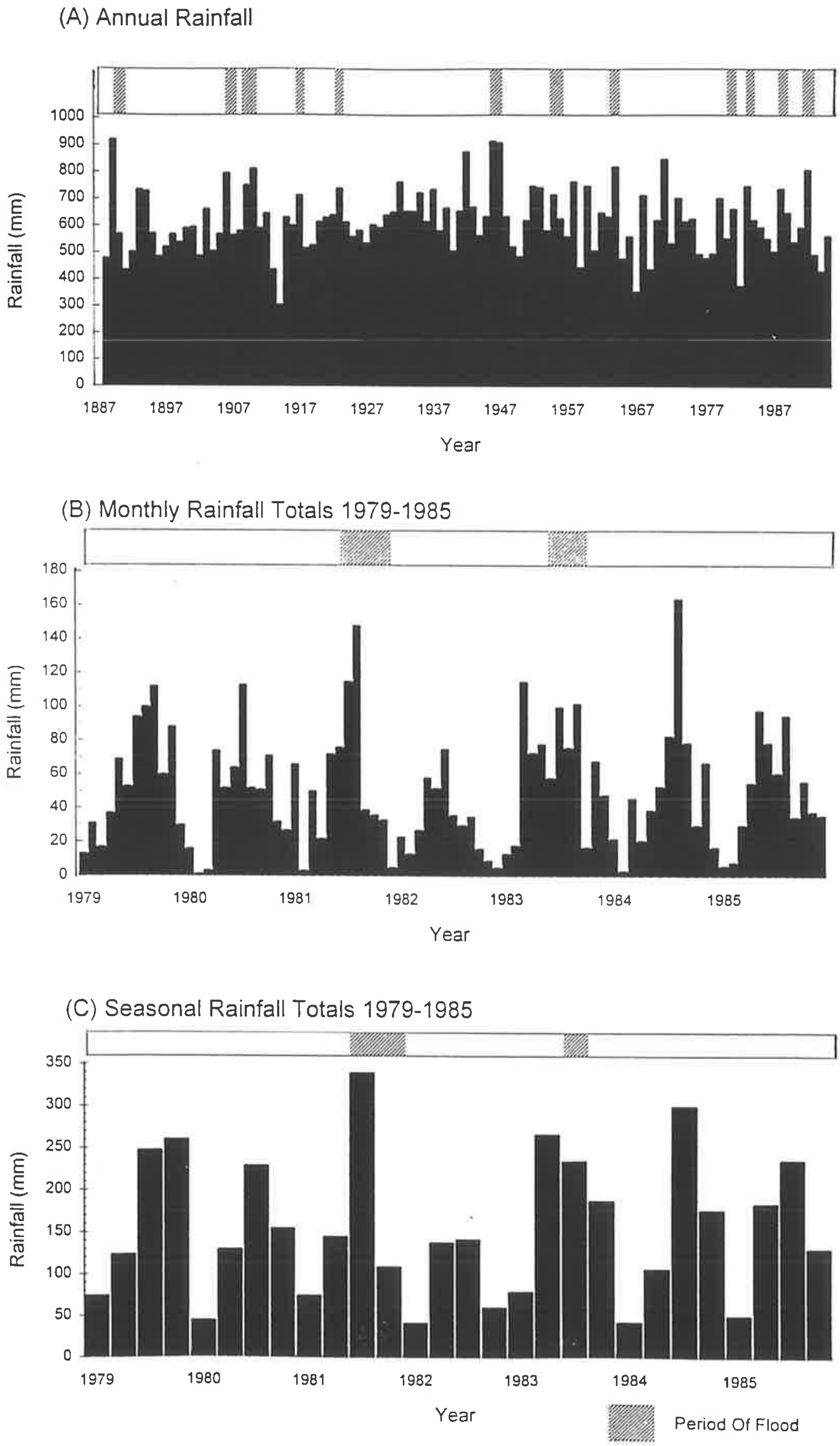


Figure 5.14: Lucindale Annual Rainfall and the Upper South East Historical Flood Event Record



similar to that experienced in 1984, in which no flood occurred. The 1983 monthly totals indicated high rainfall in the late summer and autumn months which would have contributed to the occurrence of the flood. This appears to be a atypical year.

Figure 5.14c examines the seasonal rainfall totals for the same period of time. It illustrates that 1981 had an extraordinarily large winter total that caused the flood event. The 1983 seasonal totals were large throughout the year, saturating soils and water storage areas, and resulting in a flood late in the year. Other years, such as 1984, had low summer rainfalls depleting storage areas.

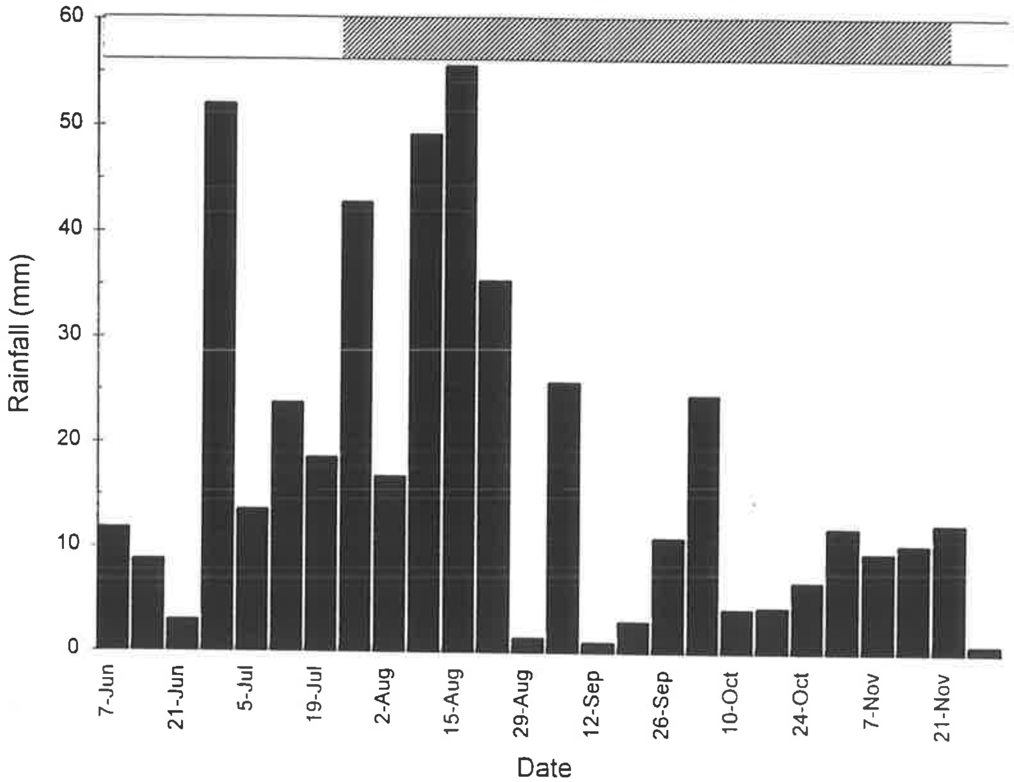
More information on the occurrence of flood events was obtained from weekly and daily rainfall totals (of the Lucindale Post Office) of the 1981 flood event, which are illustrated in Figure 5.15. The weekly rainfall totals (Figure 5.15a) illustrates that rainfall was very high throughout July and August possibly saturating soil water storage and causing a flood before water had time to soak and evaporate into the aquifers. This pattern is highlighted in the daily rainfall record (Figure 5.15b) with four weeks of very high rainfall days. The first two weeks of July experienced only eight days of rainfall, but two of these days experienced very high rainfall totals (18 mm and 22 mm). The weeks preceding and following this period also had large totals on most days of the week.

These records suggest that flood events are triggered by large amounts of rain received in very short periods of time. Floods are especially likely to occur in years of high summer rain when water storage areas fill. The trigger to a rainfall event is large amounts of rain in a period of days. At these times rain falls so rapidly that water storage areas are unable to disperse the water and instead a flood event occurs.

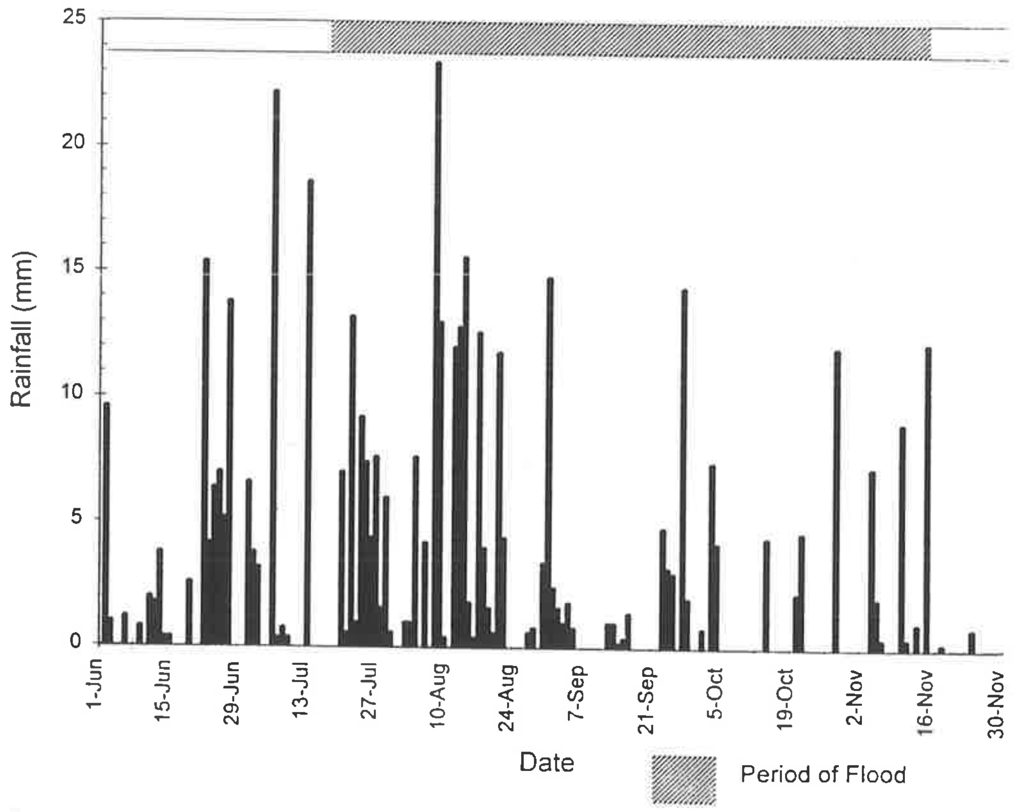
In addition, flood events in the Upper South East correlate with La Niña events. Figure 5.16 illustrates the Southern Oscillation Index (SOI) constructed by Nicholls (1991) for the

Figure 5.15: Daily Rainfall for Winter/Spring 1981

A. Weekly Rainfall Totals for Winter/Spring 1981

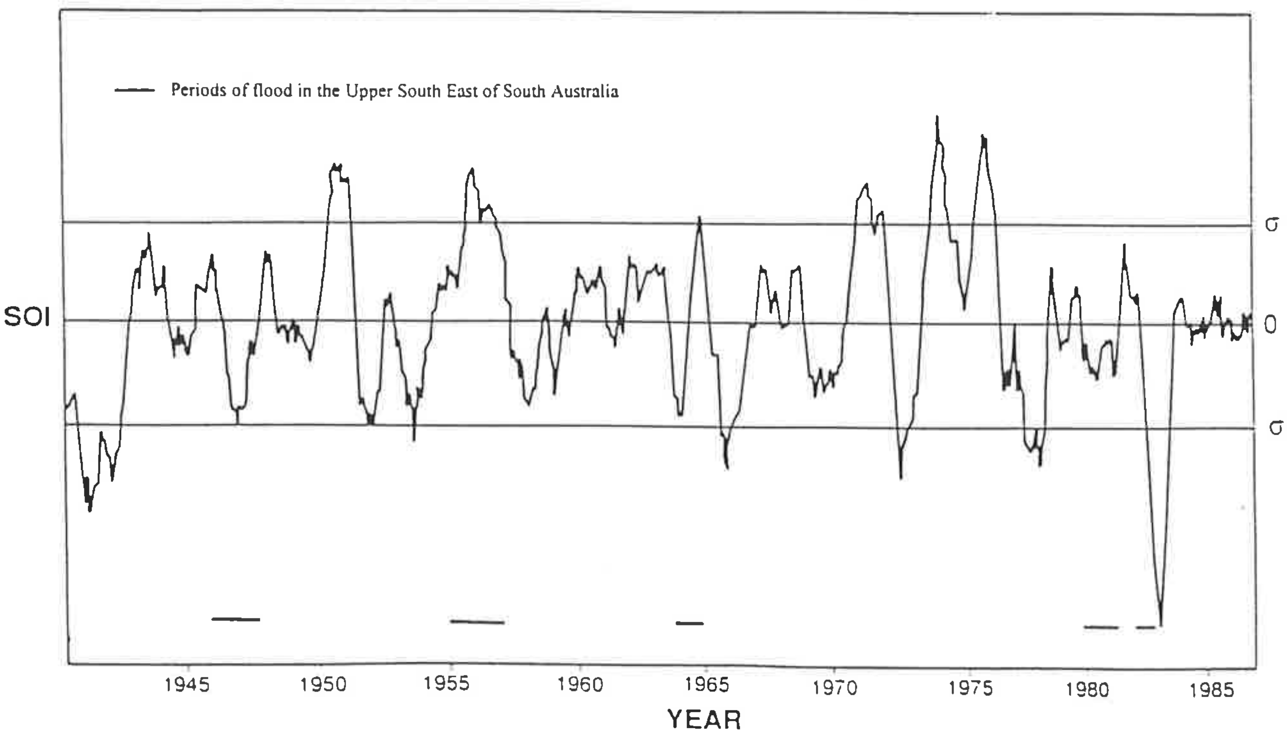


B. Daily Rainfall Totals Winter/Spring 1981



years 1940 to 1987, with the historical flood record of the Upper South East overlayed. The Figure demonstrates that floods occurring within this time frame all occurred in years in which the SOI was above average, excepting the 1946/47 flood. Thus flood occurrence in the Upper South East is affected by oscillations in the world's climate in addition to local climatic influences.

Figure 5.16: The Southern Oscillation Index and Flood Events in the Upper South East



5.3.2 Floods and Drains

European activities in the Upper South East have gradually altered the pattern and timing of floods. Primarily alterations in the hydrological regime are due to the construction of drainage related structures, but activities such as vegetation clearance and urban development have also affected the Upper South East hydrology. This section outlines the floods that have been recorded in the historical record of the Upper South East, and the known drainage structures within each watercourse that have altered the natural surface water hydrology of the region.

The first reported flood in the Upper South East occurred in 1870. Since then severe floods have been recorded in 1880, 1889, 1906, 1909, 1910, 1917, 1923, 1946/47, 1955/56, 1964, 1981, 1983, 1988/89 and 1992. Comparison of these flood events is very difficult because the method of reporting each event has differed and the construction of the many drainage structures has altered the direction and flow of surface water. Also, recording instruments have only recently been installed at key locations in order to provide quantitative data. Thus, while each flood can be described, comparison of flood events cannot be accurately conducted.

The first two floods reported in the Upper South East are briefly mentioned in newspaper or government reports. A flood in 1870 was mentioned in the *N'Hill and Tatiara Mail* (27 April 1889); "in the winter of 1870 or 1871 we had a tiny dose of the fluid ...". The 1870 flood occurred in the eastern watercourses (the Marcollat, Duck Island and Mount Charles watercourses) but it is unknown if it affected the Tilley Swamp and the Bakers Range watercourses. The second flood, in 1880, was recorded by Mr. Goyder when he was sent to survey the flood damage at Lucindale. The 1880 flood affected the Tilley Swamp and the

Bakers Range watercourses but it is unlikely to have affected the eastern watercourses as no record of it was found in the Bordertown or Naracoorte based newspapers.

There is no contemporary record of the 1889 flood, but the *Border Chronicle* of 30 July 1909, under the heading "Reminiscences" refers to "the flood that old residents like to dwell on is that of 1889 ... What we call the big flood. In that year the railway line was damaged, the bridges at Langaehr's and on the Pigeon Flat Road were swept away". Because this flood event was so large it is presumed that it affected the whole Upper South East. A subsequent flood in 1893 was also described many years after the event, this time thirteen years after its occurrence. It was reported to be a "mild flood" (*Naracoorte Herald*, July 24 1906).

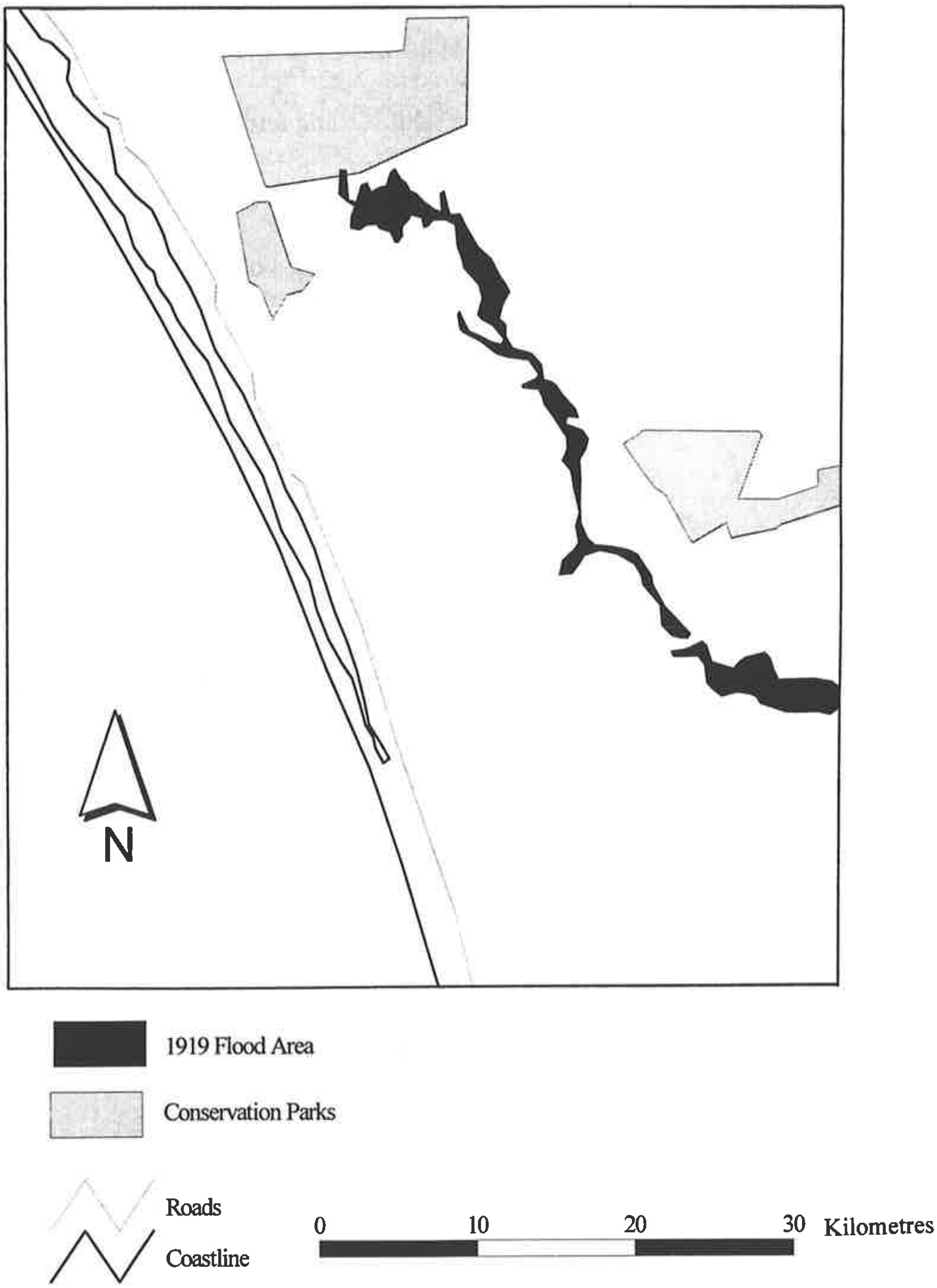
The 1906 flood was the first flood to be directly reported. It was described in the *Naracoorte Herald* to have nearly reached the levels of the 1889 flood. "Old residents are unanimous in their opinions that the present is the largest flood that they have seen here for 17 years" (*Naracoorte Herald*, 27 July, 1906). Between 1906 and 1911 there was an above-average rainfall in the South East (Jones, 1985). The biggest flood in this period was in 1909. On 30 July, 20 August and 27 August, the *Naracoorte Herald* reported the following, respectively:

> It is many years since so much water was seen lying around and farmers are grumbling at the way in which the paddocks are covered.
>
> Old residents may remember great floods in the Tatiara District in the 1880s but not since that time has such a flood been witnessed as the one we are now experiencing.
>
> When we went to press last Friday morning we stated that the flood had exceeded that of 1906 but was not equal to that of the 1880s, although the water was steadily rising. Old residents did not expect such a flood as that which resulted during Friday afternoon and evening, the extent of country covered being greater than ever before witnessed.

In 1917, another flood occurred, although little information has been discovered describing it. The only reference to it is in Jones (1985) for the Mount Charles and Duck Island catchments. The presence of flood waters in the western watercourses became apparent in the succeeding two years of literature. The Commissioner of Public Works mentioned water appearing at Alf's Flat in September of 1917 (Commissioner of Public Works, 1918). It was noted in this report that the lake had destroyed trees of thirty to forty years age due to the long period of inundation, indicating that extensive flooding in Alf's Flat had not occurred during that period. The Engineer in Chief suggested cutting bars to carry the water northward into Lake Albert. This never occurred. In fact the lake increased in extent and depth in the winter of 1919 as reported by the *Adelaide Advertiser* (March 7 1919); "an immense lake of beautiful fresh water has come into existence ... covering thousands of acres [4000 acres] and of considerable depth". Figure 5.17 illustrates the areal extent of the flood waters in spring of 1919 as identified from aerial photographs.

The wet period in the South East continued as a major flood event occurred in 1923. A Bordertown based newspaper described record rain: "heavy rain started last weekend and continued for three days. Though no single day's rain has been specially heavy the fall has been so consistent since the season broke in May that there are fears of a repeat 1906 flood" (*Border Chronicle*, 21 July 1923). On July 17 1923 the District Council of Tatiara wrote to the Commissioner of Public Works, reporting that "owing to the continuous heavy rains much of the Cannawigara and Buckingham country is practically under water, and unless some means are speedily found to drain the land, thousands of acres of crops will be ruined" (Commissioner of Public Works, 1923). This flood must have occurred in all catchments of the Upper South East to be affecting both Bordertown and the Buckingham country.

Figure 5.17: 1919 Flood Area



During the period between 1930 and 1944 no major floods were recorded. This period saw the beginning of an interest in development and closer settlement in the Upper South East. The two are probably related (Foale and Smith, 1991). However, as if to remind those concerned that perhaps this period without a flood was rather unusual, two major flood events occurred in 1946 and 1947. In 1946 the *Border Chronicle* reported exceptionally heavy falls of rain throughout the district with Nalang and Tatiara Creeks overflowing their banks causing extensive flooding (25 July 1946). Old residents of the region believed it was the biggest flood for over fifty years from the volume of backwater feeding both creeks. The *Border Chronicle* also reported the surrounding districts to be extensively submerged with the extent of the damage impossible to estimate. A repeat flood occurred in 1947 (*Border Chronicle*, 4 September 1947):

> Tatiara district has experienced its second severe flooding within two years, resulting in hundreds of acres of land being completely inundated ... Heavy falls of rain throughout the district and across the Victorian border this week have been responsible for Tatiara's second extensive flooding in two years.

The next decade (between 1947 and 1955) no floods occurred in the Upper South East. In this period settlement of the Upper South East proceeded rapidly, so when floods occurred in both 1955 and 1956 they took on a special significance. The area now contained a lot more landholders and the floods were better reported. This flood followed different directions than previous floods thus inundating previously dry areas. The influence of the drainage networks upon the region was evidenced by an old resident claiming that "the water this year had come down quicker than in earlier years. If this is so we can look for more frequent and quicker flooding" (*Border Chronicle*, 8 September 1955). It is apparent that drainage structures were altering the characteristic flow of natural flood events.

The *Border Chronicle* (11 August 1955) described 1955 as the worst flooding of the Tatiara Creek on record and the South Eastern Drainage Board described it as a 1 in 50 year flood event (Marcollat Watercourse Resources, 1979). Whilst the 1955 flood was very large and affected the entire Upper South East, its main significance was that it was followed by a similar flood in 1956.

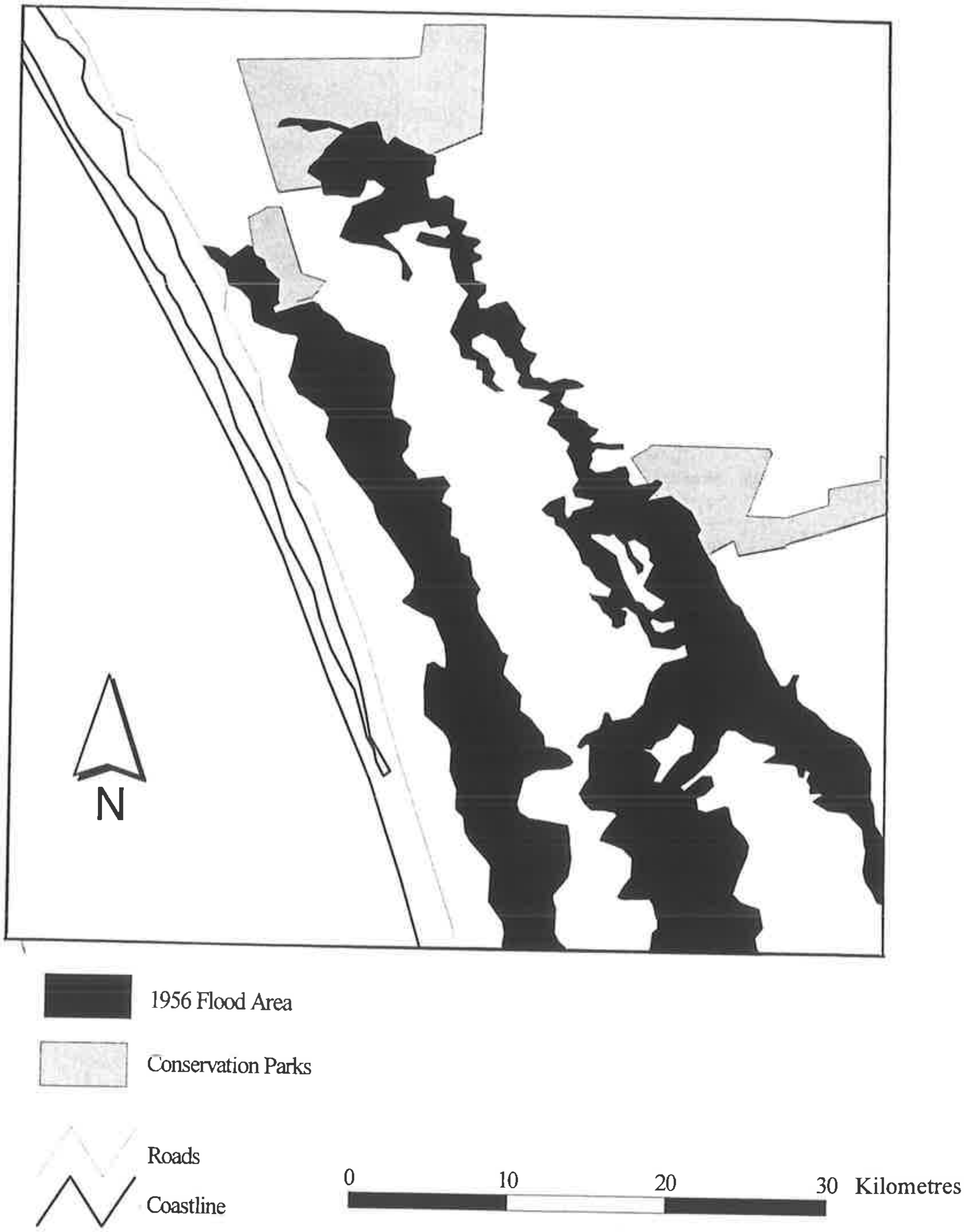
The 1956 flood raised less excitement than the 1955 flood. The *Border Chronicle* merely observed that "the roads in Buckingham and Cannigwara had been rendered impassable by the flood waters" (13 September 1956). Foale and Smith (1991) report that Alf's Flat filled up and then overflowed onto Gum Well in 1956. That is the biggest flood ever experienced in the Bakers Range watercourse, and may have been due to drainage activities in the Lower South East rather than the actual volume of rainfall. Because both the 1955 and 1956 floods rapidly succeeded each other, surface water remained in the Upper South East for a number of years afterwards until it either evaporated or seeped into the groundwater stores. Figure 5.18 illustrates the extent of the 1956 flood waters.

Flooding occurred to a much lesser extent in the early 1960s (Marcollat Watercourse Resources, 1979). The only newspaper report found was that of a flood in 1964 which occurred after a very wet winter; "large areas of the country side are inundated and the Tatiara Creek is running strongly" (*Border Chronicle*, 16 July 1964).

Once again, a dry period occurred from the mid 1960s until 1981. In 1981 the Upper South East experienced one of the largest flood events since European settlement. This flood event was also one of the best documented events because gaging instruments had been installed in the area.

In the Lower South East (South Eastern Drainage Board, 1982):

Figure 5.18: 1956 Flood Area



> Most drains were flowing to capacity during the 1981 winter and there was some flooding from nearly all subsidiary drains for a short period. The inundated land drained quickly when rains abated and drain levels dropped. Although large areas suffered shallow flooding the drains functioned well and restricted permanent damage to small areas.

However, in the Upper South East (South Eastern Drainage Board, 1984):

> The nearly average rainfall experienced by the district in June and August toppled by very heavy falls in September caused peak flows in the northern watercourses.

In the eastern portion of the Upper South East the Tatiara and Nalang Creeks were in full flood and burst their banks on 7 and 9 August 1981 (*Border Chronicle*, 11 August 1981). This situation continued repeatedly throughout August and into September. By this stage the flood mitigation measures were able to contain the flood in the south and it was only in the east that large scale flooding occurred outside of the watercourses. The large amount of flooding that occurred in the Upper South East, by comparison to the Lower South East, is indicative of the number and nature of drainage structures in the two regions. By this time the Lower South East had a complete coordinated drainage network. However, the Upper South East had very few government constructed drains and the private drain network was uncoordinated with no outlet for excess surface water.

Although 1982 was a extremely dry year, 1983 was wetter resulting in some strong flows in the Upper South East. This event mostly occurred because the excess surface water of the 1981 flood remained in some areas.

> Generally speaking, peak flows along the northern watercourses during the period of late September/October 1983 were far below 1981 winter levels. One exception being strong and prolonged flows at Jip Jip on the Marcollat watercourse, however, these were still below the 1981 levels. No serious flooding occurred as the water was mostly confined within the watercourse

> area with some inundation of adjoining flat country (Minister of Water Resources, 1982).

The most recent large flood event occurred in 1988 and 1989. The 1988 winter rainfall was above average resulting in substantial flows in all catchment areas and drainage systems (South Eastern Drainage Board, 1989). The flood highlighted the problems of an uncoordinated drainage network as disputes between neighbouring property owners arose. Figure 5.19 illustrates the flood waters remaining in November 1988.

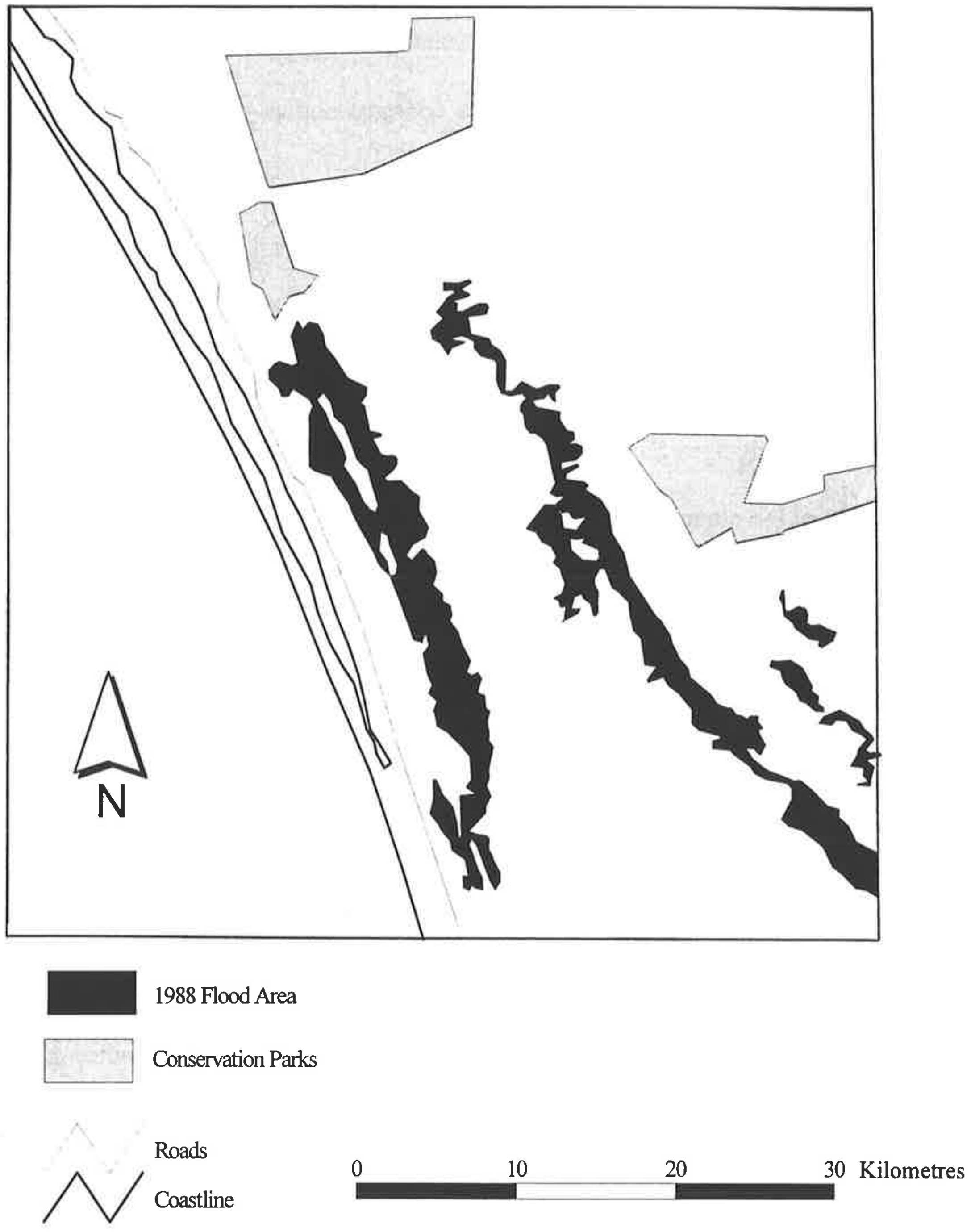
As in the mid 1940s and 1950s, the 1988 flood was followed by a flood in 1989. An account of the 1989 flooding is included in the 1989-1990 'Annual Report of the South Eastern Drainage Board' (South Eastern Drainage Board, 1989):

> The 1989 winter rainfall produced rainfall which, following the wet winter of 1988, resulted in substantial flows in all catchment areas and drainage systems. In the Upper South East the Bakers Range Watercourse flow caused significant inundation of adjoining pasture. The long term inundation of pastures causes considerable loss to landholders both through loss to grazing during inundation and also the following year and requirement for alternative agistment and pasture re-establishment costs. Many properties suffered for the second successive wet year and have sought implementation of solutions to avoid this becoming an annual loss.

The most recent flood event, the 1992 flood, was relatively mild by comparison, and was contained within existing drainage structures. The South Eastern Drainage Board Annual Report reported (South Eastern Water Conservation and Drainage Board, 1993, p. 2): "flows along the northern watercourses were above average and water reached the terminal wetlands in Messent Conservation Park for the first time since the intensive southern drainage system was completed".

Consecutive dry years in 1993, 1994 and 1995 have resulted in the Upper South East wetlands to experience below average flows. Some wetlands are now drying out except

Figure 5.19: 1988 Flood Area



areas where artificial control mechanisms exist to retain water for the benefit of flora, fauna and surrounding agricultural areas.

Table 5.6 summarises the floods that have been recorded in the Upper South East of South Australia. It also provides an attempt to compare the flood events. When doing such a comparison it should be remembered that changes in flow volumes, speeds and directions of surface water have occurred that are a consequence of the construction of drains and banks, including drains constructed by the South Eastern Drainage Board in the Lower South East and privately in the Upper South East. These alterations make the flood record of the region very complex to understand and difficult to predict. Evidence does indicate that over the period of European settlement the direction and speed of surface water movement has changed as a result of drainage constructions (Foale and Smith, 1991). A description of the alteration of surface water movements within the hydrological catchment areas of the Upper South East during the period of European settlement follows.

5.3.3 Alterations to Watercourses

5.3.3.1 Tilley Swamp Watercourse

The Tilley Swamp watercourse runs from Kingston to Salt Creek, parallel to the Coorong (Figure 5.20). Before European settlement, the major source of water for Tilley Swamp were the Reedy Creek and Avenue Flat watercourses in the Lower South East. Numerous limestone bars crossed Reedy Creek prior to European settlement hindering the flow of surface water (South Australian Parliamentary Papers, 1872), whereas Avenue Flat had few sand bars, allowing water to run freely over a large surface area. At several places the water from Avenue Flat washed into Reedy Creek until they joined at Tilley Homestead. Some waters then diverged south west into Maria Creek, the remainder flowing north west to Henry's Creek and then into Tilley's Swamp.

Table 5.6: Record of Flood Events In The Upper South East of South Australia

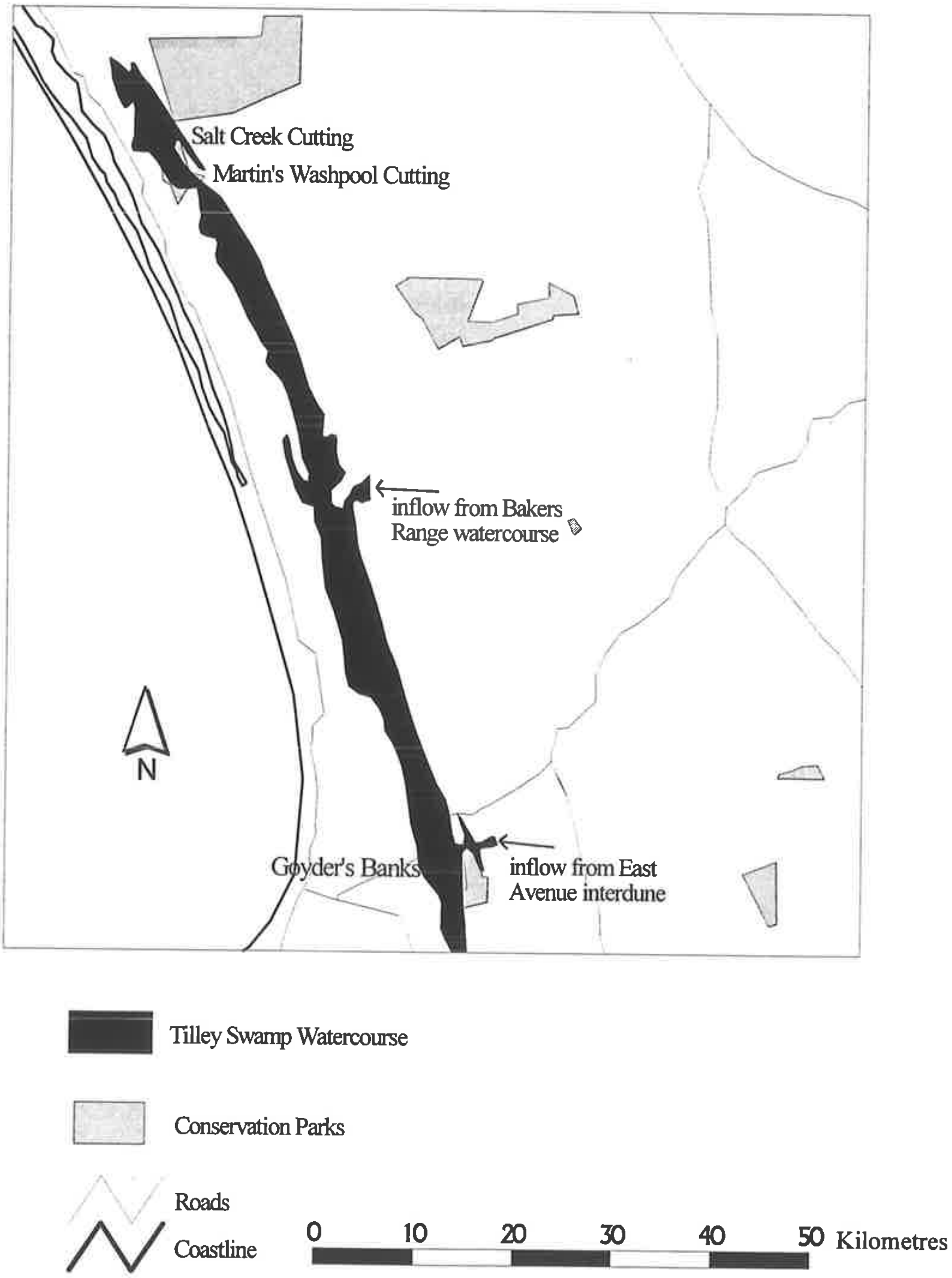
Year	Area Flooded	Source of Water	Severity of Flood
1870	Mt Charles WC*	west Victoria	mild
	Duck Is and Marcollat WC??		
1880	Tilley Swamp WC	Lower South East	moderate
	Bakers Range WC		
	Eastern WC's ??		
1889	all Upper South East catchments	west Victoria and the Lower South East	severe
1893	Mt Charles and Duck Is WC's	west Victoria	mild
	Marcollat WC ??		
1906	all Upper South East catchments	high rainfall in all catchments	mild
1909	Marcollat, Duck Is and Mt Charles WC's	west Victoria	moderate
1910	all Upper South East catchments	high rainfall in all catchments	mild
1917	Mt Charles and Duck Is WC's. Marcollat WC ??	west Victoria	mild
1923	all Upper South East catchments	west Victoria and the Lower South East	major
1946/47	all Upper South East catchments	west Victoria and the Lower South East	severe
1955/56	all Upper South East catchments	west Victoria and the Lower South East	severe
1964	Mt Charles WC. Marcollat WC and Duck Is WC ??	west Victoria	mild
1981	all Upper South East catchments	west Victoria and the Lower South East	severe
1983	no serious flooding in any catchments	west Victoria and the Lower South East	mild
1988/89	all Upper South East catchments	west Victoria and the Lower South East	severe
1992	no serious flooding in any catchments	west Victoria and the Lower South East	mild

Source: the table was compiled from a variety of sources all mentioned in the above text.

*WC = watercourse.

?? Indicates inferred flood events that were not mentioned directly in historical records.

Figure 5.20: Tilley Swamp Watercourse



Once surface water reached the northern reaches of the Tilley Swamp watercourse, it pooled in Martin's Washpool. Martin's Washpool had to fill before water overflowed to Salt Creek, the northern outlet of the Tilley Swamp watercourse. Martin's Washpool episodically filled to a depth of approximately three metres, as evidenced by unconsolidated calcrete-clast gravels and pebbles on a stranded shoreline beach (von der Borch, 1993). Examination of the beach deposit suggested that it was only periodically flooded, at which time the lake waters would have drained rapidly to the Coorong via Salt Creek (von der Borch, 1993). The course of surface water in Tilley's Swamp was very circuitous over large flats, and through narrow channels between the spurs of the hills.

Before drainage of the Tilley Swamp watercourse took place, both Reedy Creek and Tilley Swamp contained a large amount of water. In 1864, it was suggested a canal be constructed along the Reedy Creek, connecting with the Coorong near Kingston (South Australian Parliamentary Papers, 1872). It was planned that the canal would be used as a major transport route, so that steamers could communicate from the Lower South East to Kingston, which at the time was a major port for the region.

At the same time as the canal was suggested, Goyder (the Surveyor General) proposed draining the Tilley Swamp watercourse (South Australian Parliamentary Papers, 63). His proposal involved cutting a channel through the ridge that separated the northern end of Tilley's Swamp from Salt Creek. Excess surface water between Martin's Washpool and Salt Creek would then drain into the Coorong, making the area easier to cross in the winter months. This plan proceeded and was reported by the *Border Watch* in 1865: the Salt Creek cutting was in some places over twelve feet deep and "down which the water appears to be running at the rate ... of about four miles per hour, 16 to 20 inches deep and nearly twenty feet broad. Such an outlet must carry of an immense body of water" (28 January 1865).

In 1886 the Blackford embankment, also known as Goyder's banks, were strategically constructed in the path of Reedy Creek. These banks diverted all surface water towards the Tilley's Swamp watercourse, and away from the Maria's Creek outlet. The country adjacent to the upper reaches of Reedy Creek benefited, but the banks accentuated flooding in the northerly portions of the watercourse. The breaching of sandbars in the Avenue Flat watercourse, and a cutting through the West Avenue Range (the Wilmot Cutting) compounded the increase of flooding in the northern portion of the Tilley Swamp watercourse (Foale and Smith, 1991). The frequency and quantity of floodwater reaching the Tilley Swamp watercourse was thus intensified in this time period.

The trend towards increasing amounts of surface water in the Tilley Swamp watercourse was reversed in 1912 and 1913, when Stopbanks H and F, and Cutting G were constructed. These works prevented surface water from the Bakers Range watercourse moving into the Tilley Swamp watercourse by directing it north west through Cutting G. In addition, stage one of Drains L and M were completed in 1916/1918, which further decreased the flow of surface water to the Tilley's Swamp. The present system of drains has continued this trend. According to the South Eastern Drainage Board it is probable that the intermittent flow from Tilley's Swamp to the Coorong is now of the order of the flow to the Coorong before any drainage works were undertaken (Ligertwood, date unknown).

While Government constructed works were being reported, a large number of private drains were being built by landowners that went unrecorded. In 1936, Joseph Gall, who controlled the area of Tilley's Swamp, reported that "we have reclaimed about 3000 acres in Tilley Swamp by building embankments and keeping the water off. As a result of this work we have been able to utilise country we have not been able to use previously... " (South Australian Parliamentary Papers, 1936).

The other Government constructed drains that affected the Tilley Swamp watercourse were the Jacky White's and Blackford Drains, which were constructed between 1965 and 1970. These drains diverted the Reedy Creek and West Avenue watercourses directly to the sea, reducing the amount of water flowing into the Tilley Swamp watercourse.

The surface water hydrology of the Tilley Swamp watercourse has been dramatically altered during the period of European settlement. An indication of the changes that have occurred are provided in the South Eastern Drainage Board Annual Report describing the 1981 flood (South Eastern Drainage Board, 1982):

> Since the completion of the Blackford/Jacky White's drainage system no flows of any consequence have passed through this watercourse. ... Although there were large areas of inundation through the watercourse the flooding was generally confined to undeveloped land. Private works were generally successful in preventing widespread damage to developed grazing land.

Prior to the settlement of Tilley Swamp watercourse, very little water from the Lower South East reached the northern reaches of the watercourse and the Coorong. Progress of surface water was halted by bars of higher ground between the swamps and by the low range immediately east of the Coorong, thus, water accumulated in the southern swamps. Only in years of very high rainfall did the swamps fill and overflow, which allowed a limited amount of water to reach the Salt Creek and the Coorong (South Australian Parliamentary Papers, 1864).

When agricultural development of the Lower South East began, the Tilley Swamp interdune area was used as the transport route between Adelaide and the Lower South East.

Some drains, cuttings and bridges were constructed to aid road access to the south. These cuttings encouraged surface water to move north west from the Lower South East towards the Upper South East. Rather than pool in swamps along the watercourse, surface water was rapidly moved northward and discharged into the Coorong at Salt Creek. Between the 1860s and 1912 greater amounts of surface water flowed into the Tilley Swamp watercourse, and was rapidly moved northward, increasing the discharge of surface water to the Coorong, than the amounts which would have been discharged under natural conditions.

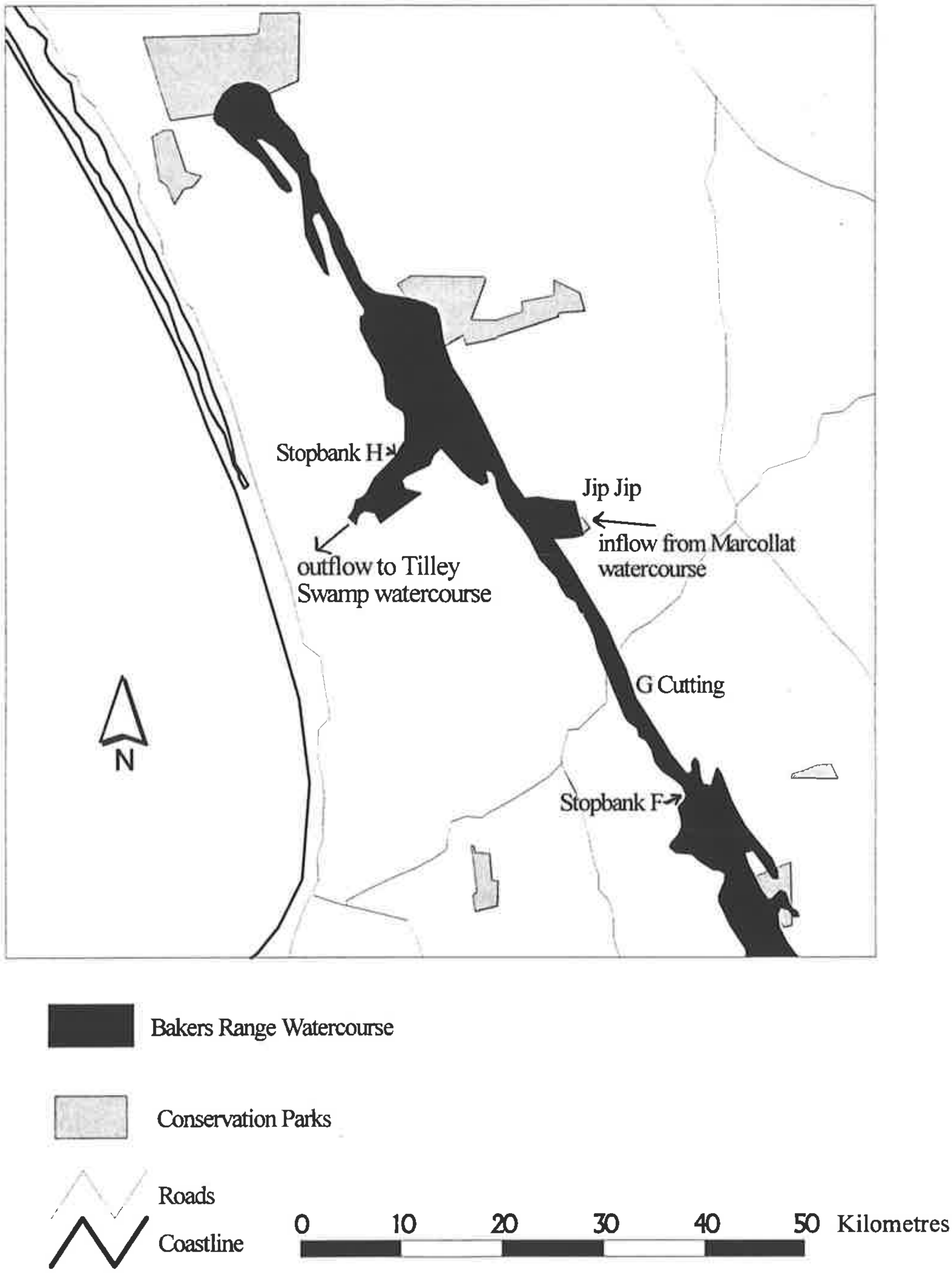
After 1912, drainage works in the Lower South East diverted water westward to the sea rather than northward to the Coorong, as this direction was the most economical method of draining the agricultural land. Thus, the Tilley Swamp watercourse experienced conditions drier than the pre European settlement regime after 1912. It was believed by the South Eastern Drainage Board that the effect of private drainage schemes within the northern reaches of the Tilley Swamp watercourse reversed the impact of the Lower South East drains, so that the new hydrological regime was not significantly different from that of the pre settlement regime (South Eastern Drainage Board, 1981).

5.3.3.2 Bakers Range Watercourse

The Bakers Range watercourse runs between the Peacock and East Avenue Ranges (Figure 5.21). It originates as a watercourse of the same name in the Lower South East. Near Jip Jip, some of the Marcollat watercourse surface water joins the Bakers Range watercourse, and from there surface water moves northward through Cortina Lakes and terminates at Alf's Flat, which is located within the Messent Conservation Park.

Drainage of this watercourse began in 1897 with the construction of the Bakers Range Drain in the Lower South East, which increased the flow of surface water into the Upper of

Figure 5.21: Bakers Range Watercourse



South East (Foale and Smith, 1991). The amount of surface water in the upper reaches Bakers Range watercourse was further increased in 1912 and 1913 when Stopbanks F and H, and Cutting G were constructed. Stopbank F prevented the Bakers Range watercourse from transferring water west into the Reedy Creek, instead surface water was directed north west through Cutting G. Stopbank H, built in 1912, prevented Bakers Range surface water overflowing westward into Henry Creek, and the total flow of water moved towards Alf's Flat (South Eastern Drainage Board, 1979).

At the same time (1912), the Bakers Range Drain was extended northwards into the Upper South East. In 1915 and 1916, Drain E was constructed in the Marcollat Watercourse to encourage the discharge of surface water from the Marcollat Watercourse to the Bakers Range Watercourse at Jip Jip waterhole. Construction of both drains increased the amount of surface water in the Bakers Range watercourse.

Bakers Range watercourse gained publicity in 1918 when a period of successive wet years filled Alf's Flat, producing a very large lake. A letter addressed to the Commissioner of Public Works from Mr Henderson and Mr Bristowe, dated 30 October 1918, certifies such (Commissioner of Public Works, 1918):

> Last Sunday morning we returned from an expedition which took us to a point 30 miles south west of Coonalpyn on perpetual lease 1182. Here we found the whole country inundated with water, huge arms or channels stretching away in all directions. In our opinion the water extends for a distance of 30 miles. All the gullies and valleys have been filled with water leaving here and there islands and peninsulas of land. The most astonishing fact is the water is pure drinking water ... Having launched the boat ... we rowed for many miles and found the quality of the water the same everywhere. In many places the water is from 20 to 30 feet deep [6 to 9 metres].

And Mr J.T. Furner (Commissioner of Public Works, 1918) wrote:

> I was informed by Mr Mason of Salt Creek that the water first appeared at Alf's Flat about September 1917. Mr Mason also informed me that the water at Alf's Flat was at its highest level in April 1918, and had commenced to fall in that month. The depth of the water at present time is approximately 10 feet at the site of the old oil bore. I was informed by Mr McCallum of Magrath's Flat that he had not previously known water to accumulate in large quantity at Alf's Flat, and there is evidence in the destruction by water of trees 30 or 40 years old in the submerged area that it had not occurred in that period. I respectfully suggest that levels be taken to determine the extent of the work necessary in cutting bars and making a channel to carry the water into Lake Albert.

All drainage affecting the Bakers Range Watercourse up to 1918 was aimed to keep water out of the Tilley Swamp watercourse or to rid the Lower South East of water. The Bakers Range watercourse was considered a wasteland and therefore suitable for the dumping of excess surface water. It was not until the Melville and Martin survey in 1936 that the area's natural features were described (Department of Lands, 1936b):

> This large expanse of country comprises many different types of soil and undergrowth. At the southern end it receives the drainage waters from the South East, the principal streams being the discharges from the Baker's Range Drain and Drain E. These waters spread out over a wide stretch of country and eventually converge to a relatively well defined water course which in very wet seasons empties out onto Alf's Flat. Owing to this annual inundation the county south of Alf's Flat and west of Didicoolum consists of a series of watercourses and permanent swamps separated by rough stony ranges covered with dense mallee and relatively high hills carrying heath. Until relieved of flood waters the low lying lands in this portion will be of low value; many of them are distinctly saline and the soils generally speaking are relatively shallow. In their present state they carry low swamp, tea tree and cutting grass.

By 1936, the Bakers Range watercourse had experienced nearly forty years of increased surface water flow. This regime changed in 1960, when Drain M was extended eastwards, traversing the Bakers Range watercourse, towards the sea. By diverting surface water from the Lower South East westwards, the amount of surface water reaching the northern portion of the Bakers Range watercourse was restricted, and the northern reaches of Bakers Range watercourse were deprived of surface water flow.

In the 1960s and 1970s (a dry period in the South East) concern about the lack of water in the Upper South East was abundant. Drain L and M (which run east to west) had prevented the flow of water moving from the Lower South East to the Upper South East. The upper Bakers Range watercourse was dependent solely upon local rainfall as a source of water. The Coonalpyn Downs Council recognised this problem in 1981 (District Council of Coonalpyn Downs, 1988):

> Council is aware that certain natural flood waters have ceased flowing into Messent National Park, probably due to the loss of water which now passes through the Government constructed drains in the South East to the sea. The loss of water from the Messent National Park has caused the disappearance of the tortoise which, until recently could be seen in great numbers. The lack of surface water where previously it had been in abundance is causing depletion of bird and animal life in the park.

The lack of surface water in the Bakers Range watercourse and its effects were highlighted by Mr Bill Bartlett in 1981 (District Council of Coonalpyn Downs, R2/10):

> I would like to bring to your attention what I feel to be a very sad and tragic state which has been allowed to happen to our Messent and Gum Lagoon Conservation Park and also the land in between and the Coorong itself. One time we had a wonderful wet lands area through from the Lower South East region flowing through to Salt Creek, which was teeming with bird and animal life and very nice recreation area. But with over drainage and over clearing, I have seen the parks slowly dying. Over the last 45 years that I have been associated with the Messent CP, the water has disappeared to the last 2 or 3 waterholes which I have cleaned out from time to time. Given a few more years no doubt they will dry up as well. I read a lot of articles concerning over drainage over clearing and excessive lucerne pastures being the reason, but I personally feel that perhaps the reason may be over talk, not enough thought for the environment and greed would be the real reason.

Whilst the South Australian government constructed drainage networks in the Lower South East, private drains were also being built in the northern Bakers Range watercourse. However, the location and date of the drainage constructions were unknown. The effect of the private drains was believed to oppose that of the Lower South East drains (Department of Lands, 2665/1939): "Probably the vast amount of private drainage being currently undertaken in County Cardwell would cancel any reduced flow in the main watercourse contributed by the Drain M extension".

While less water was received by the Bakers Range watercourse in this period, surface water was being channelled through the watercourse northward by drains, so that the northern swamps still received surface water. However, the swamps were be a lot shallower than under natural conditions.

By 1981, the drainage network in Bakers Range watercourse had been developed to the extent that agricultural land was well protected from inundation by flood waters. As a result, surface water has not reached Alf's Flat, the terminal wetland of this watercourse, since 1956 (Foale and Smith, 1991). Thus, the Bakers Range watercourse has experienced two phases in surface water hydrology since European settlement. Firstly, between 1897 and 1960, it received an increase in surface water due to the impact of drainage in the Lower South East. Floods are now rare to occur, and some wetlands are deprived of surface water. In this period floods were experienced more frequently and in greater magnitude than at other times. Since the construction of Drain M in 1960, the Bakers Range watercourse has been deprived of surface water from the Lower South East. The impact of recent private drainage construction upon the surface water hydrology of the Bakers Range watercourse in uncertain.

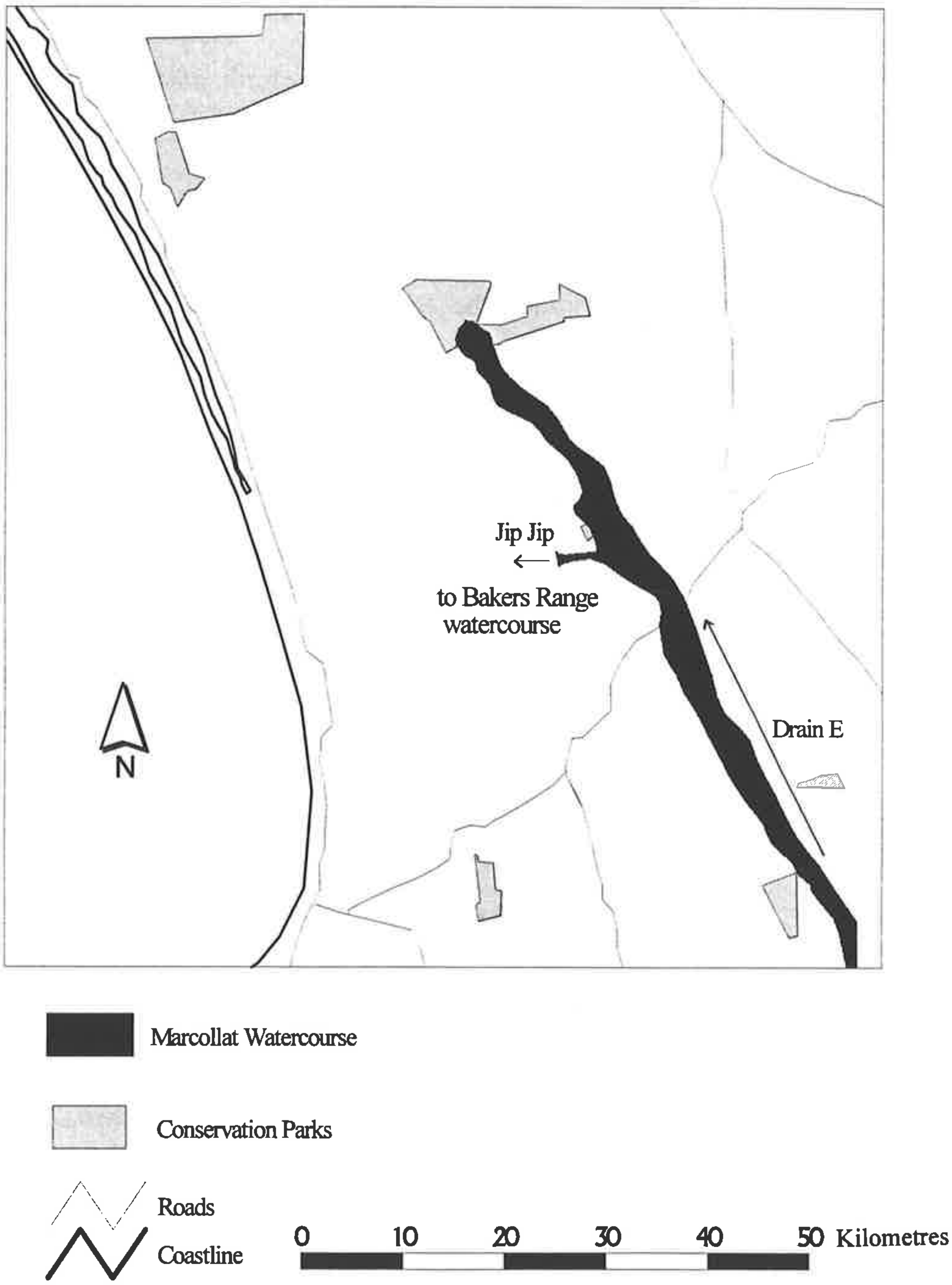
5.3.3.3 Marcollat Watercourse

The Marcollat watercourse runs between the Stewert Range and Woolumbool Range on the west and the Harper Range on the east (Figure 5.22). It is fed by the Naracoorte and Morambro Creeks, both of which originate in western Victoria. Before European settlement Naracoorte Creek ran into the Marcollat watercourse through Garey's and Lochaber Swamps, and Morambro Creek entered through a gap in the Harpers Range at Nyroca, and into the Jaffray and Lever Swamps. Surface water then continued northward until it reached a gap in the range at Jip Jip. Some of the surface water then joined the Bakers Range watercourse, but some continued north west terminating at Gum Lagoon Conservation Park (Marcollat Watercourse Resources, 119/1979). Under natural flood conditions, Gum Lagoon held water about 3.5 metres deep (judging from the line of red gum trees growing around the edge of the lagoon).

Pre European settlement the course of the Morambro and Naracoorte Creeks were impeded by bars which in some places caused considerable swamp areas to develop, such as Garey's and Lochaber Swamps. These swamps absorbed large quantities of flood water and consequently it was only when flow in these creeks was very strong or continued for a long period of time that the volume of water was sufficient to extend into County Cardwell and flood the northern reaches of the Marcollat watercourse (South Eastern Drainage Board, 1936).

The Marcollat watercourse has been extensively modified by the construction of drains in the Lower South East (South Australian Parliamentary Papers, 1965). The major drain of this watercourse, Drain E, was constructed in 1915. This drain commences at Naracoorte Creek west of the town of Naracoorte, and channels water into Garey and Lochaber swamps (Marcollat Watercourse Resources, 1979). It then grades through the natural bars

Figure 5.22: Marcollat Watercourse



forcing water northward rather than letting it pool in Garey's Swamp. The construction of Drain E caused surface water to reach the northern reaches of the Marcollat watercourse more frequently than under natural conditions (South Eastern Drainage Board, 1936). The Government constructed drain ends before Morambro Creek joins the Marcollat watercourse. At Jaffray Swamp there is a large cutting (10 metres wide and 3 metres deep) directing water northward into Lever Swamp. Thenceforth private drains encourage the movement of surface water north west.

Where Marcollat watercourse joined the Bakers Range watercourse at Jip Jip, private stopbanks have been constructed to prevent any water overflowing northward into the natural terminal wetlands (Minister of Water Resources, 1982). The banks divert water entering Jip Jip to the west so that it flows more directly into the Bakers Range watercourse. Practically all of the surface water now crosses the Willalooka-Petherick Road into the Bakers Range watercourse, and very little surface water flows into Coola Coola Swamp and Gum Lagoon Conservation Park. The northern part of this park was dry during the floods of 1981 (South Eastern Drainage Board, 1979).

Thus the direction of surface water flow in the Marcollat Watercourse has been radically altered. At its origin, surface water is encouraged to move northward by the drainage network. At Jip Jip its natural direction has been prevented by stopbanks, so that water is now forced to merge with the Bakers Range watercourse. This has left the swamps of Gum Lagoon Conservation Park permanently dry: the only swamps now existing within the Marcollat watercourse being the Garey's, Lever, Jaffray and Lochaber Swamps (Nicolson, 1993b).

5.3.3.4 Duck Island Watercourse

The Duck Island watercourse (sometimes called the Bunbury and Didicoolum watercourse) is bounded on the east by the Black Range and to the west by dunal formations along the edges of the Coola Coola Swamp, Gum Lagoon Conservation Park and an unnamed range to the east of the Cortina Lakes - the Alf's Flat waterway. This is an ill defined waterway consisting of a series of natural swamps, flats and low dunes (Figure 5.23).

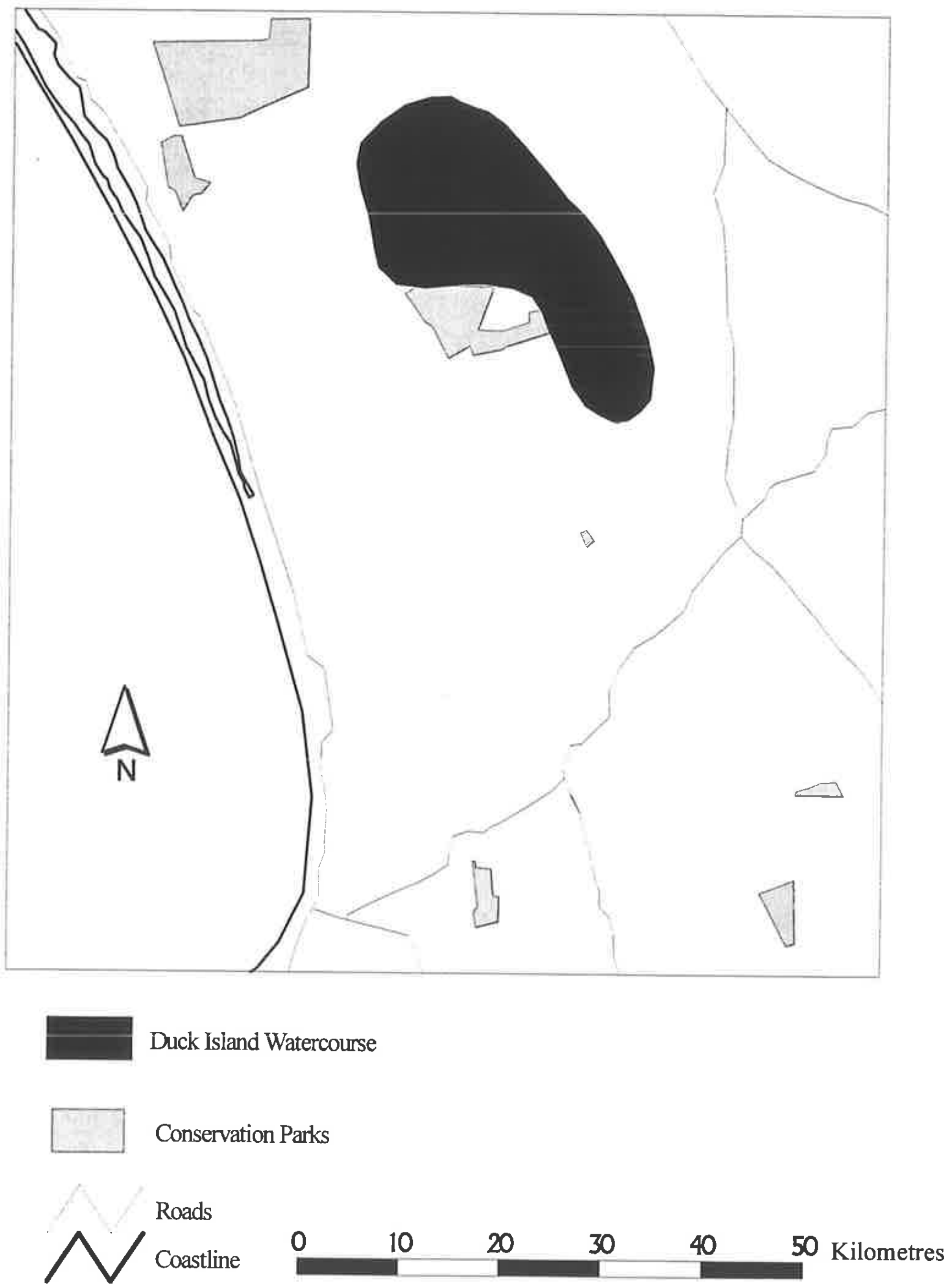
Surface water of the Duck Island watercourse does not have a specific origin or discharge point. Land holders suggest that there are two ways in which water enters the catchment: firstly by regional rainfall and run off, and secondly, through underground flow, or seepage, from the east. The latter contributes to a raised water table in the catchment area (Bakers Range/Marcollat Watercourses Working Group, 1991).

Very little information is available on the activities of Europeans in this watercourse. The Government has not constructed drains in this area, and so landholders have constructed private drains in an attempt to reduce the area of land being inundated. The location and date of construction of private drains is not known. Drains simply channel water into the deeper swamps in an attempt to retain surface water within several depressions. However, such a scheme has not been successful. The Duck Island catchment experiences annual surface water inundation and is also experiencing a rapid increase of dryland salinisation (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1992).

5.3.3.5 Mount Charles Watercourse

The Mount Charles watercourse is a landlocked catchment area in the eastern portion of the Upper South East, where localised runoff and winter rainfall accumulate (Bakers Range/Marcollat Watercourses Working Group, 1991). The catchment boundary is

Figure 5.23: Duck Island Watercourse



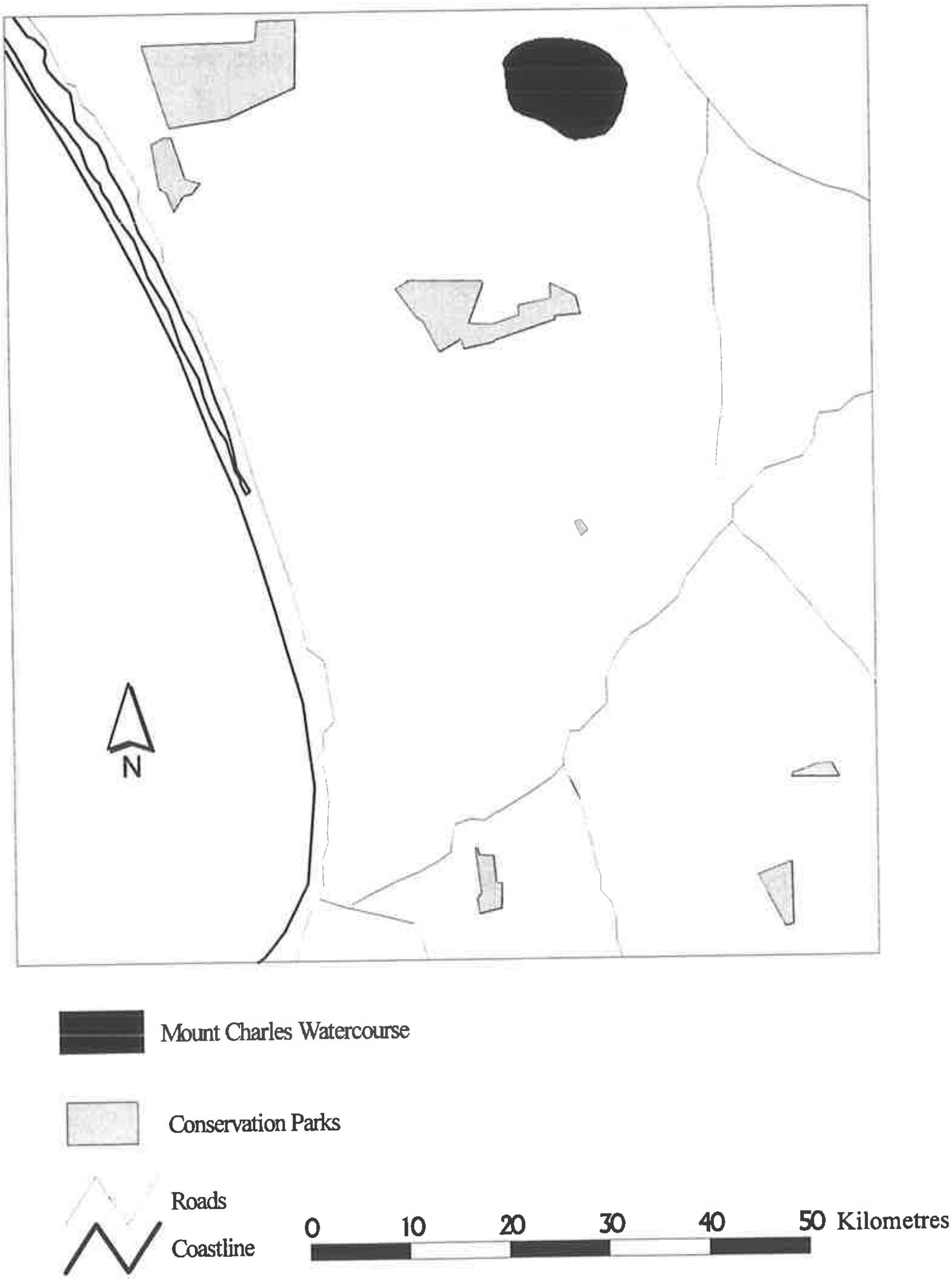
undefined on the eastern side and is fed from the Keith-Monkoora plain. It is confined on the north by an unnamed range of hills and on the south west by the Black Range. Water movement is westerly towards the Mount Charles Homestead (Figure 5.24).

Surface water of the Mount Charles watercourse has two origins: firstly, local rainfall and runoff, which result in annual inundation. Secondly, in wet years water originating in western Victoria flow through the Nalang and Tatiara Creeks, into the Moot-Yang-Gunya and Poocher Swamps respectively. Both swamps function as runaway holes, feeding surface water from these creeks into the underground aquifer. In years of above average rainfall, when the flow of water reaching the two swamps exceeds their capacity to store it and to channel it underground, the swamps flood. Excess water flows north west spreading out over the flat country: some flows north on to Lampy's runaway hole, and the rest north and north west to Sandy Joe's runaway hole. These runaway holes cope with small to medium floods but when they overflow the water continues west into the Mount Charles catchment. The Mount Charles watercourse has no drainage outlet, once flood waters are discharged into it, the only outlet is by soakage and evaporation.

Up to and including the 1923 flood, the Mount Charles catchment was uncleared and used only for rough grazing. Therefore no banks or drains had been constructed on any of the nearby properties. After the 1923 flood, some land owners of the Mount Charles catchment carried out flood control works on their properties, with the intention to carry the water across the property in a channel and prevent it from spreading out over the paddocks. But they cut off the previous natural flow of surface water northwards, and as a result large scale flooding occurred in 1942 (Jones, 1985).

Surface water flow of the region is now haphazard. The 1981 flood waters spilled onto public roads and in places flowed the roads due to parallel embankments erected by the

Figure 5.24: Mount Charles Watercourse



adjacent land holders, causing considerable damage (Engineering and Water Supply, 4096/1955). Flooding in the Mount Charles catchment has been accentuated by the clearance of native vegetation. The result has been rising water tables causing local inundation of flats and increasing salinity. Small amounts of localised flooding still frequently occur (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1992).

5.3.4 Dryland Salinity and Water Quality

Dryland salinity and surface water quality are additional indicators of the hydrological changes that have occurred in the Upper South East. Although poor records are available for both, they do highlight the difficulty of monitoring and managing such a complex environment with short term records only available.

5.3.4.1 The Spread of Dryland Salinity

Dryland salinity occurs when salts accumulate in the topsoil due to capillary movement of water from a rising saline groundwater table. The rising water table mobilises salts from the soil, and the capillary action moves them towards the surface. The accumulated salt content in the surface soil affects the type and health of the vegetation. In addition, where the water table reaches the surface, permanent or intermittent ponding (flooding) occurs, and salts are brought to the surface quicker and remain there for longer periods of time. Dryland salinity and flooding are dual problems. They have the same cause and are interrelated, each exacerbating the other (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1992).

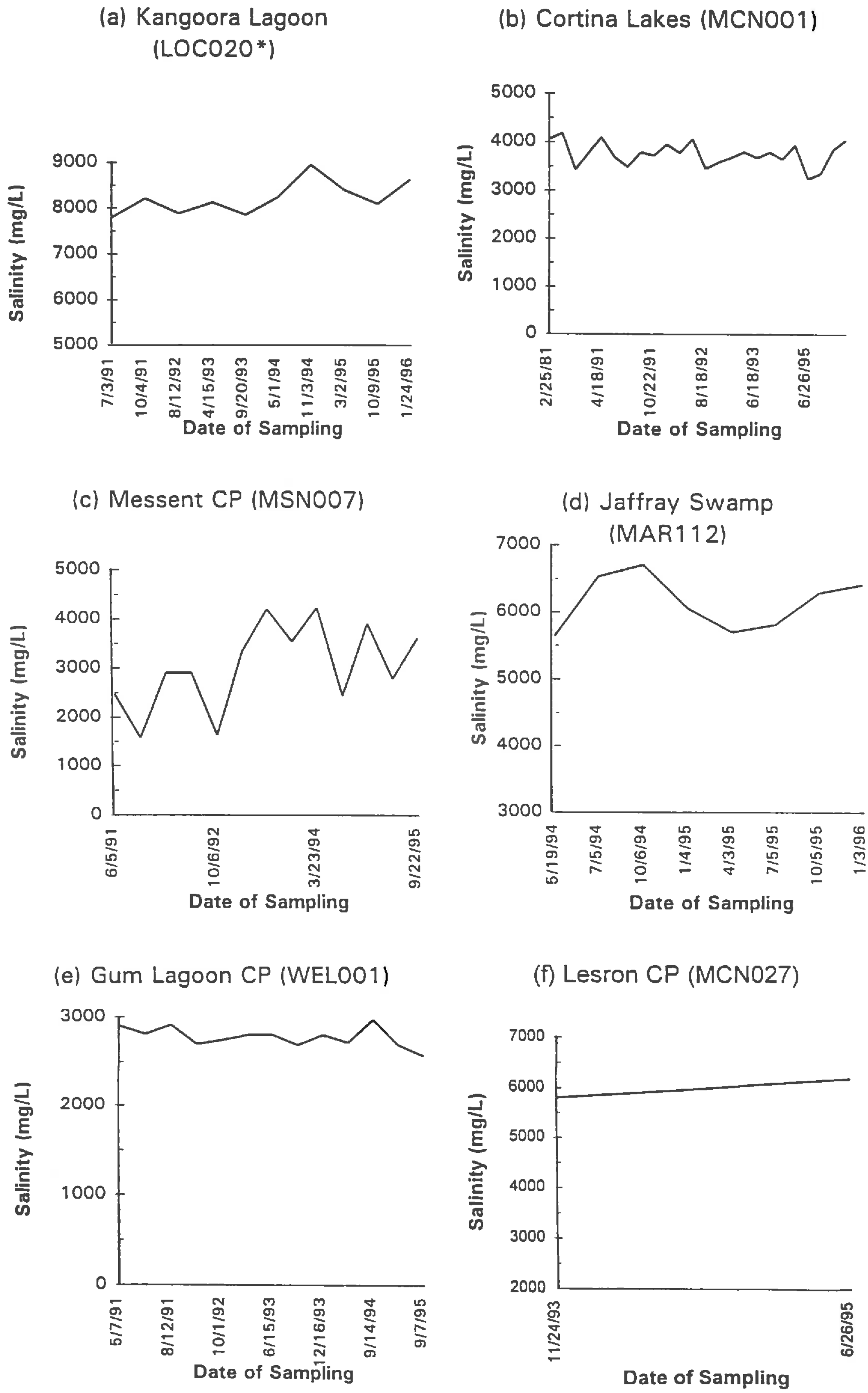
The change in salinity of the sample sites used for the palaeoecological analyses were determined by comparing the Melville and Martin (1936) field survey and the Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1992) image. The changes are summarised in Table 5.7. Messent Conservation Park and the Cortina Lakes sites experienced an increase in salinity, whereas Lesron Conservation Park remained highly saline, and Gum Lagoon Conservation Park experienced no change in salinity. Neither Jaffray Swamp nor Kangoora Lagoon were included in the Melville and Martin survey so changes in soil salinity could not be determined from historical information.

Table 5.7: Change in Salinity of Field Study Sites from Historical Records

Field Study Site	Melville and Martin (1936)	EIS (1993)	Change in Salinity
Messent CP	Not Saline	Moderately Saline	Increase
Cortina Lakes	Not Saline	Moderately Saline	Increase
Lesron CP	Highly Saline	Highly Saline	No Increase
Gum Lagoon CP	Moderately Saline	Moderately Saline	No Increase
Jaffray Swamp	Not Classified	Moderately Saline	?
Kangoora Lagoon	Not Classified	Not Saline	?

Groundwater salinity records obtained from the South Australian Department of Mines support the findings obtained from the soil salinity maps: that is, only in some areas has there been an increase in salinity. Figure 5.25 illustrates bore well salinity data for wells located nearby the sampling sites. The bore well near to Messent Conservation Park shows data collected over the past five years. The graph illustrates seasonal fluctuations in groundwater salinity but also an overall increase of salinity. The bore well near Cortina Lakes does not show an overall increase in salinity nor significant seasonal fluctuations. Only one bore was located near to the Lesron field sites. This bore had only two sampling dates and whilst it does indicate an increase in salinity over the past three years, further

Figure 5.25: Bore Well Salinity Records



* Department of Mines and Energy bore well number.

data is required to draw conclusive results. The bore well located near to Gum Lagoon Conservation Park shows an apparent decrease in salinity over the past five years. The seasonal fluctuations are quite marked at this location. Bore well data was only available for the past two years at Jaffray Swamp. This well shows distinct seasonal fluctuations but the long term trend cannot be ascertained from data of this interval. The data from the Kangoora Lagoon bore well indicates a slight increase in salinity. This trend may be related to the length of time since this area was flushed by a flood event, as all plots depicted a slight decline in 1992 when a minor flood occurred.

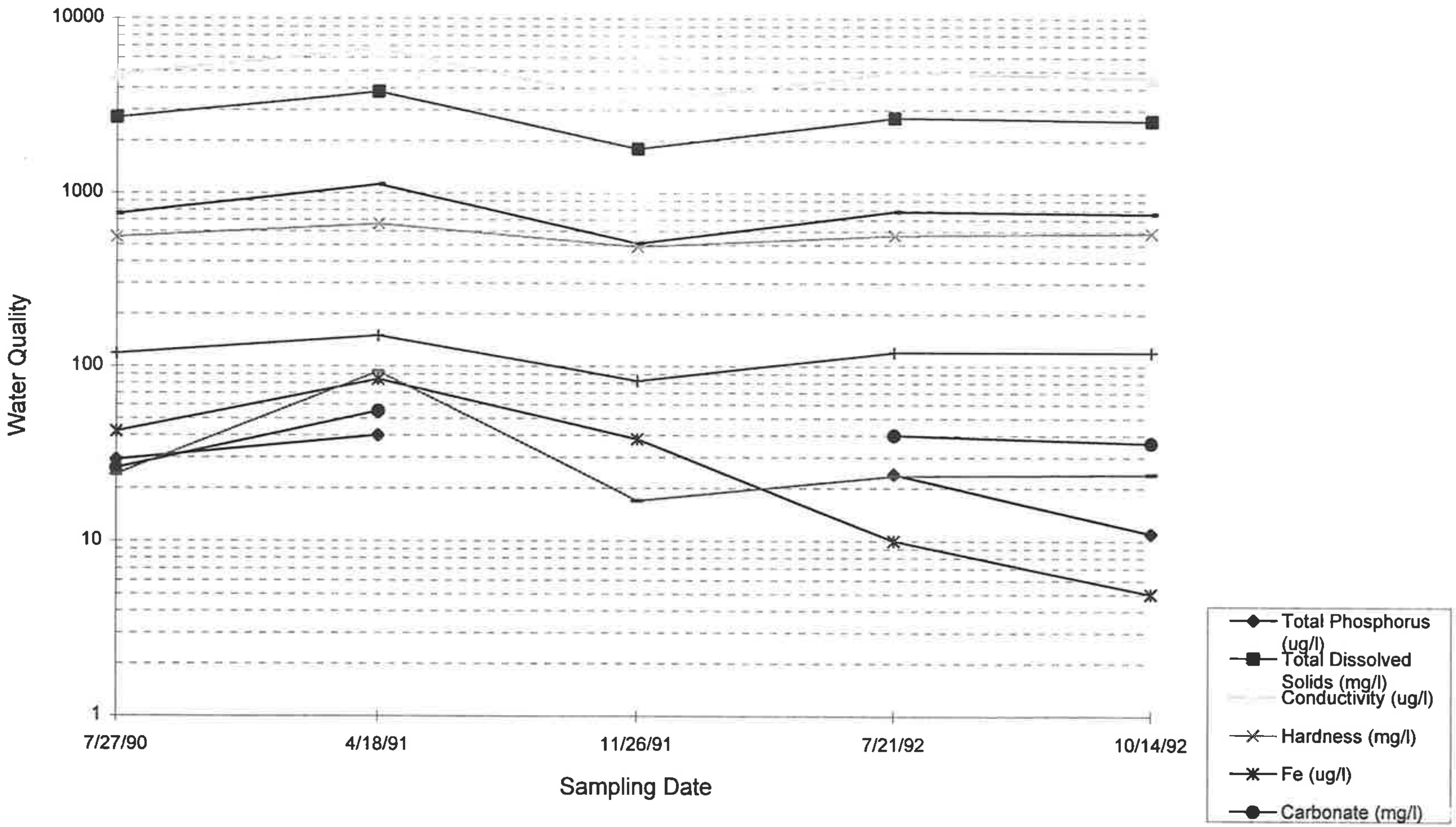
Thus in contrast to popular belief, the available evidence does not indicate that there has been a dramatic increase in the salinity experienced in the Upper South East. The area is naturally saline due to its marine origin, but, the impact of human activities on the area has not exacerbated the salinity of the soil to the extent that is widely acclaimed.

5.3.4.2 Surface Water Quality

A further indication of human impact upon the surface water hydrology of the Upper South East is the quality of the surface water. Only one study has been conducted on surface water quality and that was conducted by Eco Management Services (1994). While this study was a temporal one it only covered a two year period. Thus the change in water quality due to European activities cannot be accurately ascertained. From the Eco Management Services (1994) study, the seasonal and spatial change in water quality were illustrated.

The seasonal changes in water quality are exemplified in Figure 5.26. All aspects of water quality increased during the summer months and decreased during the winter months. The increase in the amount of surface water in winter and spring dilutes the pollutants contained in the surface water. As surface water evaporates during summer and autumn

Figure 5.26: Seasonal Changes of Water Quality in the Bakers Range Watercourse



Source: Data obtained from Eco Management Services (1992) these pollutants increase in concentration. Unfortunately data does not exist to determine if the concentration of these properties has increased over a longer period of time.

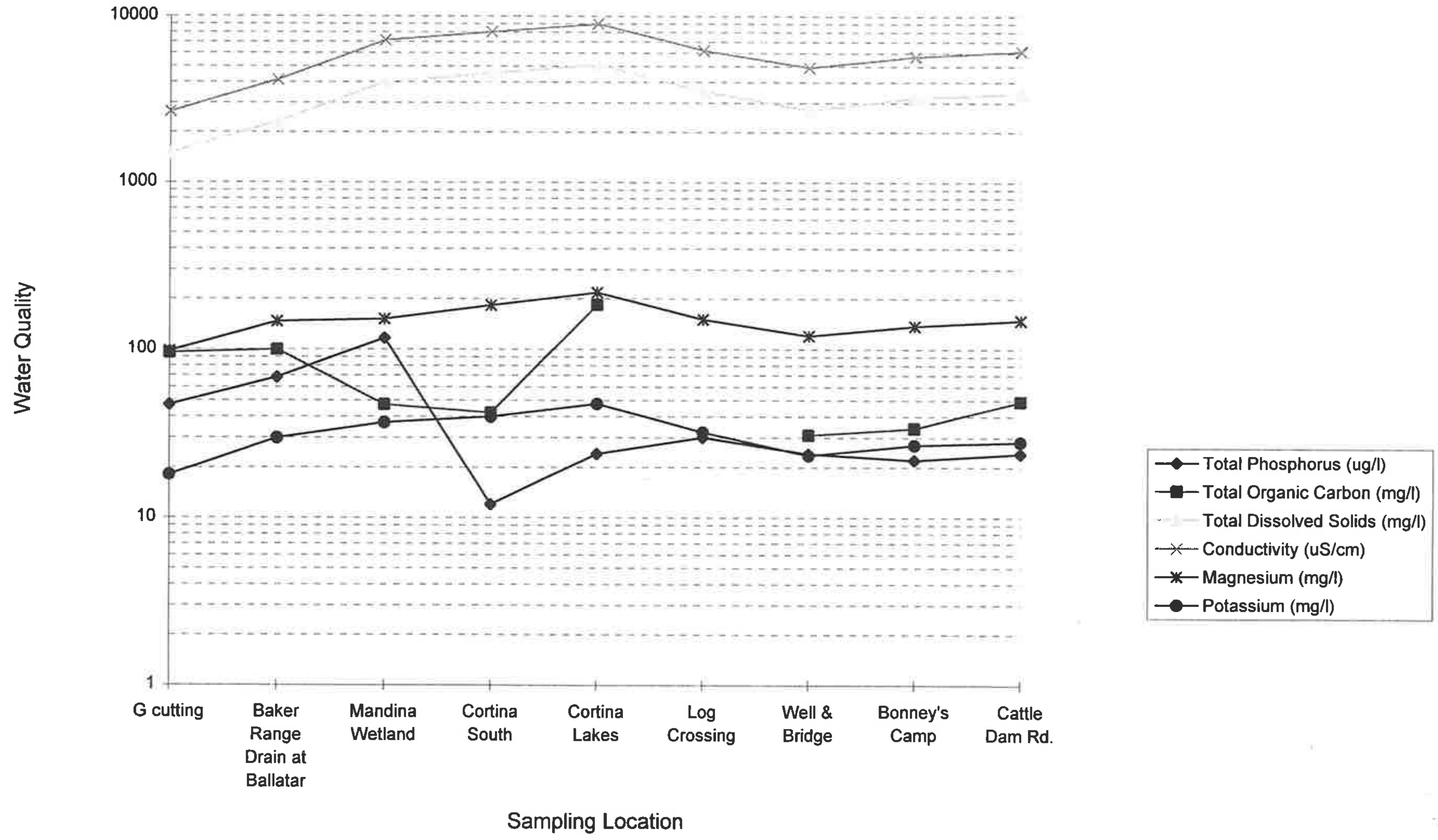
To illustrate the spatial variation of water quality, a variety of sites along the Bakers Range watercourse were selected. Data was graphed along the south to north gradient of the Bakers Range watercourse. This graph is shown in Figure 5.27. It was found that total organic carbon, conductivity, total dissolved solids, magnesium and potassium concentration increased along the watercourse until they reached Cortina Lakes. This wetland is a large area of natural vegetation that must act as a trap for nutrients, as the nutrient level of surface water after this wetland decreases significantly, but gradually increases as the water moves northward again. Phosphorus content reduces dramatically at Cortina South possibly because it is sheltered from the direct influences of agricultural activities by a buffer of native vegetation.

Unfortunately insufficient data exists to examine European impact upon surface water quality. It is well known that phosphorus and trace elements have been widely used in the development of the Upper South East for agriculture. In some areas superphosphate is added annually though trace element additions such as zinc and copper were required only when the land was first ploughed. Heavy metals and nutrients should have increased with European agricultural activities. But there is no temporal records available to support that assumption. The only trends discernible are the seasonal fluctuations in water quality and the variation in water quality along a watercourse at any point in time.

5.4 Conclusions

The historical record has provided much information about changes in hydrology that have occurred in the Upper South East in approximately the past one hundred years. Much of this information is qualitative so few analytical processes could be conducted to analyse

Figure 5.27: Spatial Variation of Water Quality in the Bakers Range Watercourse



Source: Data obtained from Eco Management Services (1992) the changes in detail. However, the information does provide an indication of the hydrological trends occurring in the Upper South East environment, whether they be natural or human induced.

The results presented above indicate that fluctuations in rainfall have produced changes in the surface water hydrology of the Upper South East over the past one hundred years. These changes are climatically induced and are common across most of eastern Australia. The fluctuating dry and wet periods influenced the rate of agricultural development of the region. Development began in the 1930s, within the most recent dry period of the region. Concern for the environment was initiated in the wettest period Europeans have experienced in the South East.

The historical record reveals that agricultural activities have greatly affected the natural environment of the Upper South East, most particularly its hydrology. The drainage structures that have been constructed within each watercourse have altered not only the water flow direction, but also its rate and frequency of flow. This has affected each watercourse, and even wetlands along each watercourse, in different ways. Some now experience drought conditions whilst others are permanently flooded. Some sites have even experienced both extremes in the past one hundred years.

The natural environment is continually adjusting to the altered hydrological conditions. Vast reaches of dead *Eucalyptus camaldulensis* at Jip Jip wetlands (Plate 5.1) and dying tea tree at Cortina Lakes (Plate 5.2) are testament the dynamic nature of the hydrological environment. Even though, at this stage, the pre European hydrological environment is unknown, it is clear that human induced changes in the past one hundred years have occurred at a rate far beyond the ability of the natural ecosystem to adapt or move into more suitable environments. Hence the current environment is experiencing degradation through both the decline in health and frequency of indigenous species and the increase in distribution of alien species.

The following chapter examines the palaeohydrological record of selected sites within the Upper South East. The nature of changes in the environment prior to European colonisation are revealed in order to place in context, the environmental changes revealed from the historical record.

Plate 5.1: *Eucalyptus camaldulensis* in Jip Jip Wetlands

Photographer: Author

Plate 5.2: Leptospermum spp. in Cortina Lakes

Photographer: Author

6.0 PALAEOECOLOGICAL EVIDENCE OF ENVIRONMENTAL CHANGE

This chapter reports results obtained from selected sites in the Upper South East using palaeoecological methods. A wide variety of analyses were conducted at each field study site. Some methods were more successful at one site than another, thus the type of information available is different for each site. The chapter is divided into four sections: the first three correspond to each watercourse examined, and in the fourth, comparisons are made between the sites and watercourses to provide a general reconstruction of the hydrological history of the Upper South East.

6.1 Field Sites of the Bakers Range Watercourse

6.1.1 Kangoora Lagoon

Kangoora Lagoon is located within Fairview Conservation Park (section 3.3.2.1). This extensive but shallow lagoon had a reduced size as evidenced by the surrounding stranded shoreline. At the core sampling location (Figure 6.1) the water was approximately 15 to 20 cm deep. A water sample was taken to determine the pH, nitrite, phosphorus and conductivity of the lagoon water. The pH and conductivity were measured on site, the nitrite and phosphorus were determined upon return to the laboratory. Table 6.1 shows the results obtained. The pH of the lagoon water was very alkaline, similar to the soils of the Upper South East. This was the case at all wetland sites sampled. Conductivity, phosphorus and nitrite were very low or undetectable. As Kangoora Lagoon is buffered from surrounding farmland by native vegetation it was expected that the nitrite and phosphorus used on surrounding agricultural land would not enter the lagoon. However, the conductivity of the lagoon was expected to be high. The only input to the lagoon is through local runoff and rainfall, and this must freshen the lagoon water. Little groundwater recharge was occurring as the groundwater salinity recorded at a nearby bore well by the South Australian Department of Mines was much higher than the conductivity of the lake water (Figure 5.25).

The Kangoora Lagoon sediment core was quite shallow, only 30 cm deep, and the entire core was a dark brown silty clay (5Y 2.5/1 by Northcote's classification) (Figure 6.2). At 30 cm depth, a calcrete layer prevented further penetration of the coring device. The pH of the entire soil horizon was 10. The homogeneity of the soil suggests that environmental conditions of Kangoora Lagoon have not radically changed over the period of deposition of the 30 cm core.

Figure 6.1: Sampling Location of Kangoora Lagoon

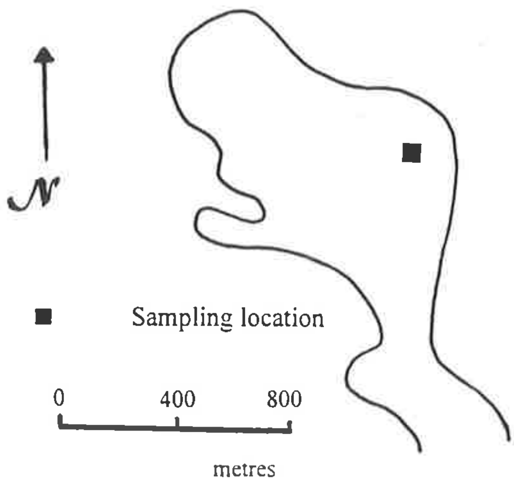
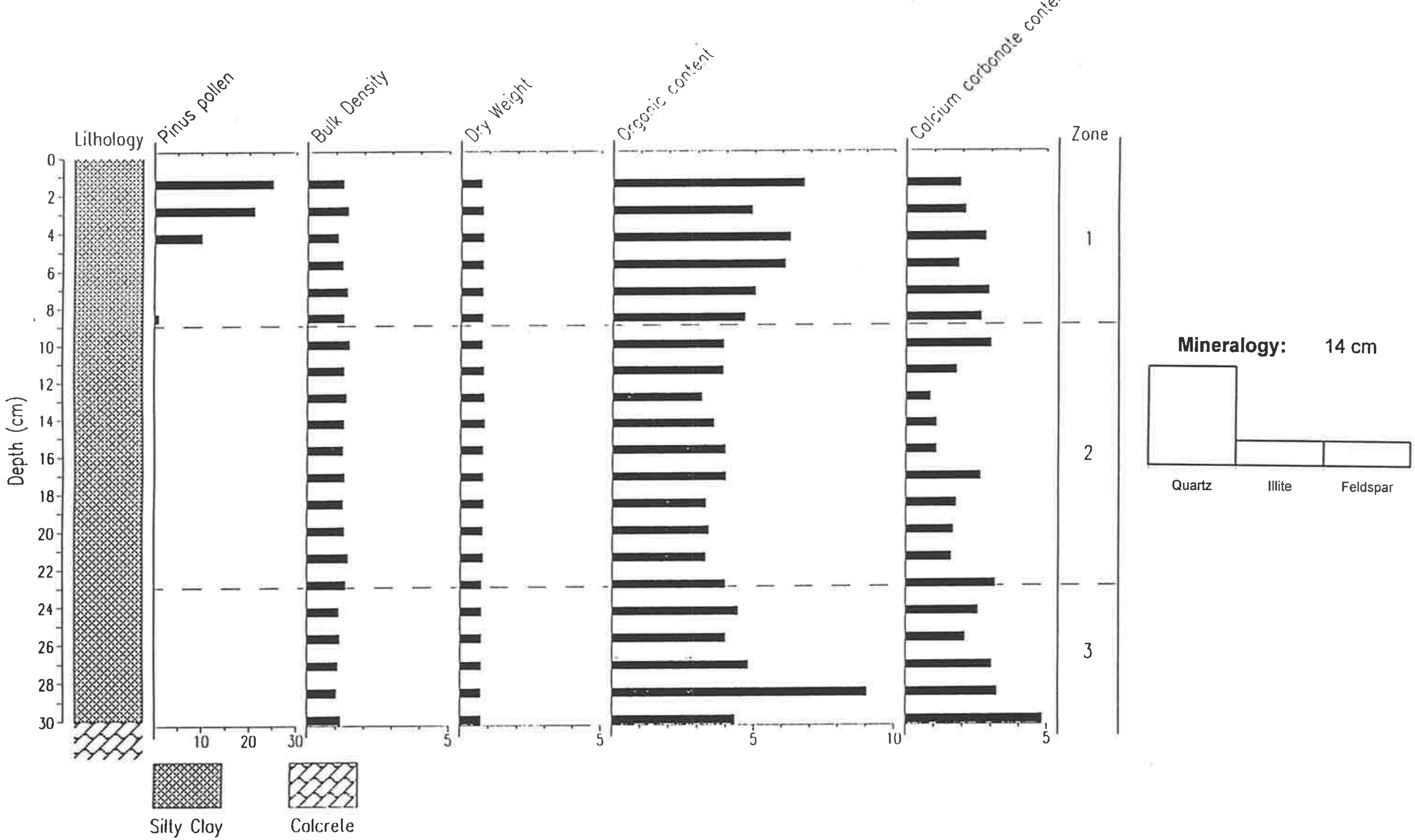


Table 6.1: Water Chemistry of Kangoora Lagoon

	Mean	Standard deviation
pH	10	0.7
Conductivity	13 ‰µS	0.45
Nitrite	6.8 µg/L	0.15
Phosphorus	Not detectable	-

The pine pollen grains counted are shown in Figure 6.2. Pollen was quite common at the surface of the lake but quickly diminished to insignificant levels at 5.7 cm. Pines were

Figure 6.2: Kangoora Lagoon



planted in South Australia at the turn of the century (Wegener, 1995). Thus the surface 5.7 cm approximately relates to the past 80 or 90 years.

Chemical analysis of the core from Kangoora Lagoon is shown in Figure 6.2. The bulk density and dry weight did not vary significantly throughout the core. The organic content was high at the surface (zone one) and decreased with depth (zone two), as would be expected when humic material is broken down over time. However, the organic content has increased within the period of European occupation, perhaps due to an increase of allochthonous material washed into the lake via the drainage network. The organic content also peaks in zone 3, which may be due to an accumulation of organic material above the calcrete layer which prevents it leaching further down the soil column.

The carbonate profile also shows a number of fluctuations. The recent reduction of carbonate content in the upper level of zone one is likely to be due to a change in the salinity of the lagoon within the period of European occupation (Kelts and Hsu, 1978). Surrounding drainage constructions direct surface water into the lagoon making it more frequently flooded, but for shorter periods of time. These conditions would usually increase the precipitation of carbonate (section 4.2.4). A reduction of carbonate in the modern samples is then more likely to reflect an increase in salinity of the lake water. The samples contained within the lower section of zone one demonstrate higher carbonate levels, indicative of an ephemeral lagoon environment. In zone two the carbonate content is reduced, and returns to higher levels in zone three. Here, the carbonate profile is possibly being influenced by the calcrete layer. It is likely that changes in water depth have caused the fluctuations of the carbonate profile, with ephemeral lake conditions prevailing in the lower part of zone one and possibly zone three, and deeper lake conditions in zone two.

As the stratigraphy of the core was homogeneous, no variation in mineral content was expected. Only one sample was processed for mineralogy (Figure 6.2). Results indicated that the core was predominantly composed of quartz with traces of illite and feldspar. The predominance of quartz in the core reflects the surrounding geology, and suggested that the quartz has been transported by both wind and water from the adjacent sand ridges. The feldspar probably originated from granite outcrops found at several locations in the South East of South Australia which are remnants of volcanic activity during the Cainozoic (Harris, 1983). The illite is thought to be forming from the weathering of feldspars, as the chemical transformation from feldspar to illite is favoured in the alkaline soils of the Upper South East (Gribble and Hall, 1985).

Diatom preservation was very poor in the Kangoora Lagoon core, and so diatoms were not counted. However, the carbonate record indicates that the salinity of Kangoora Lagoon has increased within zone one, correlating with the period of European occupation.

Evidence for the reconstruction of the environmental history of the Kangoora Lagoon site is minimal. It is likely that the change in the carbonate profile prior to European occupation is due to changes in the lagoon water depth, and thus the precipitation rate of carbonate. However, the shallowness of the core suggests that periods of erosion may have occurred at this site. Dating was not conducted because the evidence presented above did not support the likelihood of obtaining accurate dates. Results indicate a recent increase of salinity during the period of European occupation. But without supplementary evidence it would be fruitless to attempt a climate reconstruction based on this site alone.

6.1.2 Reedy Lake

Reedy Lake is perched on the edge of the Bakers Range watercourse (section 3.3.2.2). The lake level showed no evidence of stranded shorelines indicating that the lake remains at a relatively constant water level. Input to the Reedy Lake is from local runoff and precipitation. This lake does not receive floodwaters from the Bakers Range watercourse as it is situated on the edge of the nearby ridge. It may then contain a regional record rather than recording changes occurring within the Bakers Range watercourse.

The water in Reedy Lake was estimated to be 1.5 to 2 m deep at the centre. At the sampling location (Figure 6.3) the water was 80 cm deep. The lake could not be cored at the centre due to limitations of available equipment. The results of the water quality analysis conducted for Reedy Lake are shown in Table 6.2. The conductivity value indicated that the lake was fresh. As this lake is situated on the edge of the interdune corridor and the vegetation is indicative of nonsaline soils, it does not appear vulnerable to increasing salinity in the near future. The low levels of nitrite and phosphorus are possibly due to the lakes separation from the main watercourse and the surrounding buffer of native vegetation.

Figure 6.3: Sampling Location of Reedy Lake

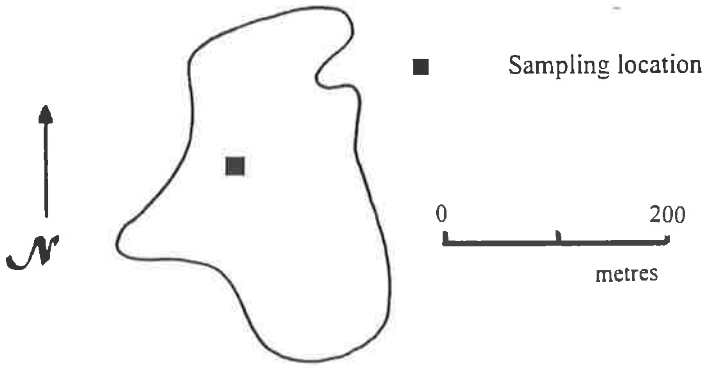
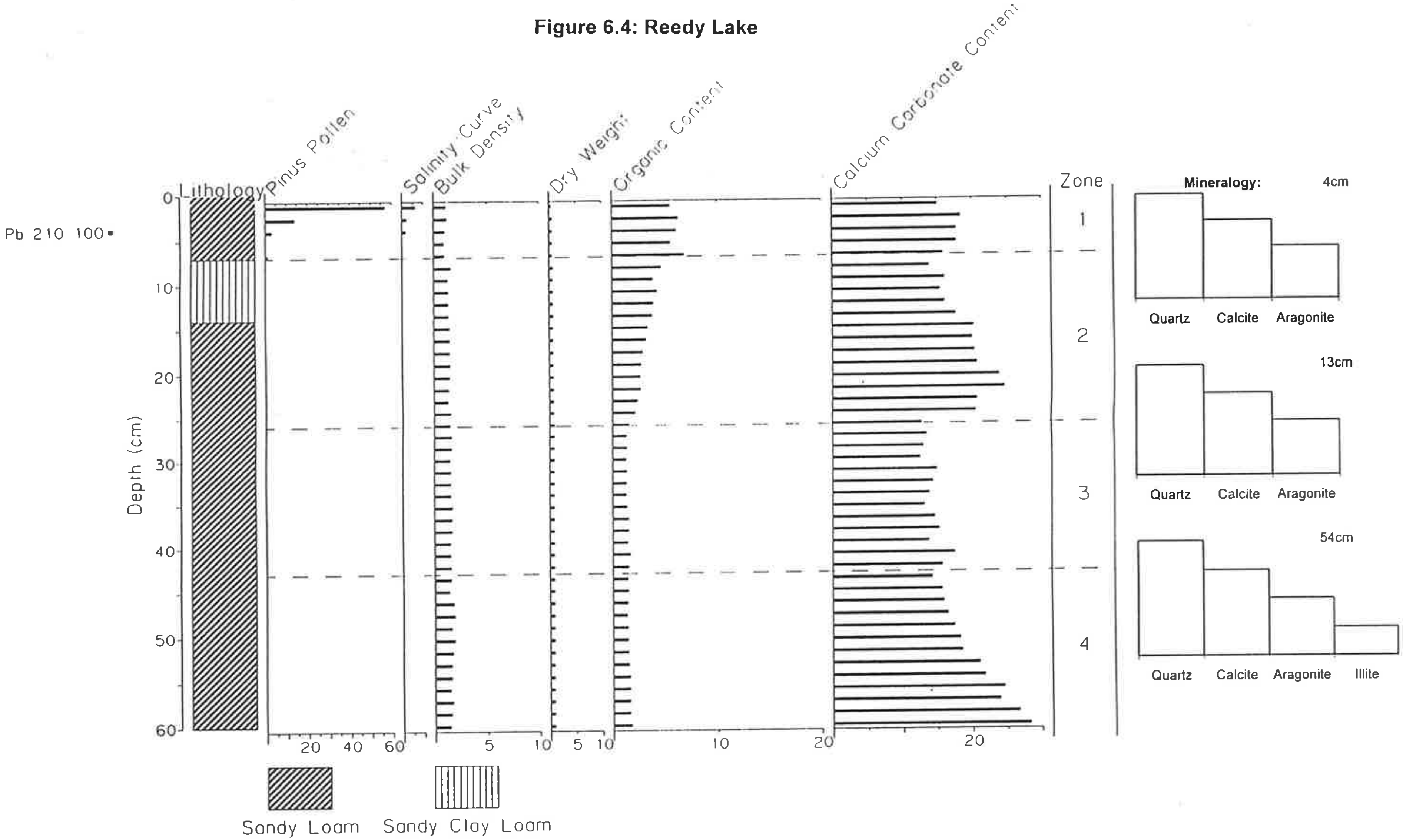


Table 6.2: Water Chemistry of Reedy Lake

	Mean	Standard deviation
pH	10	0.9
Conductivity	35 ‰μS	0.41
Nitrite	9.55 μg/L	0.21
Phosphorus	Not detectable	-

The Reedy Lake core was 60 cm in length (Figure 6.4). The surface horizon (0 to 6 cm) was a dark brown, highly organic, sandy loam (10YR 4/1). Sediments from 6 to 14 cm

Figure 6.4: Reedy Lake

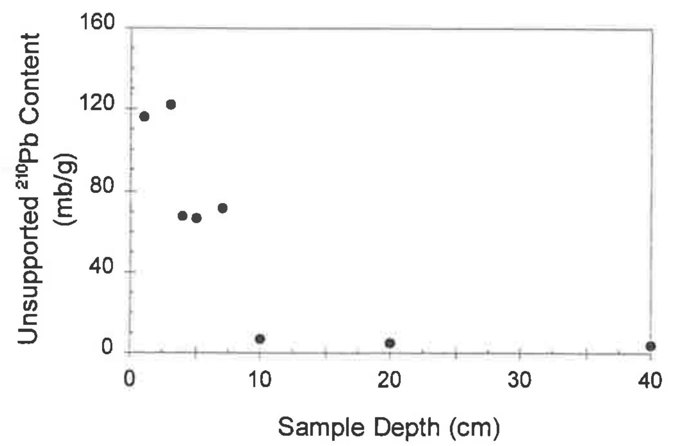


were a sandy clay loam (10YR 2/1), and the sediments returned to a sandy loam after 14 cm until the end of the core (10YR 4/2). The pH of all soil horizons was 10. The lack of variation in the stratigraphy suggests that the sediments may have all been deposited in an environment very similar to that of the present.

The pine pollen count for the surface samples of Reedy Lake were quite high, but rapidly diminished at 4 cm (Figure 6.4). It is likely that the surface 4 cm of sediment have been deposited during the period of European settlement. This is reinforced by the ^{210}Pb content analysis (Figure 6.5). The high level of ^{210}Pb in samples from 1.4 and 2.7 cm indicate an inferred age of approximately 100 years. Samples at 4.1, 5.5 and 6.8 cm may have been influenced by bioturbation, causing constant levels of ^{210}Pb of an age less than 100 years. Samples at 10, 20 and 40 cm indicate the background ^{210}Pb levels. Thus, the period of European impact is likely to be represented by the surface three to four centimetres of sediment.

Chemical analysis of this lake is also shown in Figure 6.4. The bulk density and dry weight did not differ significantly down the core. Organic content was very high in the first zone, and diminished thereafter, as would be expected from the natural decomposition of humic

Figure 6.5: Reedy Lake ^{210}Pb Content



material. The carbonate profile showed many fluctuations: most distinct is a peak in zone one, another peak at the bottom of zone two and an increase throughout zone four. Similar to Kangoora Lagoon, the recent moderation of carbonate precipitation is likely to be due to an increase in the salinity of the lake water which is related to European activities. The fluctuations at 22 cm and 60 cm may be due to water depth changes that were climatically driven. They are unlikely to be caused by soil formation processes as calcium carbonate tends to accumulate in arid soils which are not prevalent in the Upper South East (Charman and Murphy, 1991).

Three samples from the Reedy Lake core were analysed for mineral content (Figure 6.4). The first sample, taken from 4 cm, contained predominantly quartz, with calcite and aragonite also present in fairly high quantities. The second sample, from 13.5 cm, was essentially the same as the first. The third sample from a depth of 54.5 cm, which coincided with the second carbonate peak, contained traces of illite along with quartz, calcite and aragonite. Closer examination of the carbonate minerals under a petrographic microscope revealed that the aragonite was contained within invertebrate shells and was gradually being replaced by calcite, a more stable carbonate mineral. Illite was the product of feldspar transformation, and is a common mineral in the Upper South East of South Australia.

Diatom preservation was adequate for analysis of only the top seven centimetres of Reedy Lake. The diatom assemblage in this section was dominated by *Mastogloia smithi*, *Navicula cincta form minuta* and *Diploneis smithi* (Appendix 9.3). The salinity curve constructed from the diatom assemblage indicated increasing salinity levels, which reached a peak at the surface of the lake sediments (the present). The increase in salinity correlates with the period of European occupation as determined by the pine pollen and ^{210}Pb dating.

The salinity change could reflect a regional rise in groundwater salinity. The increase in salinity is also associated with a decrease of the carbonate curve at the very surface, supporting previous claims that carbonate production decreases with increasing salinity of lake water (Kelts and Hsu, 1978).

The fluctuations observed in Reedy Lake could be accounted for by a number of separate or contributing factors. Climate change, resulting in changes of lake depth, could be causing fluctuations in the rate of carbonate precipitation at depth in the core. A recent increase in the salinity of the lake, that corresponds with the period of European occupation, could be causing a reduction of both the organic content and carbonate content evidenced at the surface of the core. It is likely that this lake provides evidence of both climatic and human-induced environmental change.

6.1.3 Cortina Lakes South Lagoon

Cortina Lakes South Lagoon is located near Reedy Lake, and is within the path of surface water flow of the Bakers Range watercourse (section 3.3.2.2). The water in Cortina Lakes South Lagoon was only 40 cm deep at the sampling location (Figure 6.6). The surrounding stranded shoreline suggests that the lagoon water level was at a low. The water chemistry of Cortina Lakes South Lagoon (obtained in a similar manner to Kangoora Lagoon and Reedy Lake) indicated that the lake was hypersaline (Table 6.3). The absence of nutrients may be attributed to the large buffer of vegetation surrounding the lagoon, which prevents runoff from surrounding agricultural land directly entering the lake. The high conductivity of the lagoon could be due to the long period of time since this lagoon has experienced a flood event.

Figure 6.6: Sampling Location of Cortina Lakes South Lagoon

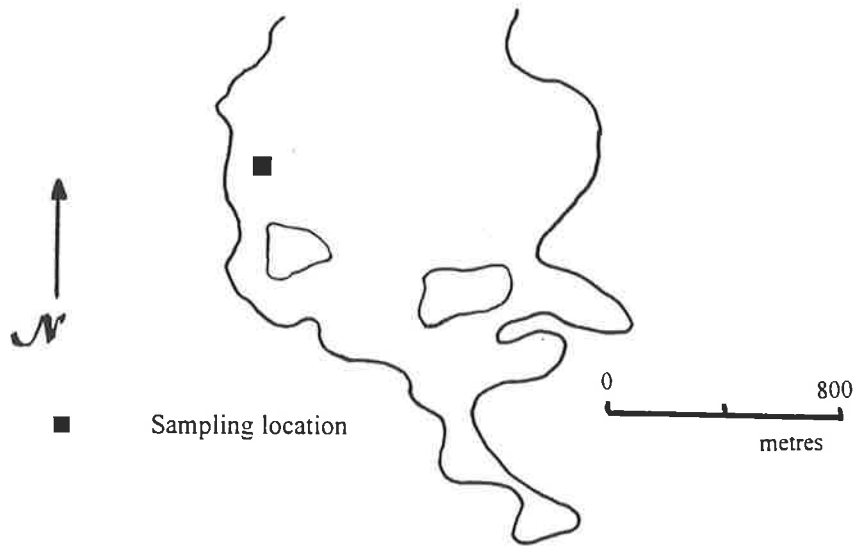


Table 6.3: Water Chemistry of Cortina Lakes South Lagoon

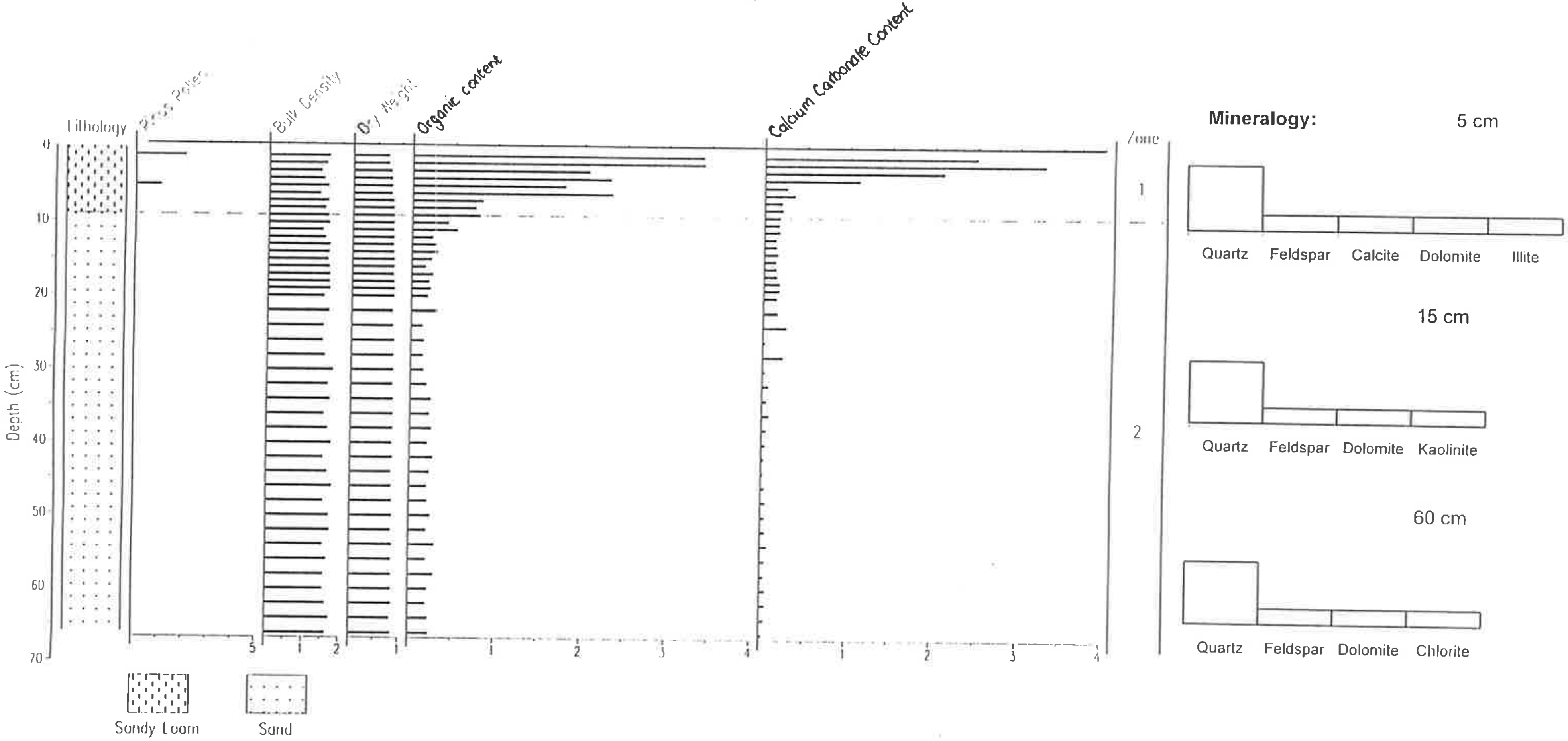
	Mean	Standard deviation
pH	10	0.87
Conductivity	112 ‰μS	0.64
Nitrite	Not detectable	-
Phosphorus	Not detectable	-

The core obtained from Cortina Lakes South Lagoon was 66 cm long (Figure 6.7). The top 9 cm of this core was brown sandy loam (10YR 4/1), and from there to the end of the core the sediment was light coloured sand (10YR 7/1). It is likely that this sand has been transported from the adjacent dune ridges to the depression in a period of a dry environment dominated by aeolian driven winds. The pH of the soil in both horizons was 10.

Pine pollen grains were very low in this core (Figure 6.7), perhaps too low to be of significance. Only a couple of grains were found in the surface layers but none were found in the samples further down the core suggesting that the sedimentation rate is very low.

The results of chemical analysis conducted on this core are also illustrated in Figure 6.7. Bulk density and dry weight did not vary through the core. Organic content peaked in the

Figure 6.7: Cortina Lakes South Lagoon



top zone but was very low thereafter: a pattern which is expected as the organics are broken down with time. In addition, organics are likely to be leached quickly from the sand horizon and/or not produced at the same time as the sand horizon was deposited. The carbonate profile showed a similar pattern to the organics. The high carbonate peak in the top zone could be due to an increase in the productivity and/or water temperature of the lake during the European settlement period. It is likely that a change from dry to ephemeral conditions has caused an increase of the precipitation of carbonate (Kelts and Hsu, 1978). The surface sample illustrates a decrease of carbonate content that may be related to the increase of salinity of modern lake water that was identifiable at Kangoora Lagoon and Reedy Lake.

Three samples were analysed for mineral content (Figure 6.7). The sample from 5 cm contained predominantly quartz with traces of feldspar, calcite, dolomite and illite. The second and third samples, from 15 cm and 60 cm respectively, were also predominantly composed of quartz with traces of feldspar and dolomite, plus kaolinite at 15 cm and chlorite at 60 cm. Thus, the high carbonate peak at the surface of the core is composed of both calcite and dolomite. Examination under the petrographic microscope indicated that the dolomite present is secondary dolomite that is being transformed from the original calcite particles. The formation of secondary dolomite may be due to the lagoon environment becoming more saline. The kaolinite found at 15 cm depth is formed from the weathering of feldspars (Gribble and Hall, 1985).

Diatom preservation was extremely poor for this core and no counting was conducted. Dates were not obtained for this core because it was very similar to Cortina Lakes North Lagoon, for which two AMS dates were obtained (see next section).

Evidence from the stratigraphy of this core indicates that in zone two the area was experiencing arid conditions. During this period the lake would have been dry, and wind blown sands were deposited in the existing depressions. Zone one represents a lake which has frequently filled with water, and becoming an ephemeral lake, has increased the precipitation of organics and carbonates. The presence of pine pollen in the samples above 6 cm suggest that during the period of European activities this lagoon has experienced an increase of organic content and a decrease of carbonate content. As drainage activities of European settlers have caused an increase of surface water in this watercourse, as well as a possible increase of the sedimentation rate, it is likely that the recent observed changes are a direct result of European impact. The increase of organic content may be due to an increase of allochthonous material transported to the lagoon by drainage lines. The observed reduction of carbonate precipitation could be due to the increase of surface water depth or the observed trend of increasing salinity found at Kangoora Lagoon and Reedy Lake.

6.1.4 Cortina Lakes North Lagoon

The Cortina Lakes North Lagoon is a small shallow lagoon (section 3.3.2.2). It is seasonally ephemeral, except after a large flood event, which may result in the filling of the lagoon for several subsequent years. The surface water in the lagoon at the time of sampling was very shallow and most likely derived from local runoff. A water sample was obtained at the very centre of the lake (Figure 6.8) and the water quality of this lagoon is given in Table 6.4. The high conductivity of the water could be a result of evaporation concentrating existing solutes in the surface water. The vegetation surrounding the lake had recently been burnt by a bush fire.

Figure 6.8: Sampling Location of Cortina Lakes North Lagoon

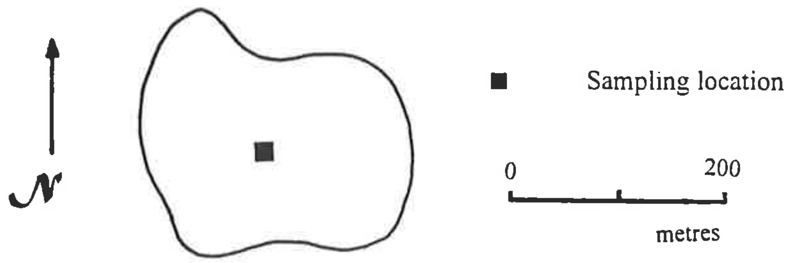


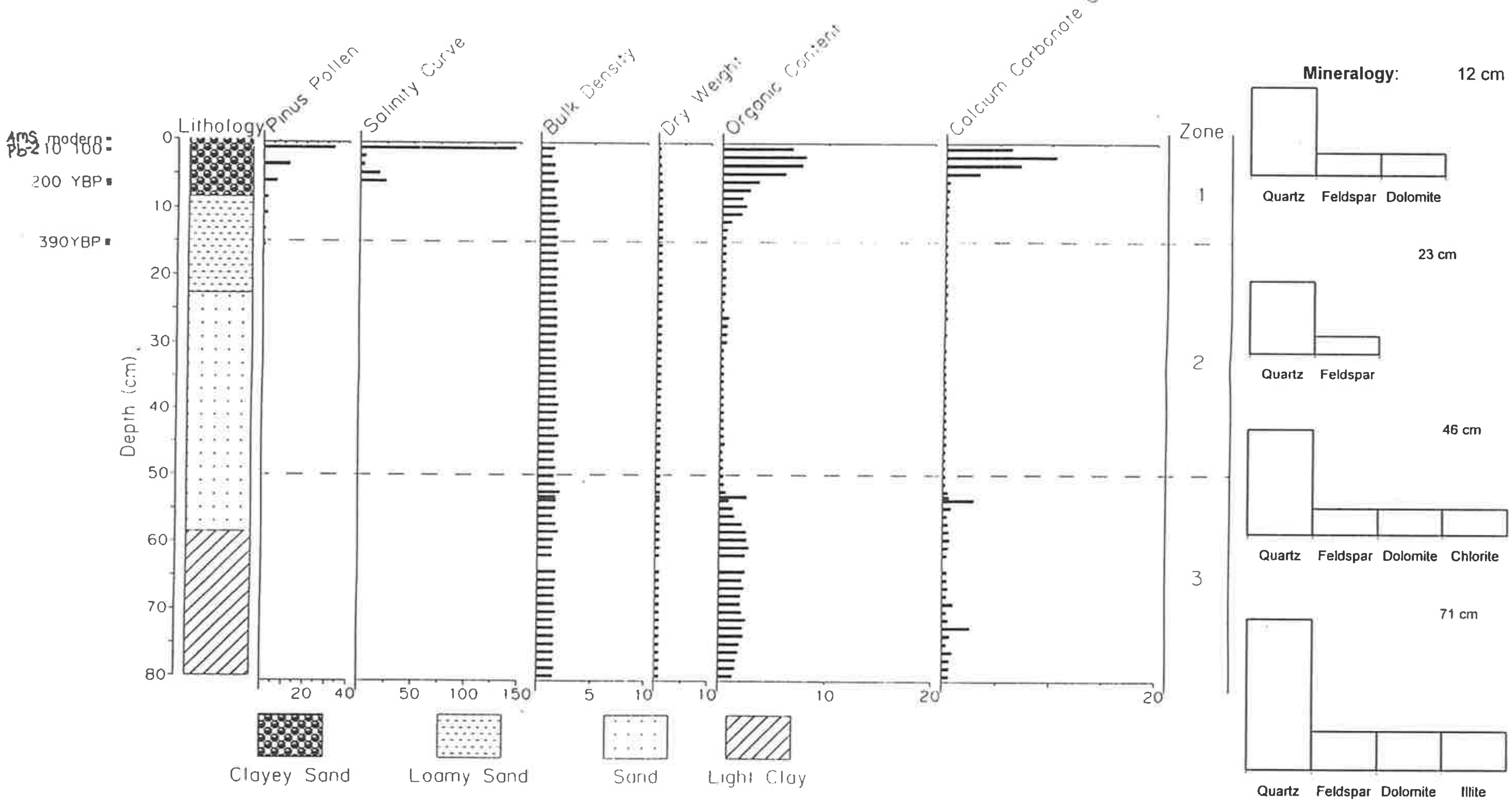
Table 6.4: Water Chemistry of Cortina Lakes North Lagoon

	Mean	Standard deviation
pH	10	0.41
Conductivity	63 %oμS	0.54
Nitrite	3.6 μg/L	0.32
Phosphorus	Not detectable	-

The Cortina Lakes North Lagoon core was 80 cm deep (Figure 6.9). The top 8 cm of the core was composed of brown clayey sand (10YR 3/2), and the second layer between 8 and 22.7 cm was composed of loamy sand (10YR 6/3). The horizon between 22.7 and 58.5 cm consisted of light coloured sand, similar to that found at the Cortina Lakes South Lagoon (10YR 7/3). At 59 cm, the sediments changed to a light coloured clay which continued to the end of the core at 80 cm (10YR 5/8). Thus the stratigraphy alternates from clay to sand and back to clay. This suggests that the core has recorded evidence of two wet periods (zones one and three) and one dry period (zone two). The lithology indicates that the sediments of zones one and three were deposited under ephemeral lake conditions rather than an aeolian environment. This may be indicative of both climatic change and the influence of human activities in the upper layers.

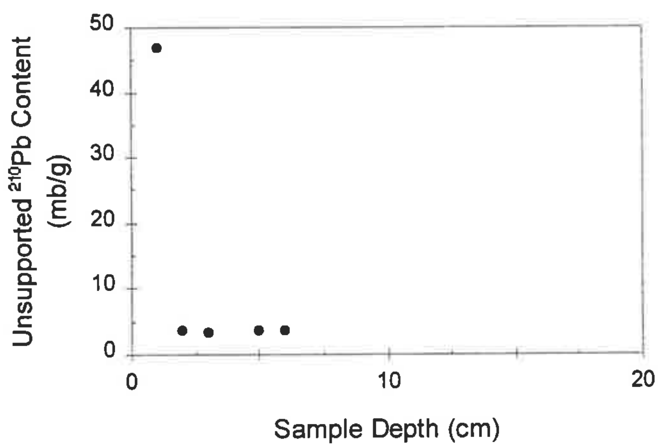
Pine pollen grains were frequent in the top four samples but diminished to very low values after 7 cm indicating that the period of European settlement is recorded in the surface 7 cm.

Figure 6.9: Cortina Lakes North Lagoon



The ^{210}Pb content results (Figure 6.10) indicate that only the surface sample at 1.2 cm had a high lead content, below which background levels were very low, with very little bioturbation indicating that only the surface sample represents the period of European settlement. The AMS dating results provided an age of modern at 1 cm, 200 ± 115 YBP at 6 cm and 390 ± 90 at 15 cm (ANSTO Sample No. OZC254, OZC253 and OZC471 respectively). The ^{210}Pb, pollen and the first AMS date indicate that the period of European settlement is represented in the upper section of zone one, where the organic and carbonate content fluctuations indicate a change in the lake environment. The remaining AMS dates of 200 ± 115 and 390 ± 90 YBP may be contaminated with dissolved modern carbon, which was being washed down from the surface sediments and heavily contaminating the samples, as their original carbon content was very low (this problem is discussed in section 7.1).

Figure 6.10: ^{210}Pb Content of Cortina Lakes North Lagoon



The results of chemical analysis conducted on the Cortina Lakes North Lagoon core are shown in Figure 6.9. Bulk density and dry weight show little change. However, the organic content is higher in zones one and three. The carbonate content shows a slightly similar pattern, but the modern carbonate peak is much higher than the rise in zone three. These increases of organic and carbonate content correspond with changes of stratigraphy, that is, zone one corresponds with the clayey/loamy sand horizon, zone 2 with a sand horizon, and zone three with the light clay horizon. It is likely that zone three represents a warm and wet climatic phase with high lake levels, zone two a dry period and zone one an ephemeral lake environment.

Five samples were analysed for mineral content from this core (Figure 6.9). All are predominantly composed of quartz with traces of feldspar. However the first sample at 5 cm also contains traces of calcite and illite, the second at 12 cm contains a trace of dolomite, the fourth at 47 cm shows additional traces of dolomite and chlorite, and the last at 71 cm shows additional dolomite and illite. Microscopic examination revealed that the dolomite is forming as a secondary mineral from the original calcite particles.

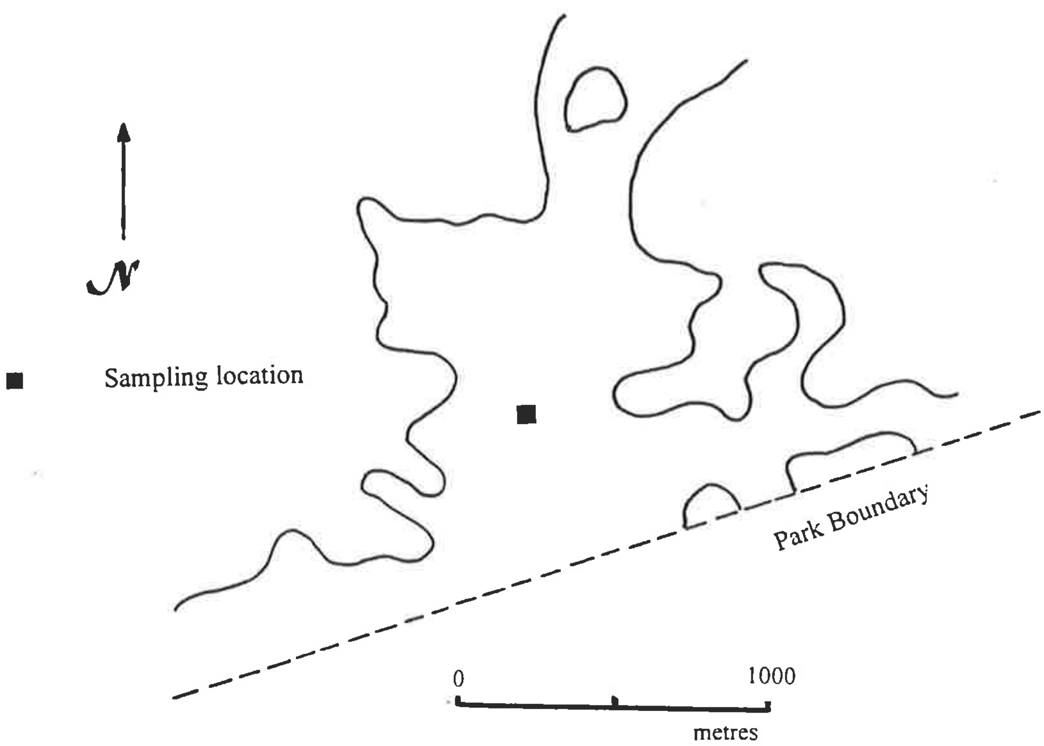
Diatoms were well preserved in the surface samples but not very well below a depth of 8 cm. The diatom assemblage was dominated by *Navicula bulnheimii*, *Denticula tenuis*, *Mastogloia smithi* and *Navicula tuscula* (Appendix 9.3). The inferred salinity curve constructed from the diatom assemblage shows a decrease of salinity towards the present but a dramatic increase at the surface of the core. The surface increase in salinity may be due to the contemporary lake conditions at the time of sampling, as the water level in the lake was shallow after a dry year when the lake would be more saline than normal. If the surface layer is omitted, the diatoms in the lake indicate a trend of decreasing salinity during the period of European settlement.

The record from Cortina Lakes North Lagoon appears to reflect both climate change and human impacts. The stratigraphy and chemical results appear to provide a more reliable guide to the likely time period than radiocarbon dating, due to the probable contamination of samples with both modern and ancient carbon. The chemical and stratigraphic changes in zone two and three are likely to be climate induced. Zone three probably represents a period of warmer, wetter climate and ephemeral or permanent lake conditions, and zone two strongly indicates a dry arid climate of aeolian conditions. The surface samples, correlating with the period of European activities, indicate a further increase of the surface water levels of the lake, perhaps due to drainage activities. Surprisingly, salinity has been reduced over time at this location during the probable period of post-European occupation. This may be due to more regular flushing of the lake by the drainage.

6.1.5 Alf's Flat: Messent Conservation Park

Alf's Flat is the terminal area for the Bakers Range watercourse within the Messent Conservation Park (section 3.3.2.3). There was no surface water present at Alf's Flat at the time of sampling this site, and in fact this depression has been dry for the past 15 years (Foale and Smith, 1991). Figure 6.11 shows the sampling location for this site.

Figure 6.11: Sampling Location of Alf's Flat

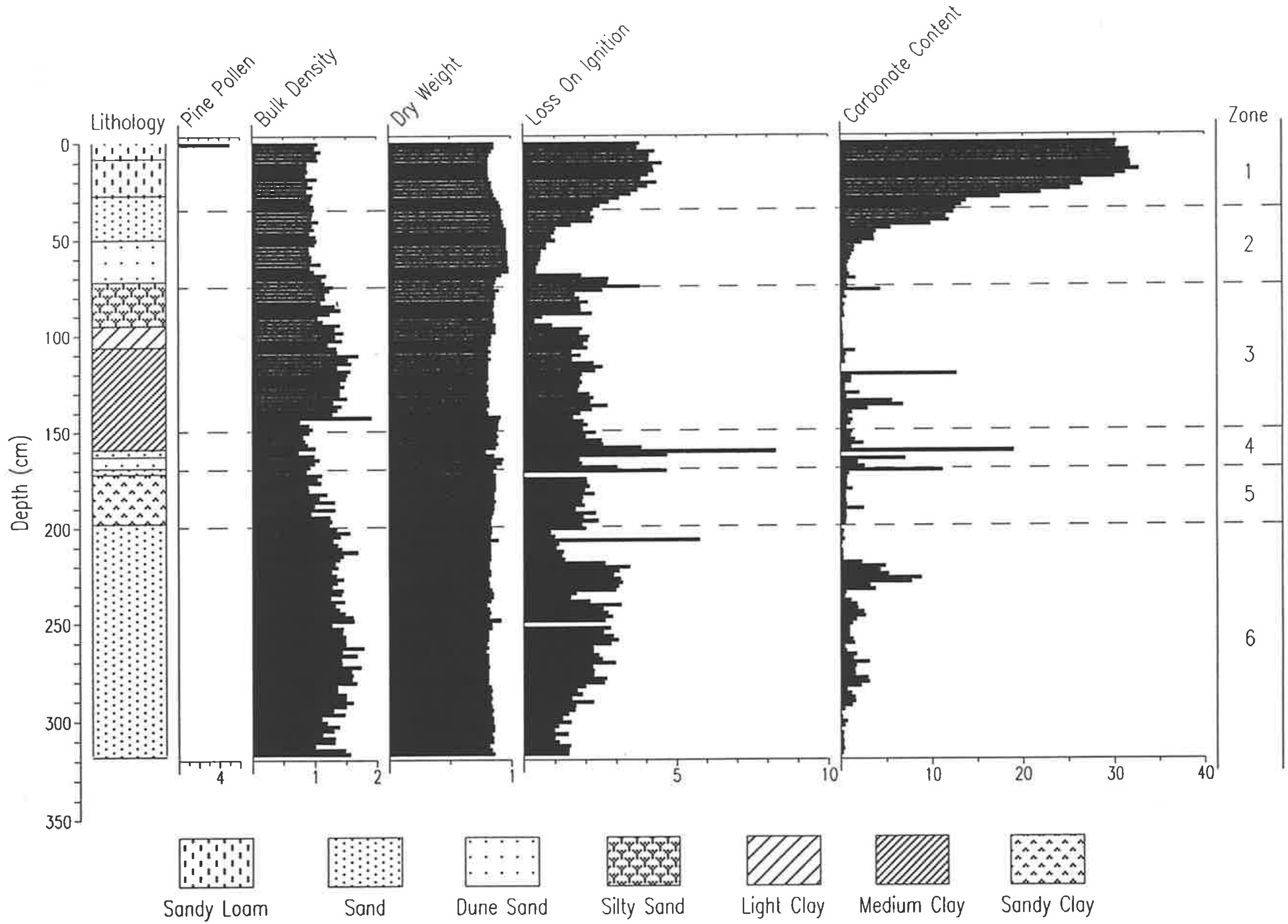


The core from Messent Conservation Park was 318 cm long and the results for this core are illustrated in Figure 6.12. The surface 8 cm was composed of dark brown sandy loam. The next layer, down to 27 cm, was a light brown sandy loam but with orange mottling. Between 27 cm and 50 cm the sediments were a light grey sand, changing to white sand between 50 cm and 72 cm and a orange silty sand between 72 cm and 95 cm after which the sequence became clay based being composed of orange/red light clay. Between 106 cm and 159 cm the clay content increased and the amount of orange mottling increased. At 159 cm the soil became sand-based again. Between 159 cm and 163 cm the soil was a dark, organic sand layer, and between 163 cm and 169 cm there is a white sand. Then, between 169 cm and 172 cm, the substrate returned to a dark coloured organic sand, and between 172 cm and 198 cm there is a reddish sandy clay that returns to a grey sand with very few mottles for the remainder of the core length. All soil horizons had a pH of 10.

The stratigraphy of the Messent core indicates many fluctuations. Because this site is the terminal depression for the Bakers Range watercourse, the changes of stratigraphy from clay-based to sand-based sediments may indicate dry and wet periods in the depression. These fluctuations are most likely indicative of past climatic changes. The mottling prevalent in this core is due to the effect of the fluctuating water table (Charman and Murphy, 1991). A chronology was not attempted for this core as the mottling indicates the amount of disturbance the fluctuating water column inflicts upon the soil column. No mineralogy content was analysed for this core.

Pine pollen were only present in the surface sample (Figure 6.12). Below this, either pollen were not preserved or the sediment was deposited prior to the period of European occupation. It is most likely that pollen were not preserved because of the fluctuating conditions experienced at this locality. Similarly, diatoms were not preserved. However, it

Figure 6.12: Alf's Flat (Messent Conservation Park)



is expected that the sedimentation rate would be very low at this site, and it is likely that only the surface sample represents the period of European occupation of the region.

Chemical analysis for this core is illustrated in Figure 6.12. Both bulk density and dry weight contain a number of fluctuations not found in the other cores. Fluctuations in bulk density and dry weight may indicate changes in the composition and/or compaction of the sediments. As the fluctuations do not relate to visible changes in the stratigraphy, the fluctuations are more likely to represent changes in the sedimentation rate.

The organic content profile shows a number of fluctuations. The change from zone one to zone two is related to a change of sediment from a sandy loam to a sand horizon. Throughout the clay based horizons (zone three) the organic content remained relatively constant. Zone four and six contain other organic content peaks. This indicates that the organic accumulation has been very high throughout the record contained in Messent Conservation Park, with some distinct peaks in productivity perhaps relating to changes in water depth.

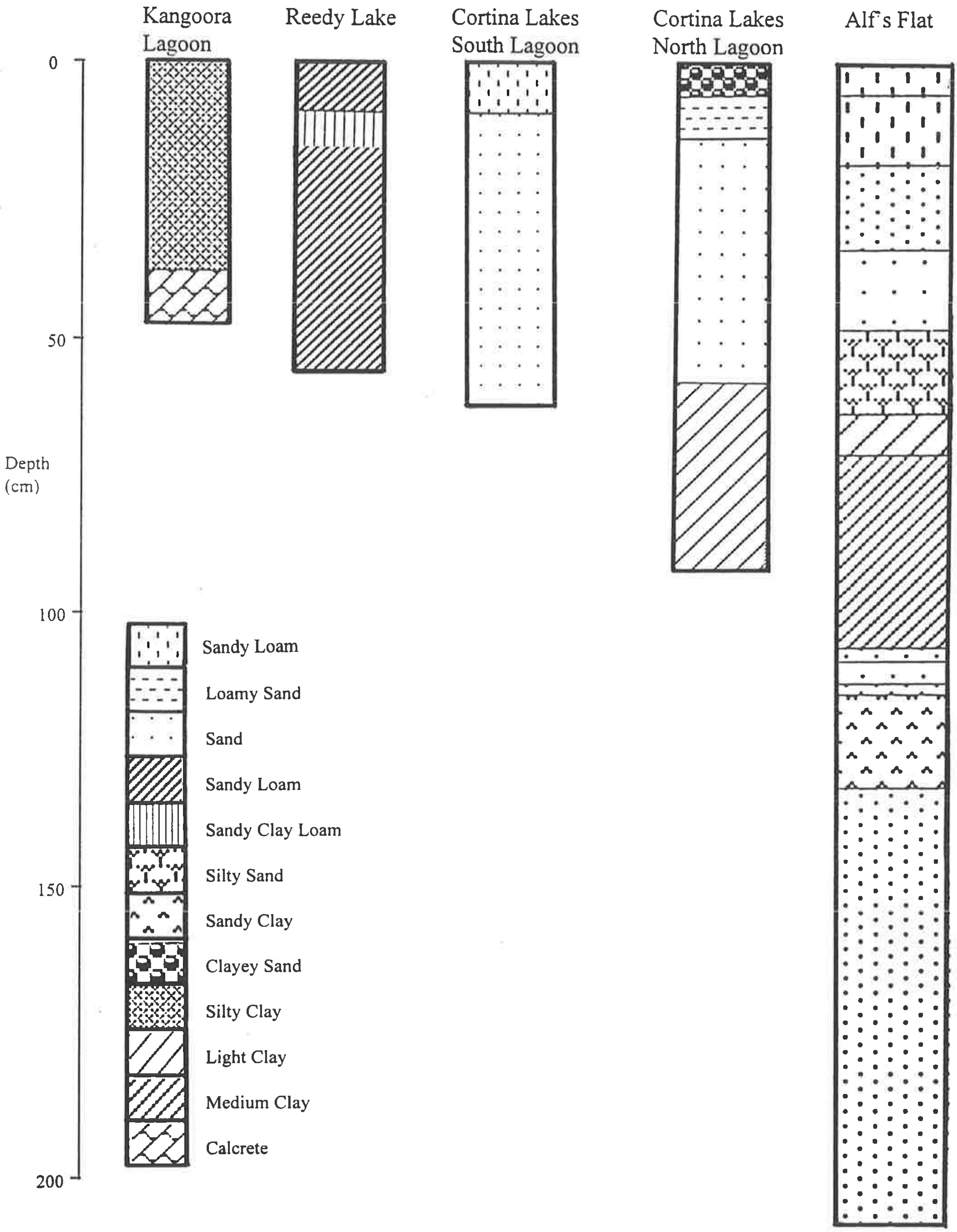
The carbonate profile shows a massive peak in zone one, and minor fluctuations at greater depths in the core. The minor fluctuations at depth are most likely to represent lake conditions when carbonates were precipitated within the lake body. The recent peak of carbonate indicates ephemeral conditions of high pH and water temperature, which are conducive to the precipitation of carbonates (Kelts and Hsu, 1978).

The Messent Conservation Park core illustrates a number of changes in the environment of Alf's Flat. The fluctuations are most likely due to changes in depth of the surface water over thousands of years. The stratigraphy, organic and carbonate profiles indicate ephemeral conditions of high pH and high water temperature in zone one, which is of different nature to any other previous era recorded within the Messent core. A period of cold, dry conditions is probably represented in zone two, and zone three again indicates lake conditions, with high organic deposition but low carbonate production, which is perhaps indicative of a deep lake where carbonates are not precipitated rapidly. The carbonate peak in zone four reflects an environment similar to zone one. It is likely that a warmer climate lessened the depth of lake water and increased the temperature of the lake aiding the precipitation of carbonate. Zone five appears to be a drier period similar to zone two, and zone six another possibly warmer, wet period producing a deep water lake.

6.1.6 Bakers Range Watercourse Trends

Correlation of the core stratigraphy for the sites of Bakers Range watercourse is illustrated in Figure 6.13. Kangoora Lagoon and Reedy Lake appear to operate separately from the remainder of the field sites in this watercourse, because their stratigraphy could not be correlated with that of the other cores. In Kangoora Lagoon, the influence of local runoff and the calcrete bedrock mask any changes occurring in the main interdune corridor. Reedy Lake is separate to the main Bakers Range watercourse, and thus demonstrates only climatic or very local changes. The Alf's Flat, Cortina Lakes North and Cortina Lakes South Lagoon cores could be coarsely correlated. The most recent sediments have been silty or sandy loams overlying a sand horizon. In Cortina Lakes South Lagoon this was as far as was sampled. However, in Cortina Lakes North Lagoon the stratigraphy showed a return to a clay based stratigraphy. This pattern is followed in the Alf's Flat core which changes from a surface sandy loam to a sand horizon and then returns to a clay base. The Alf's Flat core, however, contains an even longer record and shows several fluctuations from sand based horizons to clay based horizons. It is believed that the macro changes in these three cores were induced by the same influences at approximately the same time. The

Figure 6.13: Stratigraphy of sites of the Bakers Range Watercourse



cause of these changes is hypothesised to be changes in surface water depth indicating dry and wet periods in the Upper South.

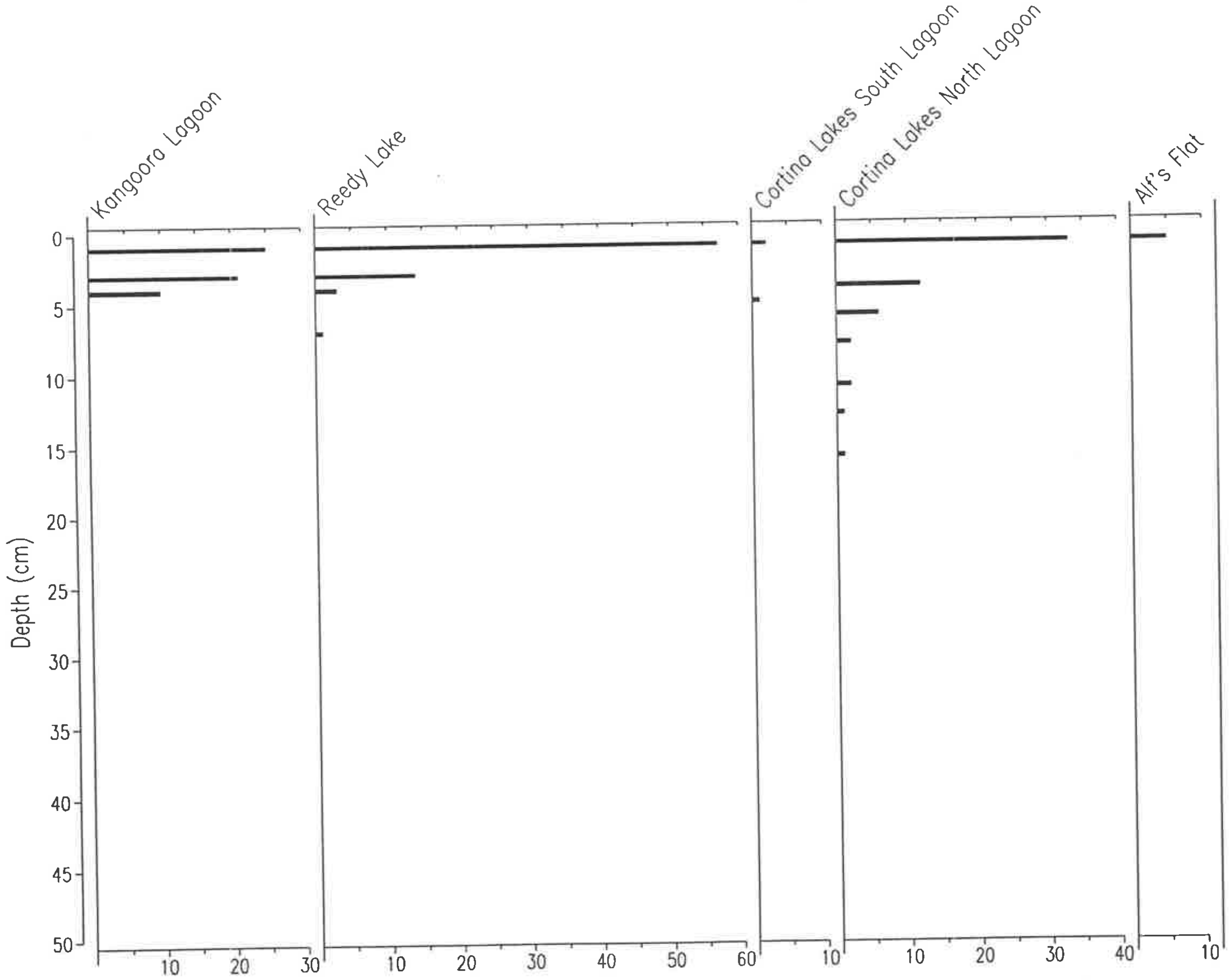
Table 6.5 shows the summarised water quality analysis for the sites of the Bakers Range watercourse. There are no real variations within this data set. The water quality data was indicating very local conditions rather than watercourse trends. The high pH at all sites is indicative of the alkalinity of Upper South East soils.

Table 6.5: Water Chemistry of the Bakers Range watercourse

Water Quality	Kangoora Lagoon	Reedy Lake	Cortina Lakes South Lagoon	Cortina Lakes North Lagoon
Conductivity (‰ µS)	13	35	112	63
pH	10	10	10	10
Nitrate (µg/L)	6.8	9.55	Not detectable	3.6
Phosphorus (µg/L)	Not detectable	Not detectable	Not detectable	Not detectable

The pine pollen record (Figure 6.14) indicates that a record of European settlement exists at all sites, but the sedimentation rate at each site is different. At sites where either lead or AMS dating was conducted, the correlation between the layers where pine pollen were present and the post European radiometric dates were very close. At Reedy Lake the pine pollen curve ended at approximately 4 cm, which corresponded with an inferred age of just over one hundred years. At Cortina Lakes North Lagoon, the pine pollen record ended at 7 cm and an age of modern occurred at 1.5 cm. Thus it may be concluded that pine pollen is an approximate indicator of the age of the sediments. Pre European radiometric results do not appear to be reliable indicators of chronology in the Upper South East sediments, within samples of low organic content, due to the fluctuating water table dissolving modern carbon and transporting it downwards (discussed in section 7.1).

Figure 6.14: Pine Pollen Content of sites of the Bakers Range watercourse



Comparison of the organic content of cores from the Bakers Range watercourse (Figure 6.15) indicates that all cores show a modern peak of organic material. This is a natural phenomenon caused by the decomposition of leaf matter and other debris. However, except for Reedy Lake and Cortina Lakes South Lagoon, the sites have a second, or in the case of Alf's Flat several, organic peaks throughout the core. Had the Reedy Lake and Cortina Lakes South Lagoon cores continued to a greater depth, it is expected that this phenomenon would have been encountered. The successive peaks in organics is likely to indicate a wet period causing deeper lake conditions. Where the lakes are deeper they are more productive, and thus more organisms contribute to the autochthonous organic production. In addition, it is unlikely that organic deposition would be very high in the drier periods represented by the sand horizon.

Figure 6.16 compares the carbonate content profiles of the Bakers Range watercourse core sites. All cores show similar fluctuations. The modern environment appears to be conducive to the precipitation of carbonate in all lakes. Prior to this very little carbonate was produced except in Reedy Lake which has a high carbonate content throughout the core, but does show fluctuations similar to the remainder of the sites. There is a second peak, to varying degrees, in all the cores. This indicates that conditions similar to the modern environment have existed in the past. Thus, the organic and carbonate record together, appear to indicate changing water levels in the lakes of the Bakers Range watercourse.

Unfortunately only two sites provided for a reconstruction of salinity levels (Figure 6.17). Reedy Lake illustrated a trend of increasing salinity toward the present. This trend supports the evidence of increasing salinity in the Upper South East during the past fifty years which is a direct result of European activities. Cortina Lakes North Lagoon showed a trend

Figure 6.15: Organic Content of sites of the Bakers Range watercourse

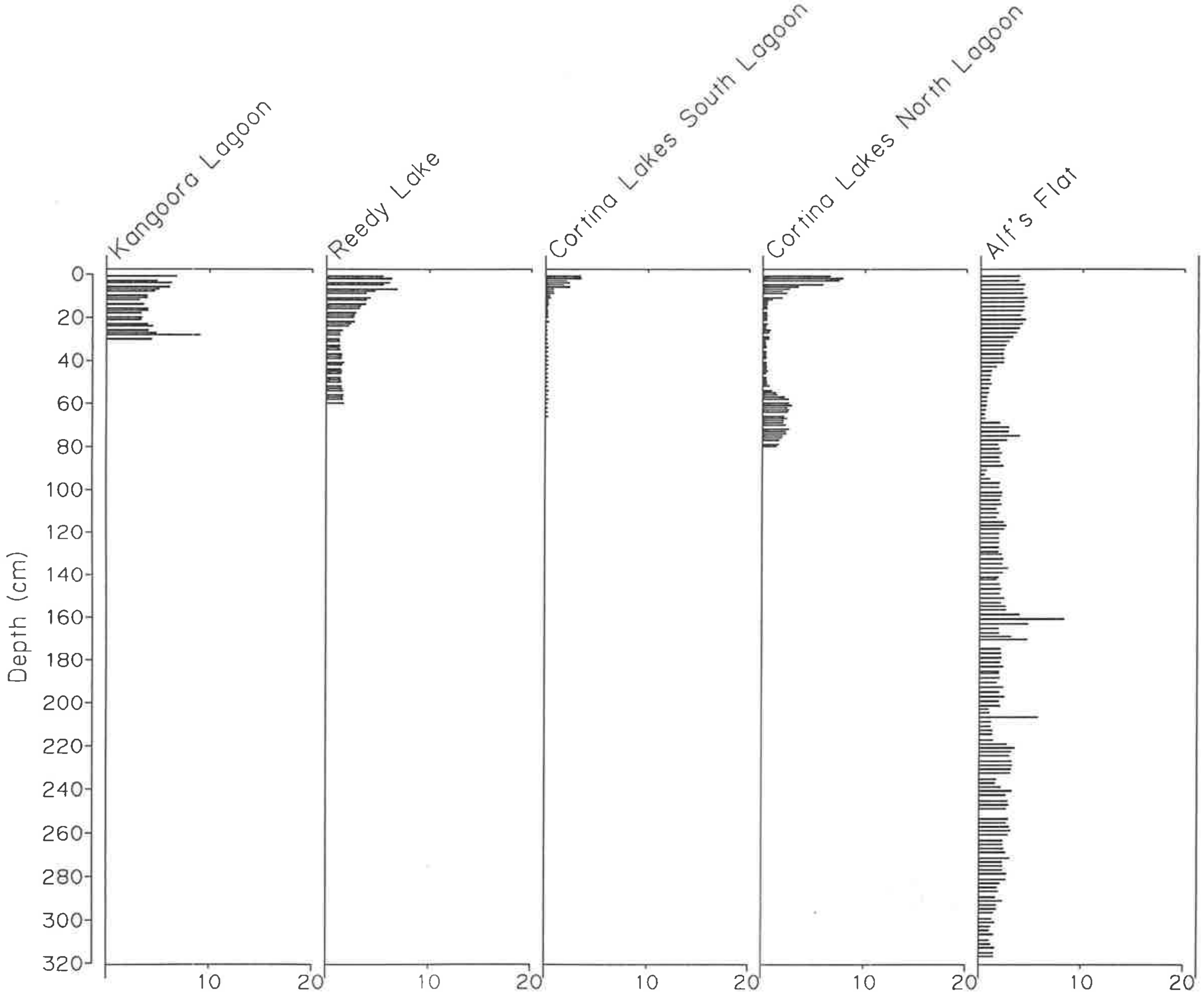


Figure 6.16: Calcium Carbonate Content of sites of the Bakers Range watercourse

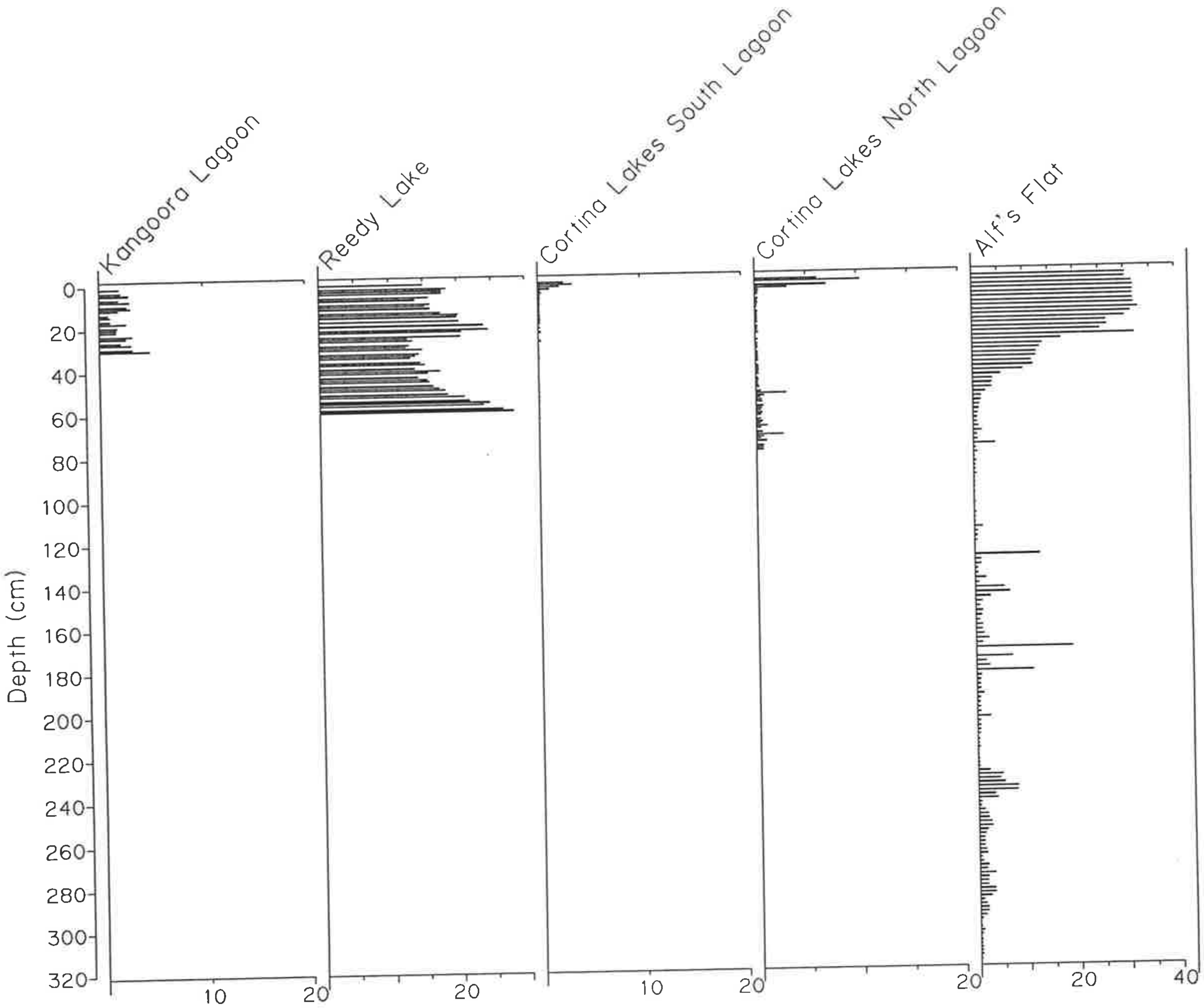
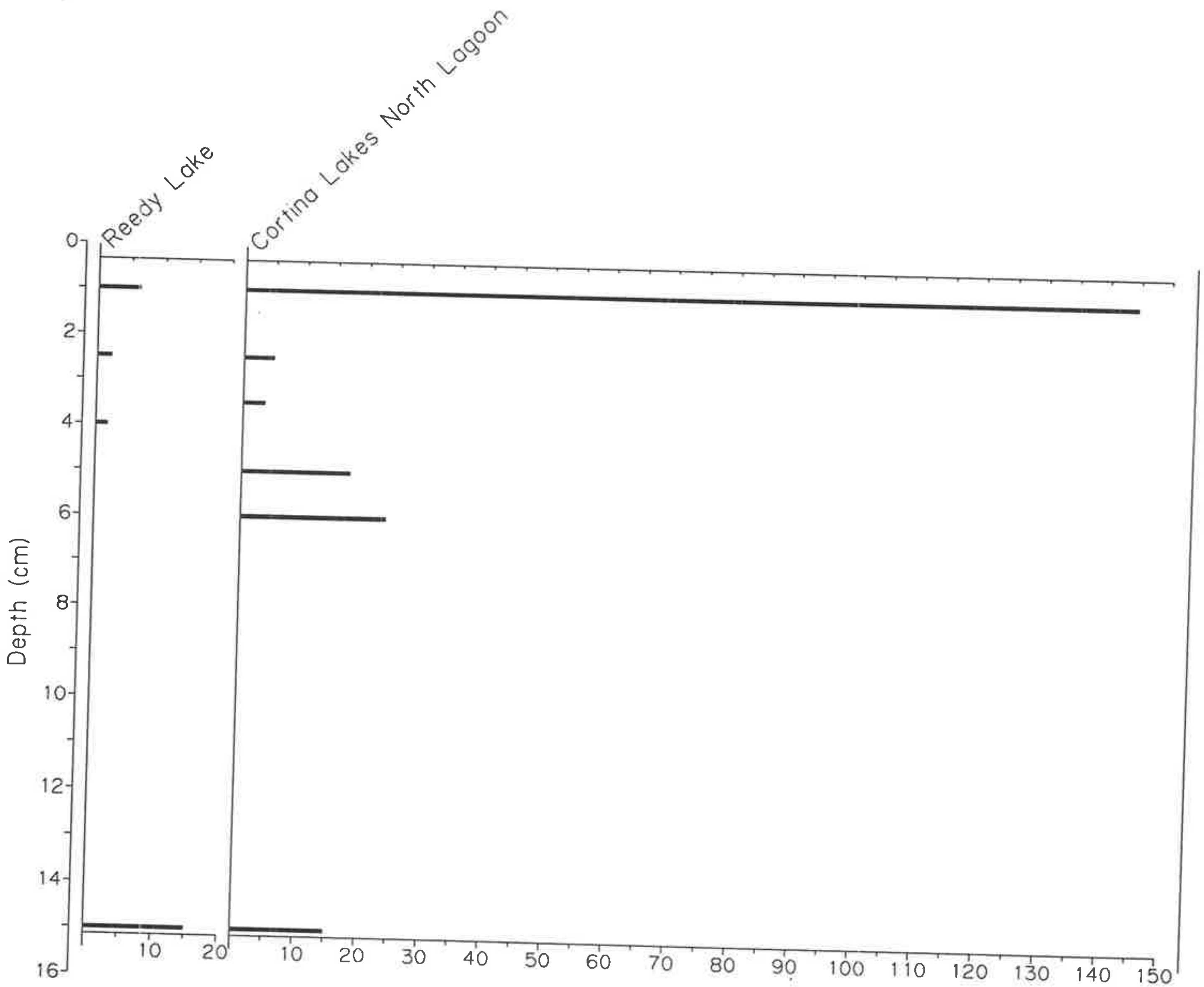


Figure 6.17 Inferred Salinity Curve of sites of the Bakers Range watercourse



of decreasing salinity, except for the modern sample where the high value may be due to the time of sampling. Thus this site indicates a trend in direct opposition to that of Reedy Lake. It is likely that the Reedy Lake core illustrates a regional trend of increasing salinity, while the Cortina Lakes North Lagoon core is indicative of a trend occurring in major wetlands of the region that are now heavily modulated by drainage structures and are experiencing a reduction of salinity due to the more frequent flushing of surface water through the wetlands.

Thus, while little evidence was obtained from Kangoora Lagoon, the remaining sites of the Bakers Range watercourse all appear to show fluctuations that are a result of both climatic change and European activities. It is suggested by the palaeoecological results that an analogue of the present day environment existed in the past as evidenced by the organic and carbonate content. In this environment the lakes were under permanent or ephemeral surface water conditions, resulting in very high rates of both deposition of organic material and precipitation of carbonates. In between these events the Bakers Range watercourse had a very dry environment where the lakes were dry and aeolian processes prevailed. The salinity curves reconstructed from the sediments of Reedy Lake and Cortina Lakes North Lagoon provide conflicting histories that could only be accounted for by local conditions.

6.2. Field Sites of the Marcollat Watercourse

6.2.1 Jaffray Swamp

Jaffray Swamp receives surface water directly from the Morambro Creek in addition to surface water from the Lower South East (section 3.3.3.1). At the time of sampling, a flood gauge on the northern side of Jaffray Swamp registered 60 cm. This level was much reduced from that of the preceding winter as evidenced by surrounding mud flats. Figure

6.18 shows the sampling location for water chemistry analysis and extraction of the core. The water chemistry of the swamp is shown in Table 6.6. It is likely that the salinity of this lake had peaked due to the sampling time being in early June. The salinity of surface water increases during the summer and early winter months until rainfall is sufficient to dilute the remaining surface water. Nitrite was very high, presumably because Jaffray Swamp drains an agricultural area. It was surprising that phosphorus was undetectable as it is widely used in the Upper South East for agricultural activities.

Figure 6.18: Sampling Location of Jaffray Swamp

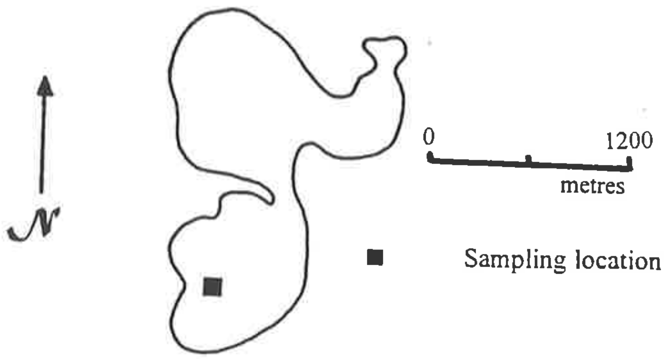
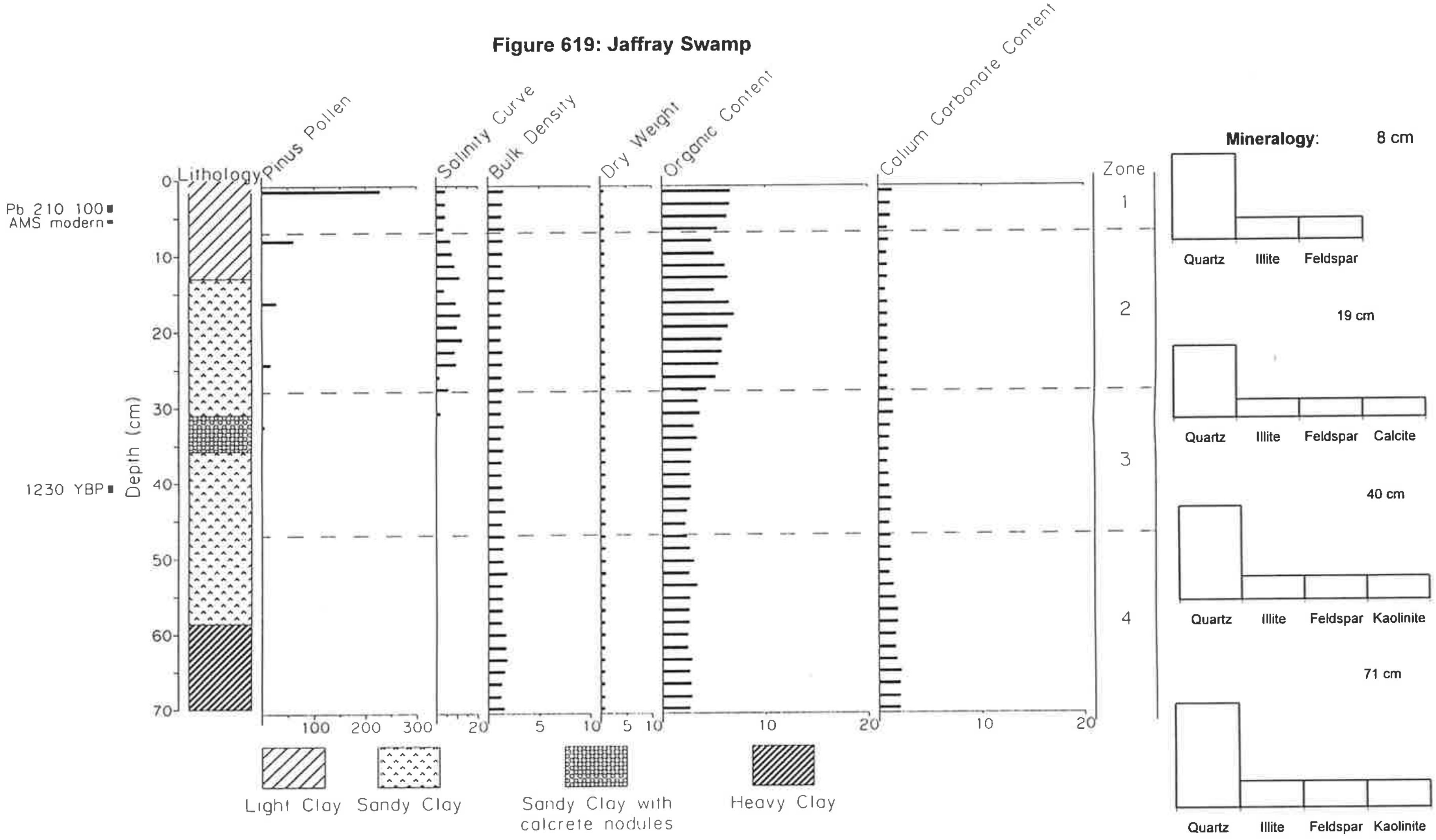


Table 6.6: Water Chemistry of Jaffray Swamp

	Mean	Standard deviation
pH	10	0.54
Conductivity	61 ‰µS	0.21
Nitrite	9.09 µg/L	0.12
Phosphorus	Not detectable	-

The core obtained from the Jaffray Swamp was 70 cm long and the results of analyses on it are shown in Figure 6.19. The surface 13 cm was composed of a dark brown light clay (2.5Y 2/0). From 13 to 57 cm the soil was a sandy clay (2.5Y 2/0) but within this horizon, between 31 and 35 cm, calcrete nodules were present. The calcrete nodules are composed of calcium carbonate and were formed at the depth of water infiltration, by chemical reaction between water and the soil constituents (Charman and Murphy, 1991). Below 57

Figure 619: Jaffray Swamp



cm the sediment was heavy green/creamy clay (2.5Y 4/2). The pH of all soil horizons was 10. As the entire core is clay based it is unlikely that this swamp has experienced dry conditions for the period of time represented in the core.

A large number of pine pollen grains were found in the Jaffray Swamp core (Figure 6.19). This may be due to the influx of grains from western Victoria via the Morambro Creek. The surface sample had a count of 228 grains per millilitre of sediment. Pine pollen grains were not found below 32.5 cm suggesting that 33 cm of sediment has been deposited since Europeans began planting pine trees. Figure 6.20 illustrates the ^{210}Pb content of Jaffray Swamp. The ^{210}Pb content of the core indicates an inferred age of one hundred years at four centimetres depth, indicating that the pine pollen grains are probably infiltrating the soil column in this core since the pines were planted approximately one hundred years ago. In this core only the peak of pine pollen in zone one is a reliable indicator of the core chronology. The ^{210}Pb profile and the AMS dated sample at 5 cm (recorded as modern (OZC255)) do correspond to each other. As the organic content of the AMS dated samples was high, contamination from younger carbon was not expected to be significant (Head, 1997, pers. com.).

Figure 6.20: ^{210}Pb Content of Jaffray Swamp

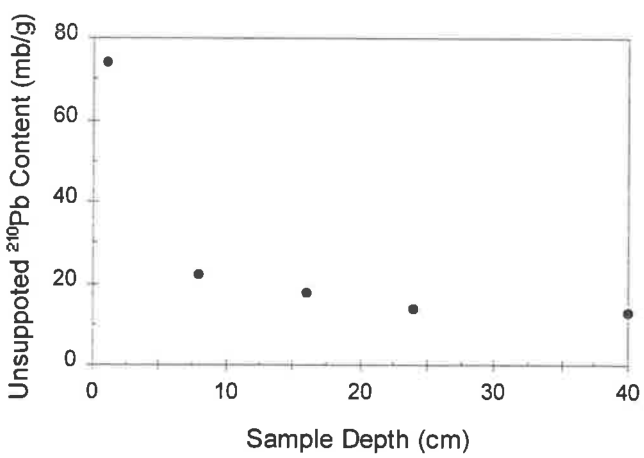


Figure 6.19 illustrates the chemical analysis results for Jaffray Swamp. Bulk density and dry weight show no distinct fluctuations. By contrast, the organic content shows a peak at the surface and minor fluctuations throughout the length of the core. Of particular interest are the higher values in zone one, and again in zone two, and the decrease in organic content in zones three and four. These fluctuations may indicate a change in the water depth of the lake which has influenced the productivity rate. Water level fluctuations are probably caused by climatic change as the organic content decreased just before the sample that was dated at 1230 ± 110 YBP (ANSTO sample no. OZC256).

The calcium carbonate content of the Jaffray Swamp core was very low with respect to the other field sites. The carbonate curve shows minor fluctuations throughout the profile, but these do not correspond to the changes in organic content. The reduced rate of carbonate production in comparison to the Bakers Range watercourse sites could be due to a number of factors, the most probable being that a relatively constant and high water depth, caused by the constant influx of surface water from Morambro Creek, has reduced the rate of carbonate precipitation during the period of core deposition. The Jaffray Swamp depositional environment may be responding to changes occurring in the catchment area in western Victoria, rather than changes occurring in the Upper South East of South Australia.

Results from the mineral analysis of Jaffray Swamp support the chemical analysis findings of the swamp having a very low carbonate content. Four samples were mineralogically analysed (Figure 6.19), and all were predominantly composed of quartz with traces of illite, feldspar and calcite or kaolinite. The XRD results highlight the lack of carbonate minerals contained in this core.

The sediment core from Jaffray Swamp gave the best preservation of diatoms of all the study sites. The diatom record was very good down to a depth of 42 cm, after which dissolution began occurring and the diatom count was no longer considered accurate. Jaffray Swamp's diatom assemblage was dominated by *Cocconeis placentula*, *Navicula cincta form minuta* and *Navicula lanceolata* (Appendix 9.3). The salinity curve constructed from the diatom assemblage indicated a change from fresh conditions in modern times to brackish and then back to fresh again around 25 cm, with a peak in salinity occurring at 32 cm due to the increase in the *Epithemia adnata* population. The salinity change does not correspond with the organic profile, but does correlate with the carbonate profile, as there is a slight reduction in carbonate content during the period of brackish conditions. The period of European occupation corresponds with a change from brackish to fresh lake water, indicating that European activities in this catchment have not produced a significant increase in surface water salinity.

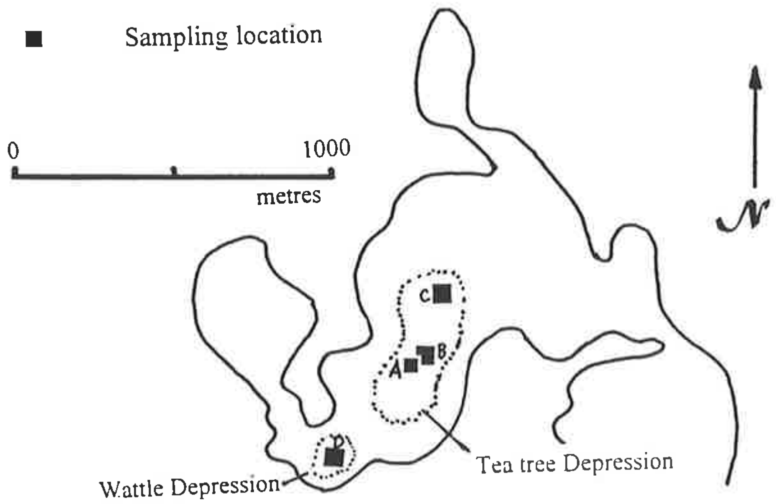
Jaffray Swamp contains the best palaeoecological record for reconstructing previous environments so far examined, as the preservation of the fossil record is reasonably good. The diatom-inferred salinity curve showed a reduction of salinity toward the present and within the period of likely European activities. This would imply that European activities have not caused a dramatic increase in dryland salinity within Jaffray Swamp. However, an increase in the salinity of the swamp occurred in zone two, which must be climatically driven. The increase in organic content in zone two does not correlate with the period of European occupation suggesting that there have been changes in the water level occurring in the past one thousand years resulting in an increase of lake productivity, and an increased preservation of the organic material. The carbonate profile appears to relate to salinity changes, with reduced precipitation correlating with periods of high salinity. Jaffray Swamp appears to show fluctuations that are both climate and human-induced.

Changes in zone one may reflect the activities of European agriculture, and changes deeper in the core may be caused by climatic fluctuations.

6.2.2 Gum Lagoon Conservation Park

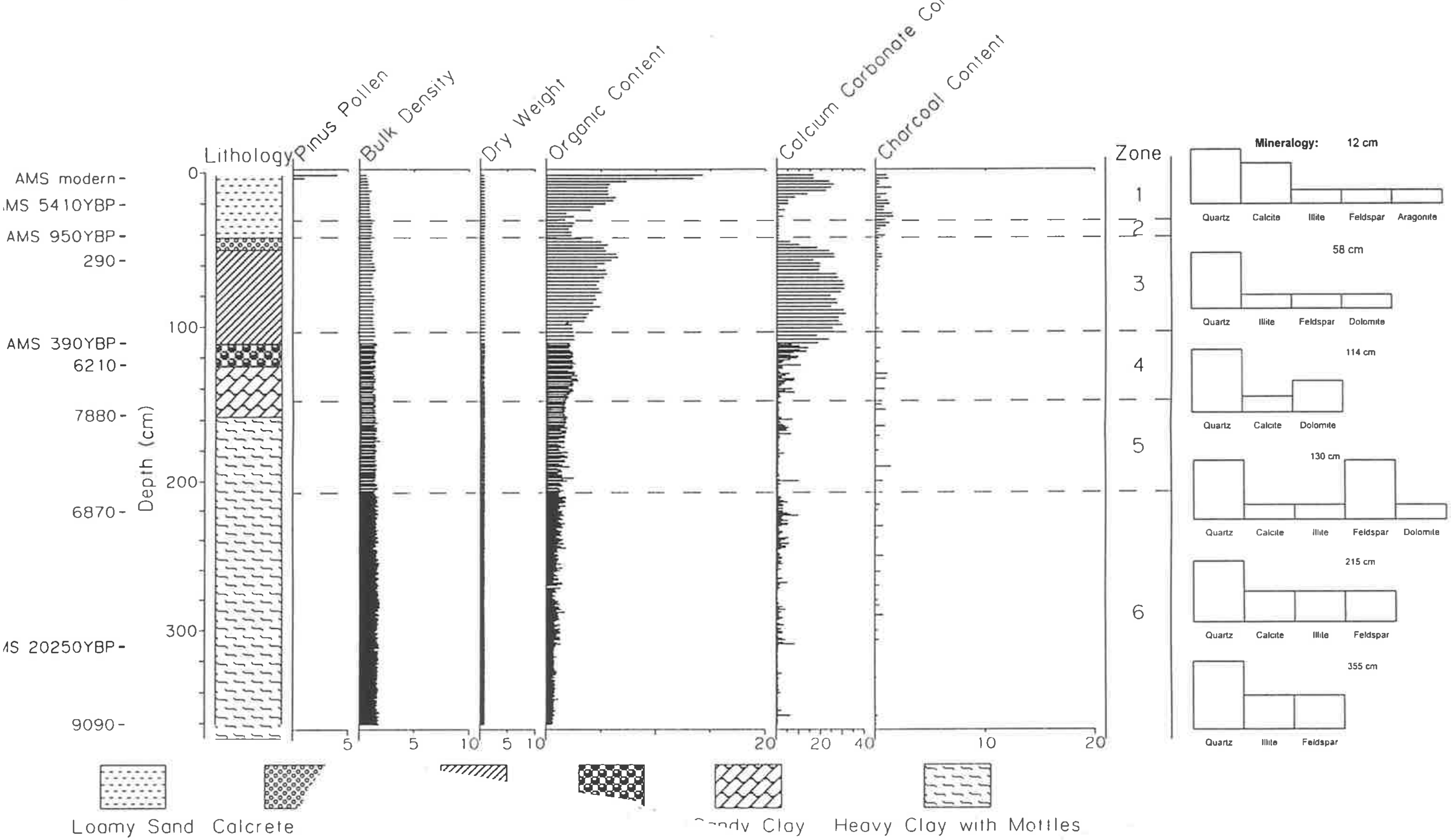
The Gum Lagoon Conservation Park is located at the terminal end of the Marcollat watercourse (section 3.3.3.2). Three cores from Tea tree depression and one from Wattle depression were obtained in the Gum Lagoon Conservation Park. The location of these sites is shown in Figure 6.21. At the time of sampling the depressions were both dry and were last inundated in 1992 from local runoff. The previous period of major inundation occurred as a result of the 1955/56 flood (Foale and Smith, 1991).

Figure 6.21: Sampling Location of Gum Lagoon Conservation Park Cores



The core from the centre of the Tea tree depression, core A, was the longest core extracted for this field site (360 cm), and was analysed in detail. The results for this core are first reported and then the other cores are correlated with this one. The stratigraphy of core A is quite complex (Figure 6.22). The surface 42 cm of the core was composed of dark brown loamy sand (10YR 5/1), followed by a layer between 42 and 50 cm which was composed of the same material but contained small calcrete nodules. From 50 to 111 cm the material

Figure 6.22: Tea Tree Depression Core A: Gum Lagoon Conservation Park



changed to a white medium clay, and between 111 and 126 cm the soil became a cream clayey sand that had green coloured mottles within the cream colour. The mottles indicate slow internal drainage, a result of the heavy clay horizon. Between 126 cm and 158 cm the soil became a khaki sandy clay and from 158 cm to the end of the core (360 cm) the soil increased in clay content and became quite green in colour.

Similar to Cortina Lakes North Lagoon radiometric dating results did not appear reliable at this location. Figure 6.22 illustrates the dating results. It is more likely that the chemical analysis results provide a better guide to the age of the sediment. At Gum Lagoon Conservation Park the water table fluctuates widely, due to seasonal variations of effective rainfall. Evidence of such is provided in zones 5 and 6 where the clay is heavily mottled. The AMS dating results indicate that the lower end of the peak in zone one is approximately 5410 ± 200 YBP (ANSTO sample no. OZC249). The sample at 310 cm, which provided an age of 20 250 ± 240 YBP (OZC251), indicates that this core provides a record of hydrologic changes over a long period of time. The remaining AMS dating results were discarded for this core as they contained very low levels of organics and thus were susceptible to contamination from modern carbon. Only small amounts of pine pollen were found in the two surface samples of the core indicating a very slow sedimentation rate.

The chemical analysis of core A is also illustrated in Figure 6.22. Bulk density and dry weight did not show any unusual fluctuations. However, both the organic content and carbonate profiles show many fluctuations. The two main peaks in the organic profile occur in zones one and three, indicating two periods where organic accumulation was very high. It is noteworthy, that the surface sample is quite low in organic content, which is probably an artefact of the recent period of drought conditions (post 1970s). The peak in zone three may initially have been a higher percentage than the surface peak but has undergone decomposition since its burial. The linear decrease of organic content after the second peak may be due to decomposition.

The carbonate content also shows two major peaks in zones one and three, and there are many smaller peaks in zones five and six. It would appear that the carbonate profile also indicates two main periods of climate that have been conducive to carbonate precipitation. These peaks correspond with the organic peaks. Thus, this site has undergone periods of a fluctuating lake environment.

A charcoal analysis was conducted for this site using samples which had been prepared for an unsuccessful pollen count (chapter 4.2.10). The charcoal count for this site showed an increase in charcoal per millilitre of sample in the periods where organics and carbonates were very low: that is, in zone three and at the end of zone five (Figure 6.22). This may indicate that fire frequency has increased in periods when the lakes dried out, and decreased in periods where the water level of the lakes was high. The charcoal evidence is consistent with a cycle of wet and dry periods.

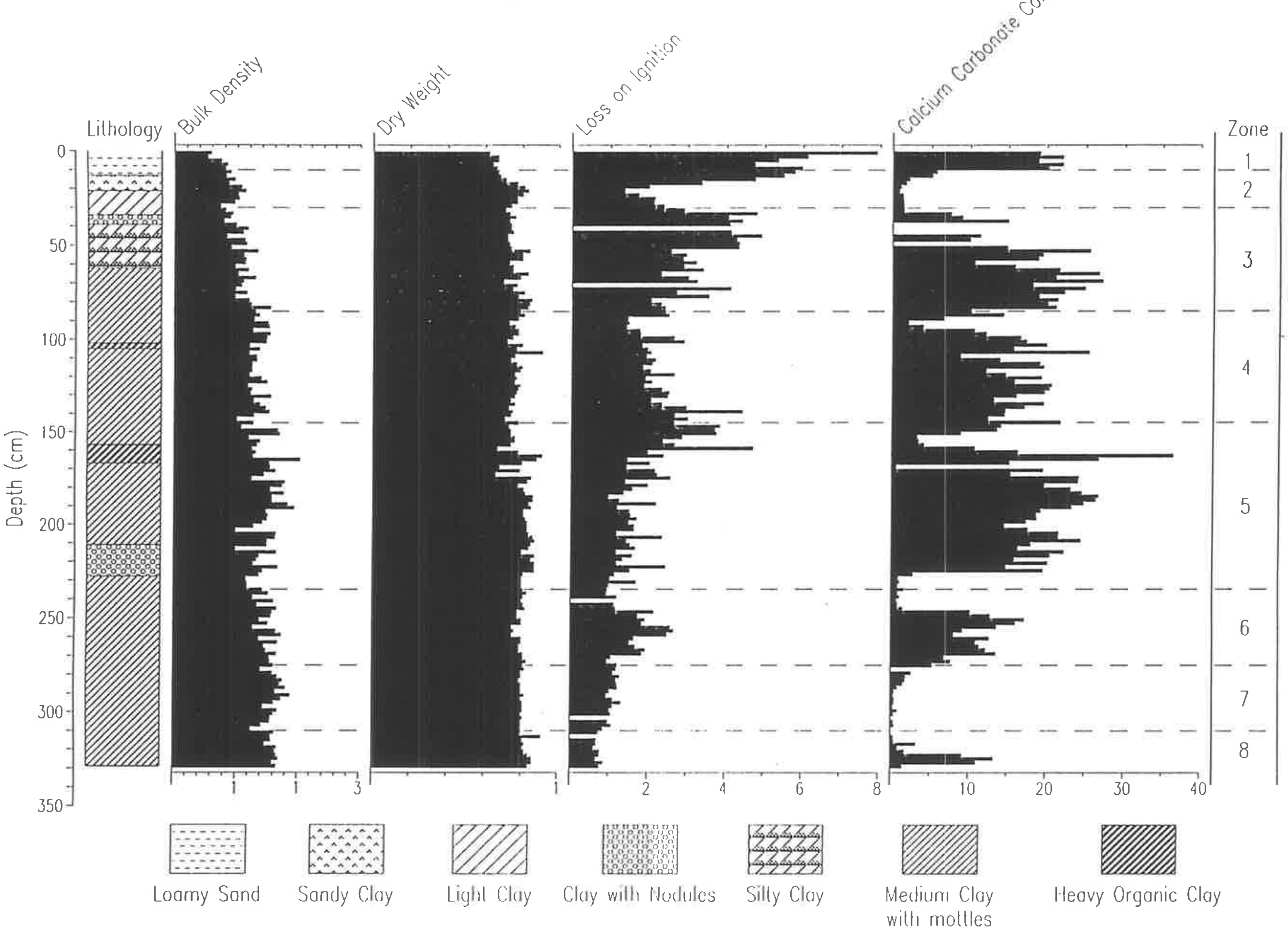
Six samples underwent mineral analysis (Figure 6.22). The first was from the carbonate peak at 16 cm, which was composed predominantly of calcite, with subdominant quartz and traces of illite, feldspar and aragonite. The second sample (60 cm) correlated with the second carbonate peak, and was predominantly composed of quartz with sub dominant dolomite and feldspar with a trace of illite. The dolomite has formed from the transformation of calcite crystals to dolomite. The third sample (115 cm) at the edge of the carbonate peak is predominantly quartz with sub dominant dolomite, and a trace of illite. The fourth, fifth and sixth samples (130 cm, 216 cm, 350 cm) were all basically composed of quartz but have small amounts of feldspar and illite, and the fifth sample also contained calcite. These results suggested there have been two periods in the environmental history of this depression that have been conducive to carbonate precipitation, which are represented in zones one and three.

Thus core A records alternate periods of dry and wet conditions at the terminal end of the Marcollat watercourse. The charcoal profile indicates that fire frequency increased in the arid period when the lakes were dry. The organic profile indicates that the prevailing environment in zone three was wet with deep lake conditions conducive to the production and preservation of organics. The organic peak in zone one is more characteristic of shallow and/or ephemeral lake conditions which may have occurred throughout the Holocene. European impact upon this site was not substantial. The reduction of organic matter on the surface sample may be due to the drainage activities in the Upper South East, which have reduced the amount of water reaching the terminal wetland, but, the sedimentation rate is too low to detect changes over the past fifty years.

The results for Tea tree depression core B are shown in Figure 6.23. Although this core was located very close to core A, problems of compaction were encountered while drilling. Thus, while core B is approximately the same length as core A, it seems to contain a longer record of environmental change. Dates were not obtained for this core, due to funding limitations.

Core B was 330 cm long. The surface 33 cm was composed of loamy sand. A horizon of calcrete nodules was encountered between 33 cm and 39 cm and the remainder of the core was composed of medium clay with bands of heavy organic clay. There is also another band of calcrete nodules between 210 cm and 228 cm. Thus, only minor variations of stratigraphy between core A and core B were encountered. The variations could be due to sampling differences.

Figure 6.23: Tea Tree Depression Core B: Gum Lagoon Conservation Park

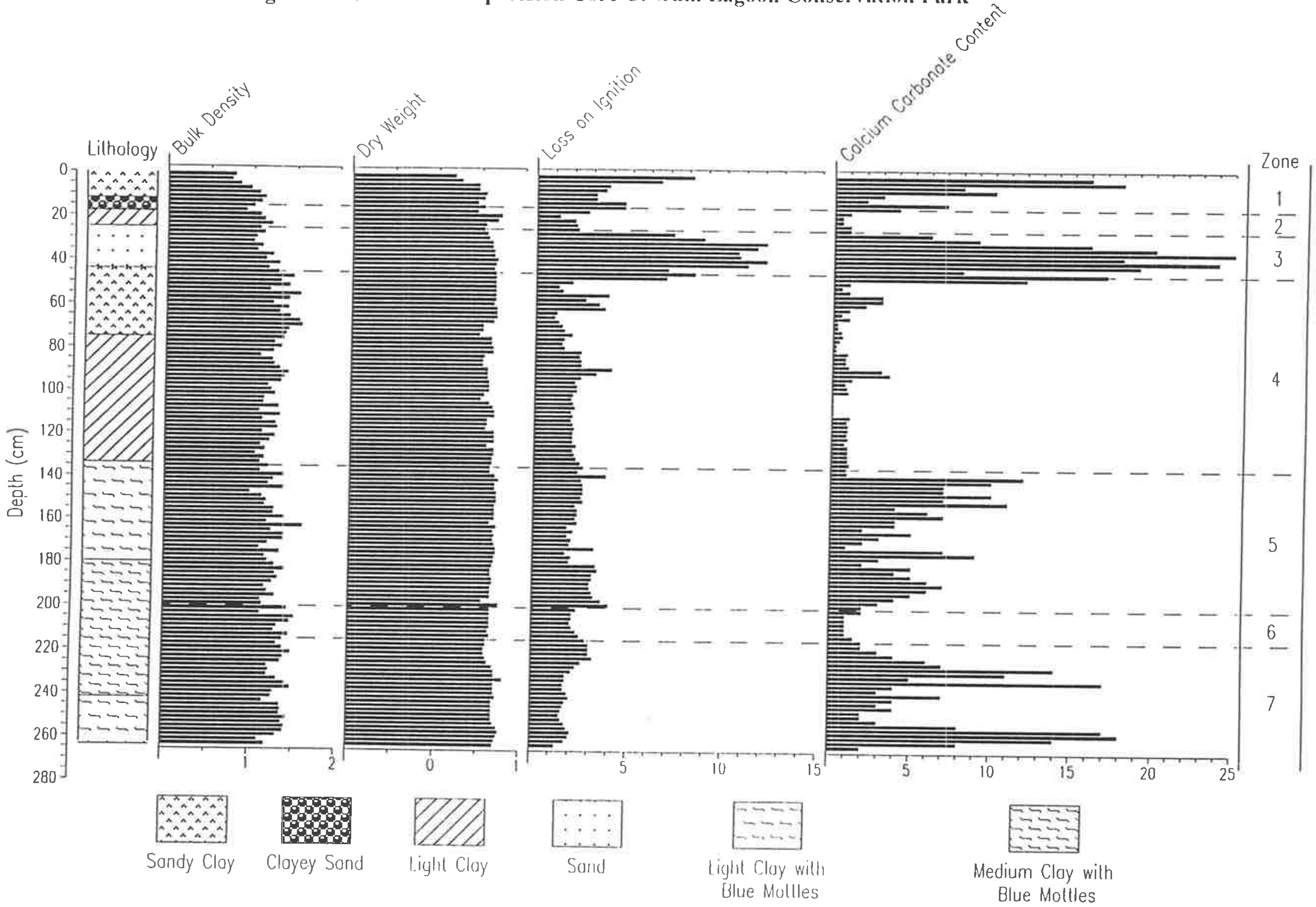


The results of the chemical analysis on core B are also shown in Figure 6.23. Bulk density and dry weight did not show distinct fluctuations indicating a slow but steady sedimentation rate. The organic content and carbonate profiles can be correlated with those of core A, but show amplified peaks in zones 4, 5 and 6, and the carbonate record shows an additional peak in zone 8. Thus, core B provides corroborative evidence that there has been large scale hydrologic changes, probably climatically driven, in the Upper South East of South Australia.

The third core from Tea tree depression, core C, was located on the inside edge of the depression surrounding the central core. The sedimentation rate of this location was expected to be much lower than that for core A and core B. Figure 6.24 illustrates the stratigraphy of this core. The top 12 cm is composed of brown sandy clay and between 12 and 18 cm is a clayey sand. A clay horizon between 18 and 25 cm overlays a sand horizon between 25 and 43 cm. The clay substrate returns with a sandy clay between 43 and 76 cm which becomes a light clay between 76 and 133 cm. The clay substrate continues but with increasing mottling for the remainder of the core. The stratigraphy of this core is quite different to that of cores A and B. Of particular interest is the band, of possibly aeolian sand, between 25 and 43 cm. This may indicate a period during which this locality was under aeolian influence, but the other Gum Lagoon Conservation Park sites still contained water.

Chemical analysis results obtained for this core are also shown in Figure 6.24. Bulk density and dry weight show no distinct fluctuations. The organic content profile shows two major peaks in zones one and three, with minor fluctuations throughout the remainder of the core. The carbonate profile shows many distinct fluctuations throughout the core. The organic profile is similar to that of core A and core B but the carbonate profile is very different.

Figure 6.24: Tea Tree Depression Core C: Gum Lagoon Conservation Park



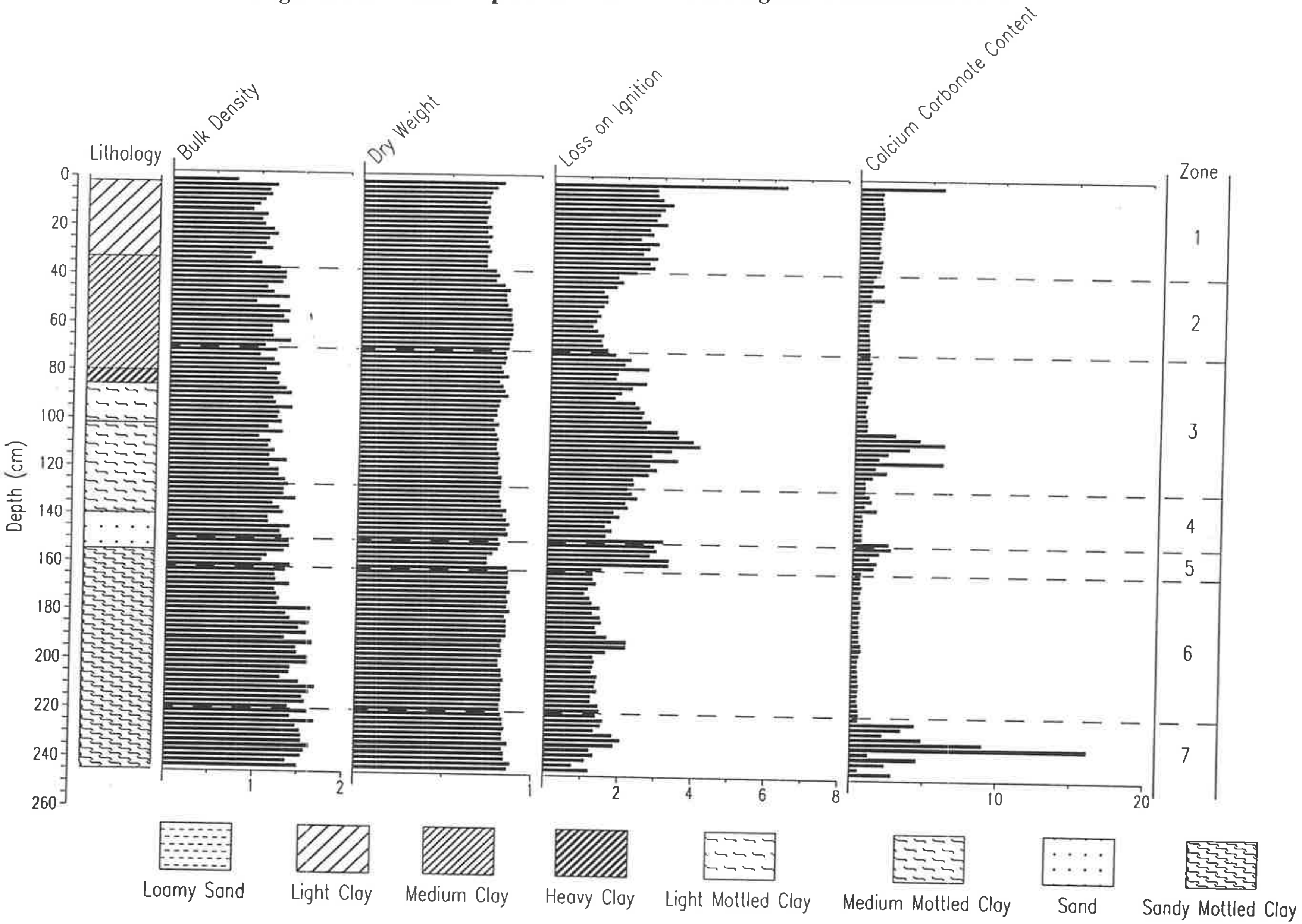
This difference may be due to the fact that the sampling location of the core was on the inside edge of the depression. Carbonate is precipitated more readily in shallow water bodies due to the increase in water temperature (Kelts and Hsu, 1978). This should account for the greater percentage of carbonate and the additional peaks in the carbonate profile of core C. Thus core C illustrates changes in the lake edge conditions of the Tea tree depression.

A fourth core was obtained from Wattle depression, an area that would rarely receive flood waters. Results for this core are shown in Figure 6.25. The stratigraphy does indeed show major differences to core A. From the surface to a depth of 32 cm is a light clay. Between 32 and 80 cm is medium clay with a band of heavy clay between 80 and 87 cm. The clay substrate continues, but with a distinct mottle between 87 and 138 cm. The mottling is due to the influence of the fluctuating groundwater table (Charman and Murphy, 1991). A sand horizon is found between 138 and 155 cm, which may correspond to that found in core C. The remainder of the core is composed of medium clay with a distinct mottle.

The results of the chemical analysis are also shown in Figure 6.25. Bulk density and dry weight show only slight fluctuations indicating a steady sedimentation rate. The organic content can be correlated with that of the other Gum Lagoon Conservation Park cores. However, the carbonate content is very low, showing distinct peaks, which may be due to the fact that surface water rarely overflows to this lagoon, but when infrequent periods of inundation do occur, they are of short duration, and rarely precipitate carbonate.

Thus, the four cores obtained from the Gum Lagoon Conservation Park field site, provide a history of the terminal wetlands of the Marcollat watercourse. Cores A, B and C indicate fluctuating water depth in the main depression. The Wattle depression (core D) shows that only rarely has water filled the main (Tea tree) depression to overflow into the smaller

Figure 6.25: Wattle Depression Core D: Gum Lagoon Conservation Park



(Wattle) depression. All sites provide evidence of hydrologic fluctuations over thousands of years that probably represent climatic changes. Evidence of European impact within these cores is minimal due to the low sedimentation rate.

6.2.3 Marcollat Watercourse Trends

The stratigraphy of the field site cores in Marcollat watercourse are shown in Figure 6.26. The Jaffray Swamp core appears dissimilar to the Gum Lagoon Conservation Park cores, due to it having a regular source of water input from the Morambro Creek. This swamp is stable and the sedimentation rate very high, providing detail of flood events in the past 1500 years. Sites in the Gum Lagoon Conservation Park appear to provide detail of environmental change over a much longer period suggesting large scale climatic changes, which could be coarsely correlated by the sand horizon between the cores. Core D is very different to cores A, B and C because it fills with surface water only after the Tea tree depression is full, thus recording only very wet hydrological events.

A comparison of the organic profiles of the Marcollat watercourse sites are shown in Figure 6.27. All cores show a peak in organic content at the surface associated with the decomposition of a humus layer. However, the Gum Lagoon Conservation Park cores illustrate successive peaks in organic content that may represent hydrological changes. Jaffray Swamp is dissimilar due to the influence of Morambro Creek. Evidence from this swamp suggests that it has always been a permanent water body, and that there are fewer fluctuations indicative of climate change. In addition the Morambro Creek provides a source of sediments to the Jaffray Swamp resulting in an increased sedimentation rate in comparison to the Gum Lagoon Conservation Park cores. Thus, Jaffray Swamp contains a shorter record of time.

Figure 6.26: Stratigraphy of sites of the Marcollat Watercourse

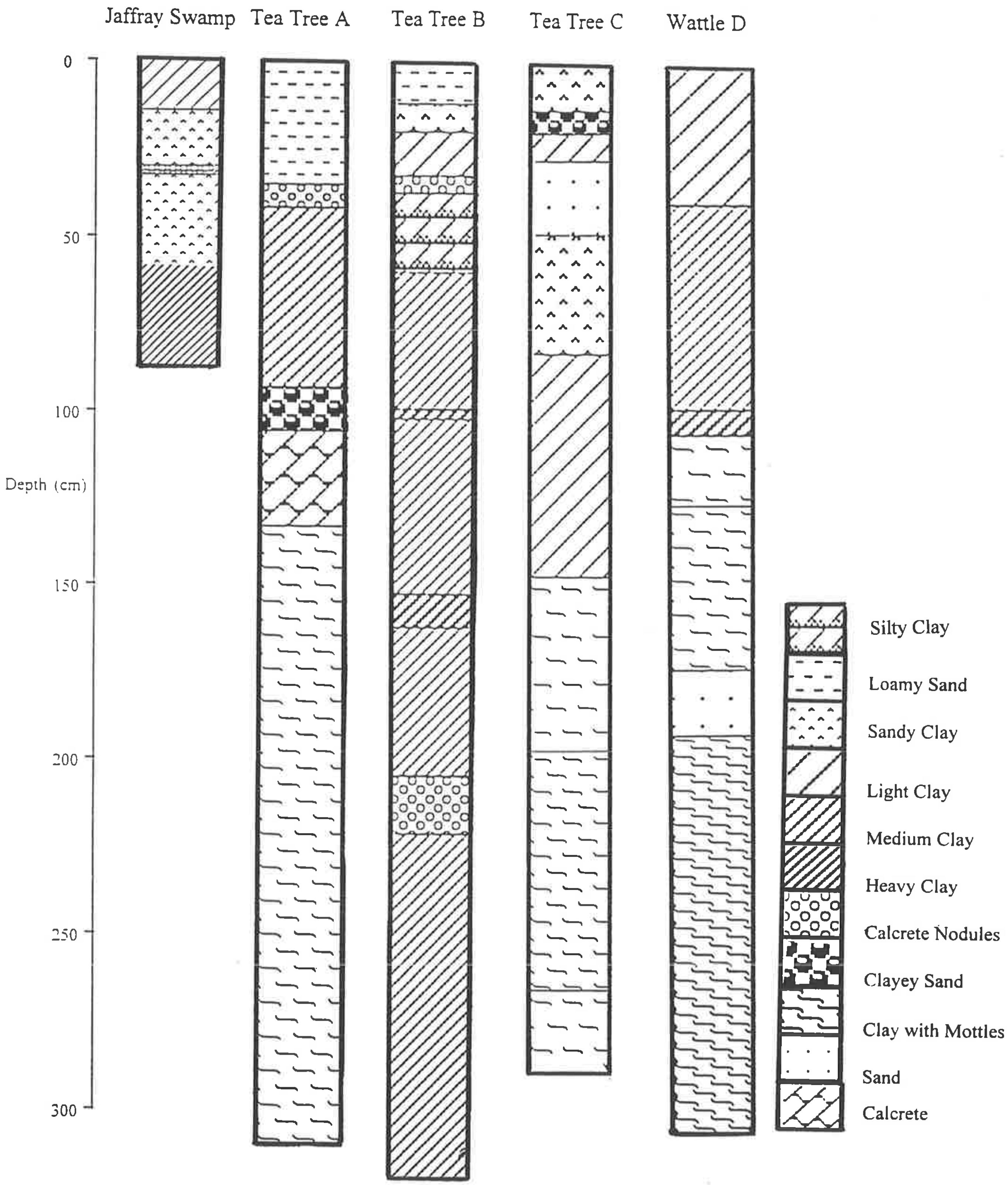
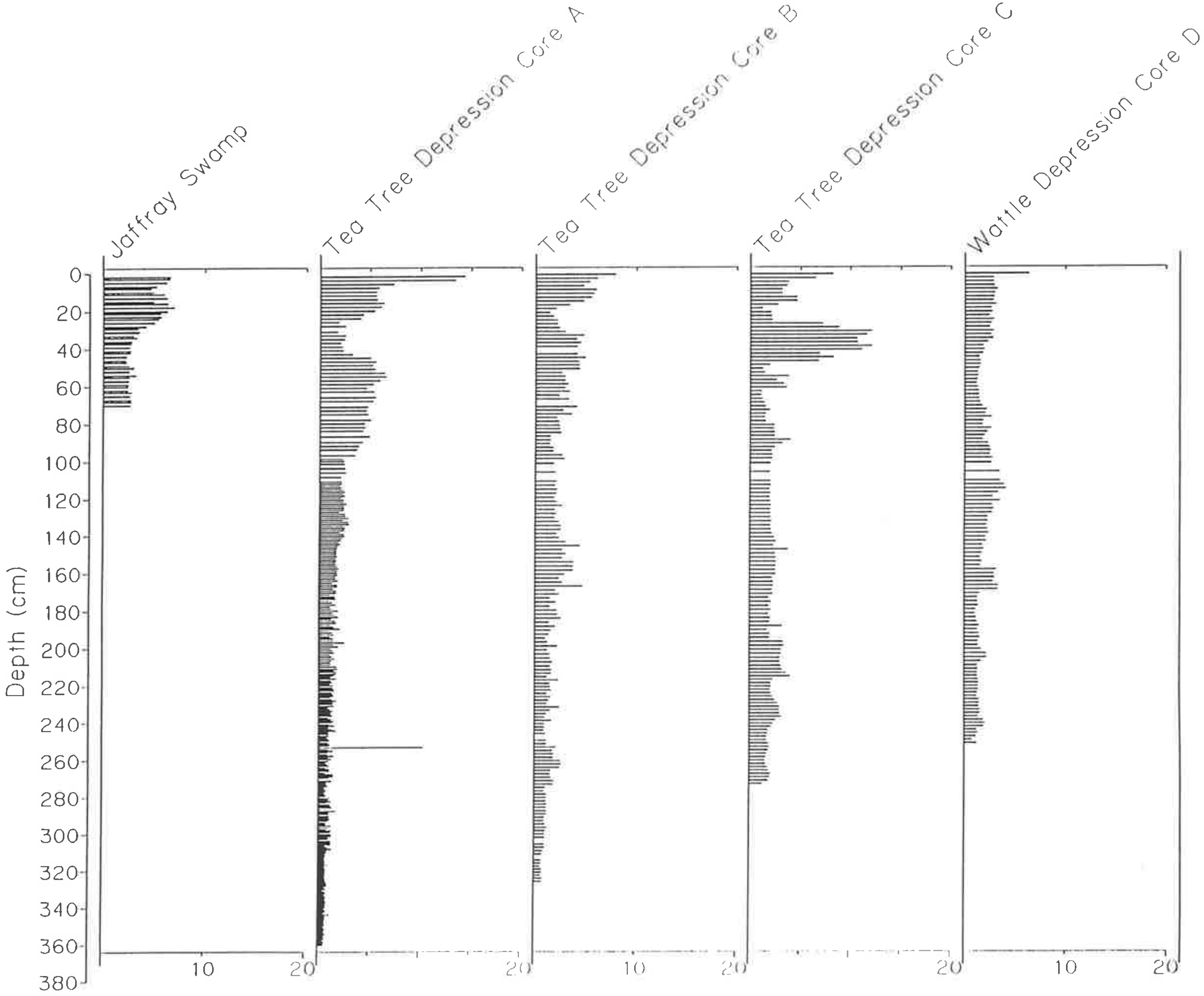


Figure 6.27: Organic Content of sites of the Marcollat watercourse



The carbonate profiles of sites of the Marcollat watercourse are shown in Figure 6.28. This graph exemplifies the scenario that Jaffray Swamp is a very different environment to that of Gum Lagoon, as it has a very low percentage of carbonate content. This is due to Jaffray Swamp being a permanent and deep lake, which reduces the rate of carbonate precipitation. The carbonate profiles of the Gum Lagoon Conservation Park cores indicate a similar scenario to the organic profiles, that is, one of oscillating lake full and lake dry conditions. Differences in the cores can be accounted for by the location of the core with respect to the main depression. For example, core C has fewer carbonate peaks than core A as it is located on the edge of the depression, and core D has very few carbonate peaks as water rarely overflows from Tea tree depression to the Wattle depression.

The chemical results and the charcoal record obtained for core A provide evidence that the Gum Lagoon Conservation Park cores do contain a long term record of hydrologic change that has occurred in the Upper South East. Results from these cores illustrate that the influence of European activities has been minor relative to the hydrological fluctuations that have been recorded in the cores.

6.3 Field Sites of the Duck Island Watercourse

6.3.1 Lesron Lagoon

Lesron Lagoon is a lake within the Duck Island watercourse (section 3.3.3.1). The lagoon was surrounded by samphire vegetation, indicating that the lagoon was very saline. However, it did have some aquatic flora and fauna present in the water. A water sample and a core were extracted from a site shown in Figure 6.29. The water chemistry of the lake is shown in Table 6.7 and the conductivity confirmed that the lagoon was hypersaline.

Figure 6.28: Calcium Carbonate Content of sites of the Marcollat watercourse

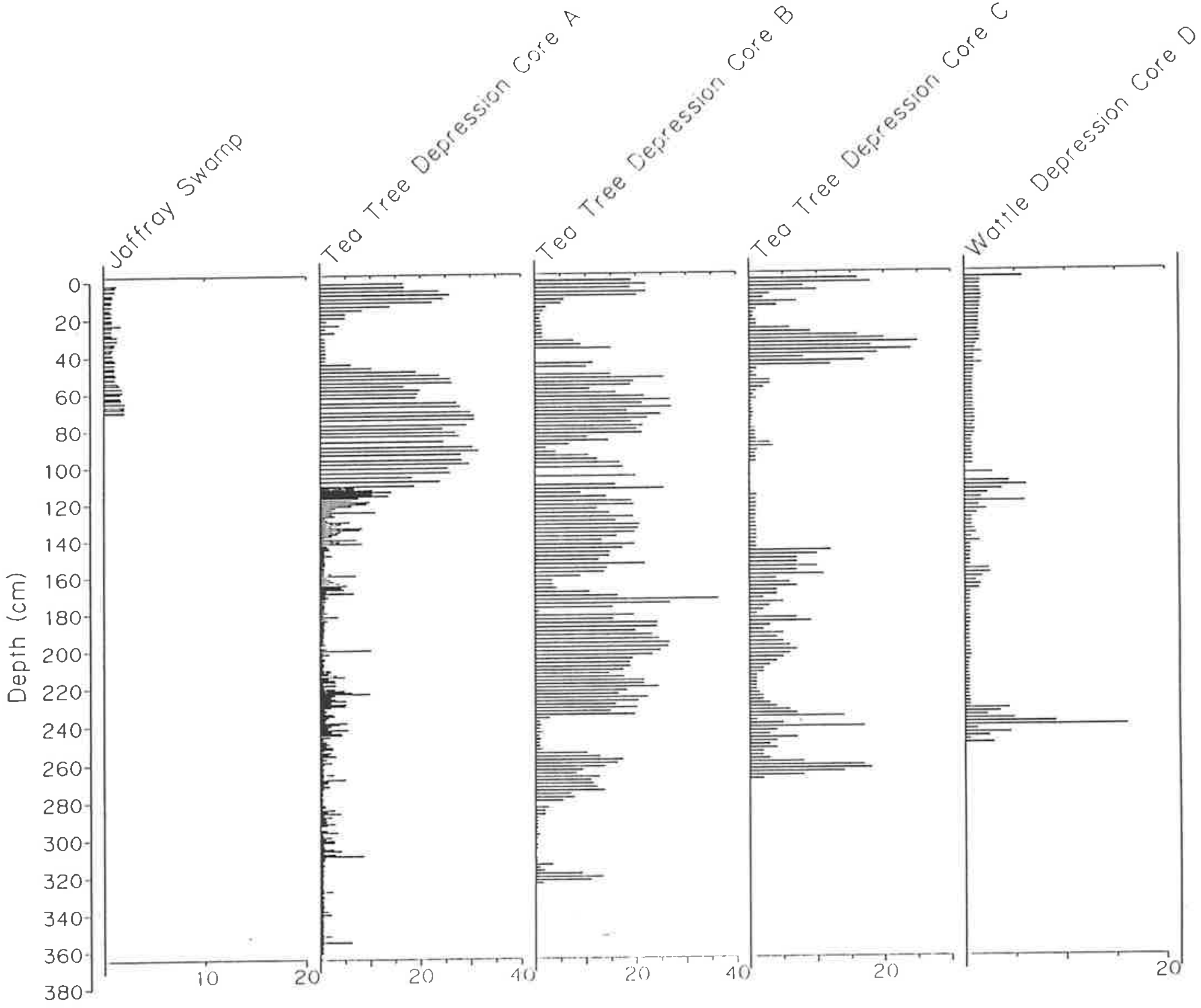


Figure 6.29: Sampling Location of Lesron Lagoon

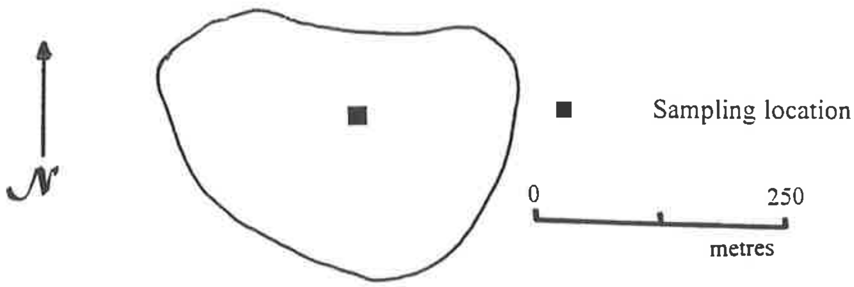


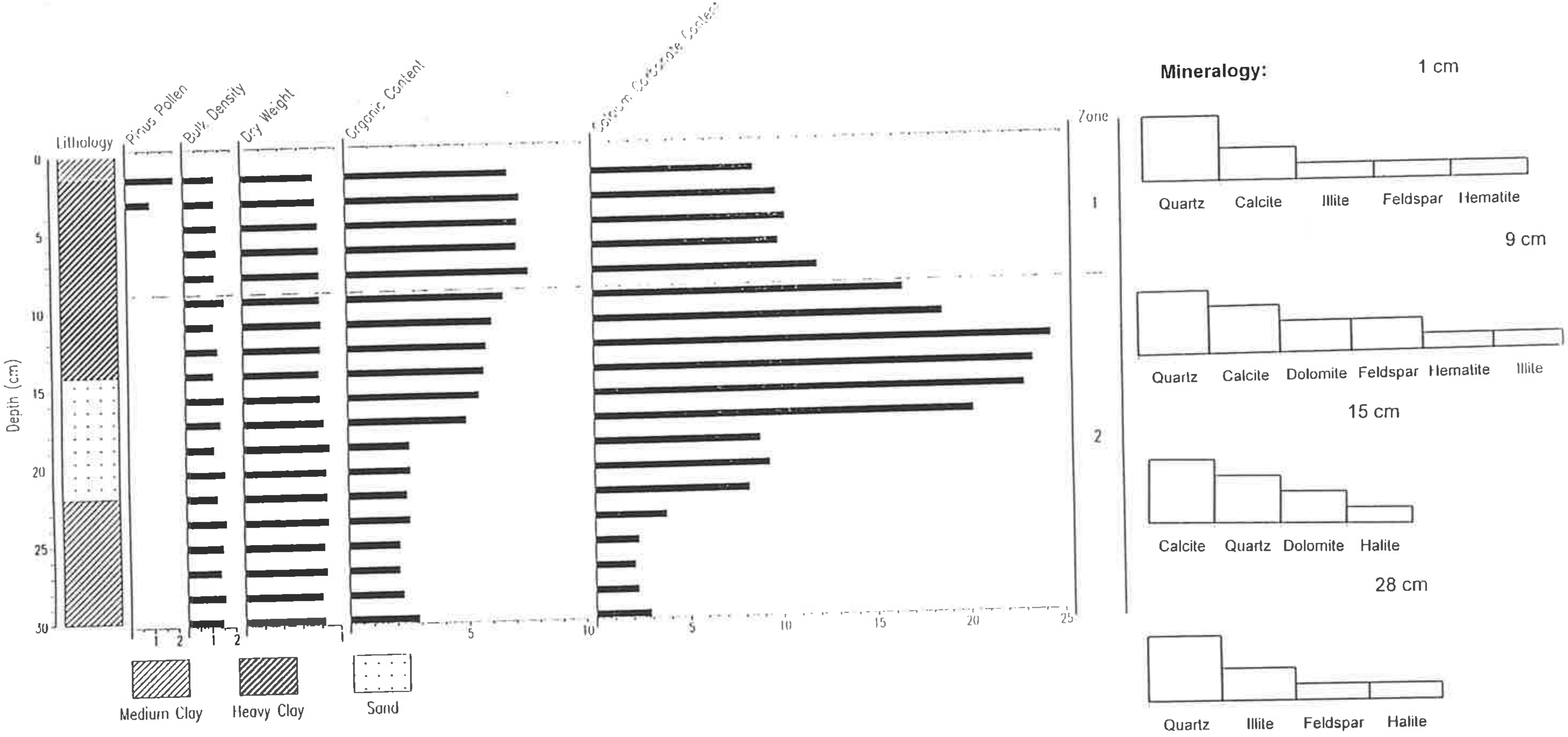
Table 6.7: Water Chemistry of Lesron Lagoon

	Mean	Standard deviation
pH	10	0.54
Conductivity	111 ‰µS	0.74
Nitrite	3.6 µg/L	0.23
Phosphorus	Not detectable	-

Results of the chemical analysis for Lesron Lagoon core are shown in Figure 6.30. This core was only thirty centimetres long. The surface 1.5 cm was a highly organic medium clay (10YR 4/1) and below that there was a heavy cream clay until 14 cm (10YR 8/2). From 14 to 22 cm the substrate changed to a white sandy layer (10YR 8/1) and between 22 and 30 cm the substrate returned to clay, this time brown in colour (10YR 4/2). All strata had a pH of 10. The separation of the clay substrate by a sand based substrate indicates a major change of climatic conditions.

Very few pine pollen were found in this core. The count was too insignificant to make any conclusions, except that no pollen were found below the surface samples, and the blanks contained no contamination. No diatoms were preserved in this lake, probably due to the very high salinity and pH of the lake soil and water. Fossils are rarely preserved at all under such conditions because dissolution occurs so rapidly. Dating was not conducted on this core.

Figure 6.30: Lesron Lagoon



The bulk density and dry weight of Lesron Lagoon show no distinct fluctuations (Figure 6.30). The organic content is high in zone one and diminishes in zone two. The carbonate curve shows a peak in zone two. If carbonate production can be associated with the productivity of a lake, as previously suggested, then this pattern suggests that the lake has become less productive with the progression of time. This may be indicative of increasing salinity.

Four samples were analysed for mineral content (Figure 6.30). The surface sample contained predominantly quartz with traces of calcite, illite, feldspar and hematite. The second sample, from a depth of 9.5 cm, at the beginning of the carbonate peak, contained predominantly quartz and calcite with sub dominant feldspar and dolomite and traces of illite and hematite. The third sample, from a depth of 15 cm, contained predominantly calcite with sub dominant quartz and traces of dolomite and halite. The fourth sample, from a depth of 28.5 cm, was predominantly quartz with small amounts of illite, feldspar and halite. The presence of halite at depth indicates that this lagoon has been saline and ephemeral for a very long time (Gribble and Hall, 1985).

Lesron Lagoon shows fluctuations of organic and carbonate content that reflect either changes of water depth or salinity changes that are unlikely to be a result of European activities. Climatic change probably accounts for these fluctuations, due to their depth in the soil core. The mineralogy of this lagoon indicates that this site has been saline and ephemeral well before European settlement occurred.

6.3.2 Roo Lagoon

Roo Lagoon is also within the Duck Island watercourse (section 3.3.3.2). The lake environment appeared very saline: so saline that it looked sterile. No aquatic vegetation or fauna could be observed in the lake. The sampling location for this site is illustrated in

Figure 6.31. The water chemistry of the lake indicated that the lake was indeed hypersaline as the conductivity was measured at over 200 ‰ µS (Table 6.8).

Figure 6.31: Sampling Location of Roo Lagoon

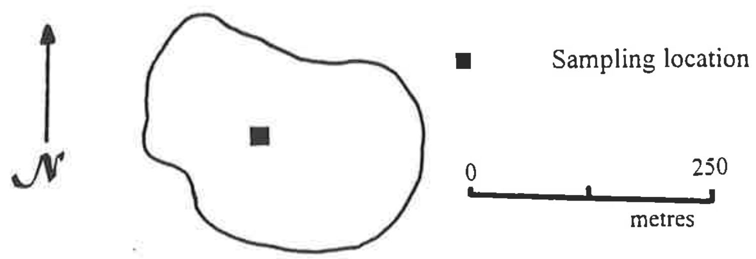


Table 6.8: Water Chemistry of Roo Lagoon

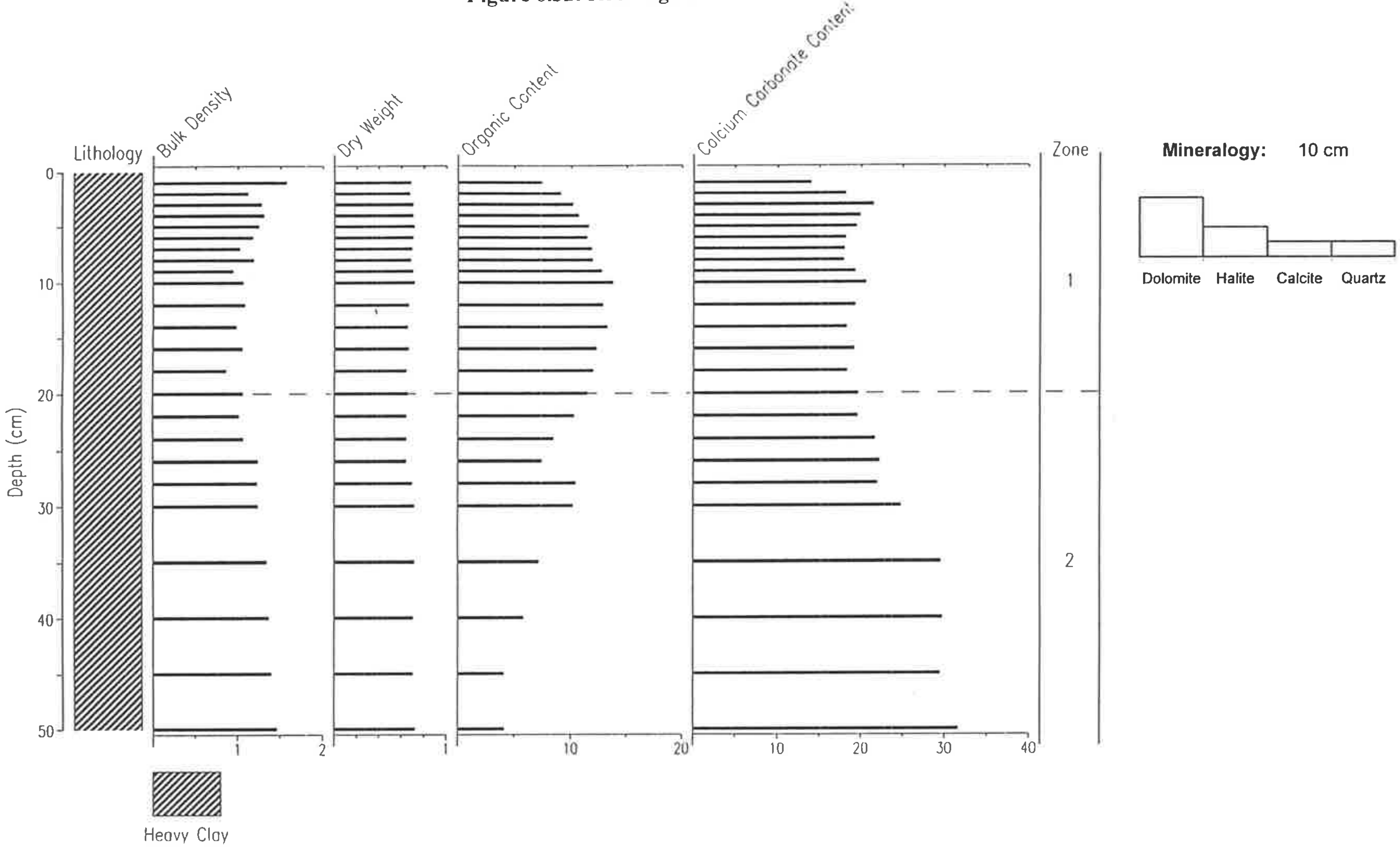
	Mean	Standard deviation
pH	10	0.52
Conductivity	200+ ‰µS	0.79
Nitrite	3.6 µg/L	0.32
Phosphorus	Not detectable	-

Figure 6.32 illustrates the stratigraphy of Roo Lagoon. This core was homogeneous for the 50 cm cored. The sediment was composed of a white heavy clay (10YR 7/1). The soil pH was 10.

No pine grains or diatoms were preserved in this core. The lack of preservation of fossil remains in this lake are due to the very high salinity and high pH of the soil and water. Under these conditions dissolution of diatoms and pollen occurs very rapidly, and thus no remains are present to be identified or counted.

Bulk density showed minor fluctuations, indicating a changing sedimentation rate or the degree of sediment compaction (Figure 6.29). The organic content increases below the surface in zone one and then gradually diminishes in zone two. Previous cores examined have demonstrated a peak in the organic content at the surface of a lake and a diminution

Figure 6.32: Roo Lagoon



peaks just below the surface, which may indicate a change in environmental conditions. It could be that the lake has become increasingly saline, and that less organics are being deposited.

The carbonate content shows minor fluctuations along the core, generally increasing towards the older sediments in zone two. As carbonate precipitation is related to the productivity and salinity of a water body, these results suggest that the lake has become less productive and/or more saline towards the present.

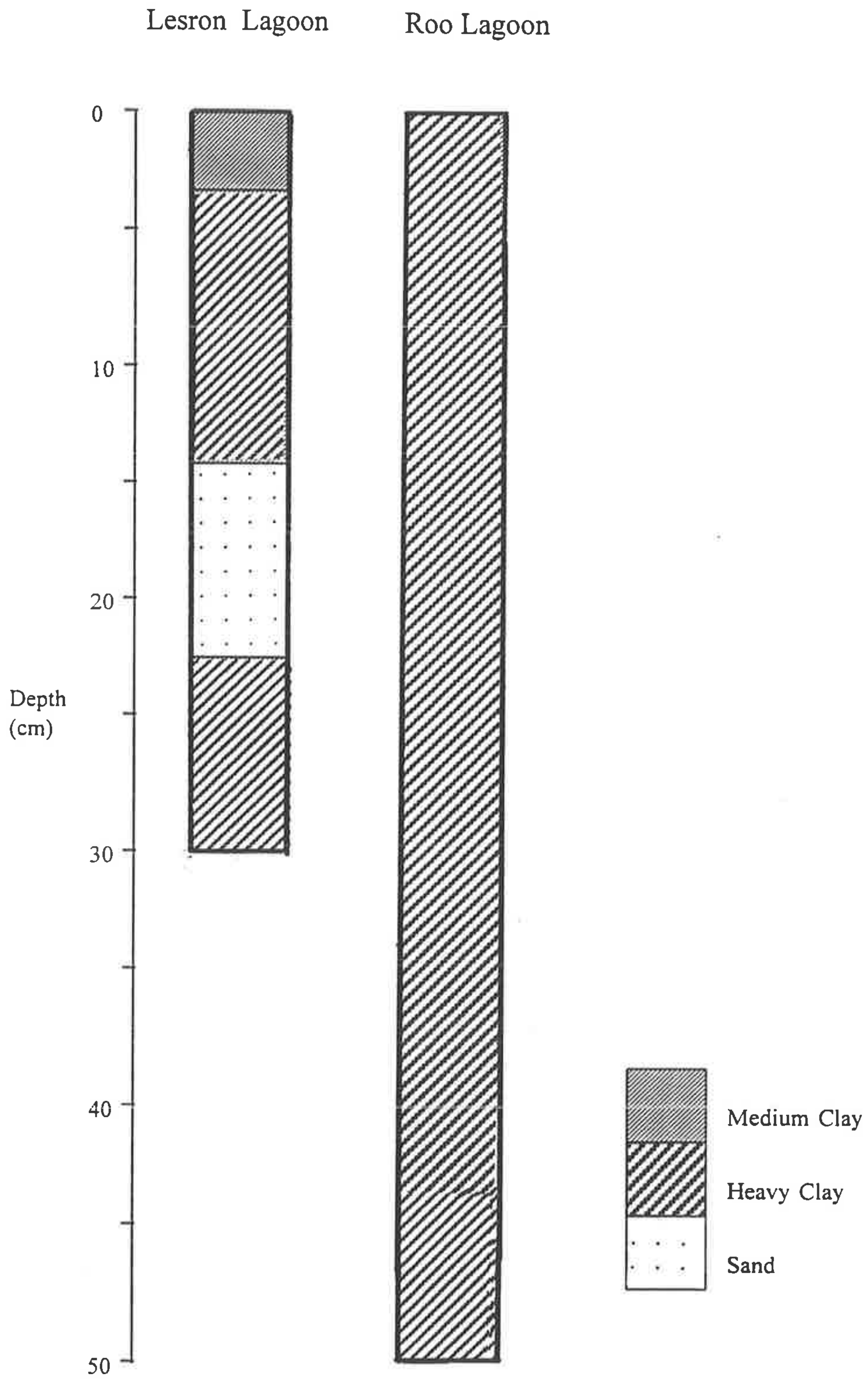
Only one sample from this core underwent mineral analysis, and was taken from a depth of 10 cm. The sample was predominantly composed of dolomite with a small amount of halite and a trace of calcite and quartz (Figure 6.32). The dolomite was examined under a petrographic microscope and was found to be a secondary deposit forming from the original calcite particles as part of a natural transformation. As was the case with Lesron Lagoon, the presence of halite indicated an ephemeral saline environment which has been in existence at this site for a long period of time.

Thus, Roo Lagoon has been a saline, ephemeral lake for a long period of time. The carbonate profile indicates that the lake may be becoming more saline over time, which reduces the precipitation of carbonate. This supposition is supported by the organic profile, which shows a reduction towards the surface that is likely to be caused by an increase in salinity of the surface water. It is suggested that the increase of salinisation has occurred prior to European settlement.

6.3.3 Duck Island Watercourse Trends

Correlation of the stratigraphy of the Lesron and Roo Lagoon cores are shown in Figure 6.33. The sedimentation rate in Lesron Lagoon appears much lower than that of Roo Lagoon because it is linked to the surrounding lakes, meaning that surface water will flow

Figure 6.33: Stratigraphy of sites of the Duck Island Watercourse



through rather than deposit the sediment load except in periods of very slight inundation. As Roo Lagoon is a separate lagoon from the main watercourse, sedimentation in this depression is much higher and the sediment is relatively undisturbed. Thus it is thought that the Lesron core, although shorter in length, contains a longer record of environmental history. The heavy clay layer at the surface of Lesron Lagoon relates to the heavy clay throughout the Roo Lagoon core. The sand horizon of Lesron Lagoon probably indicates a dry period in the Upper South East, similar to that found at many other field sites. The surface organic clay strata of Lesron Lagoon is possibly a result of the change in water quality of the lagoon due to European agricultural activities.

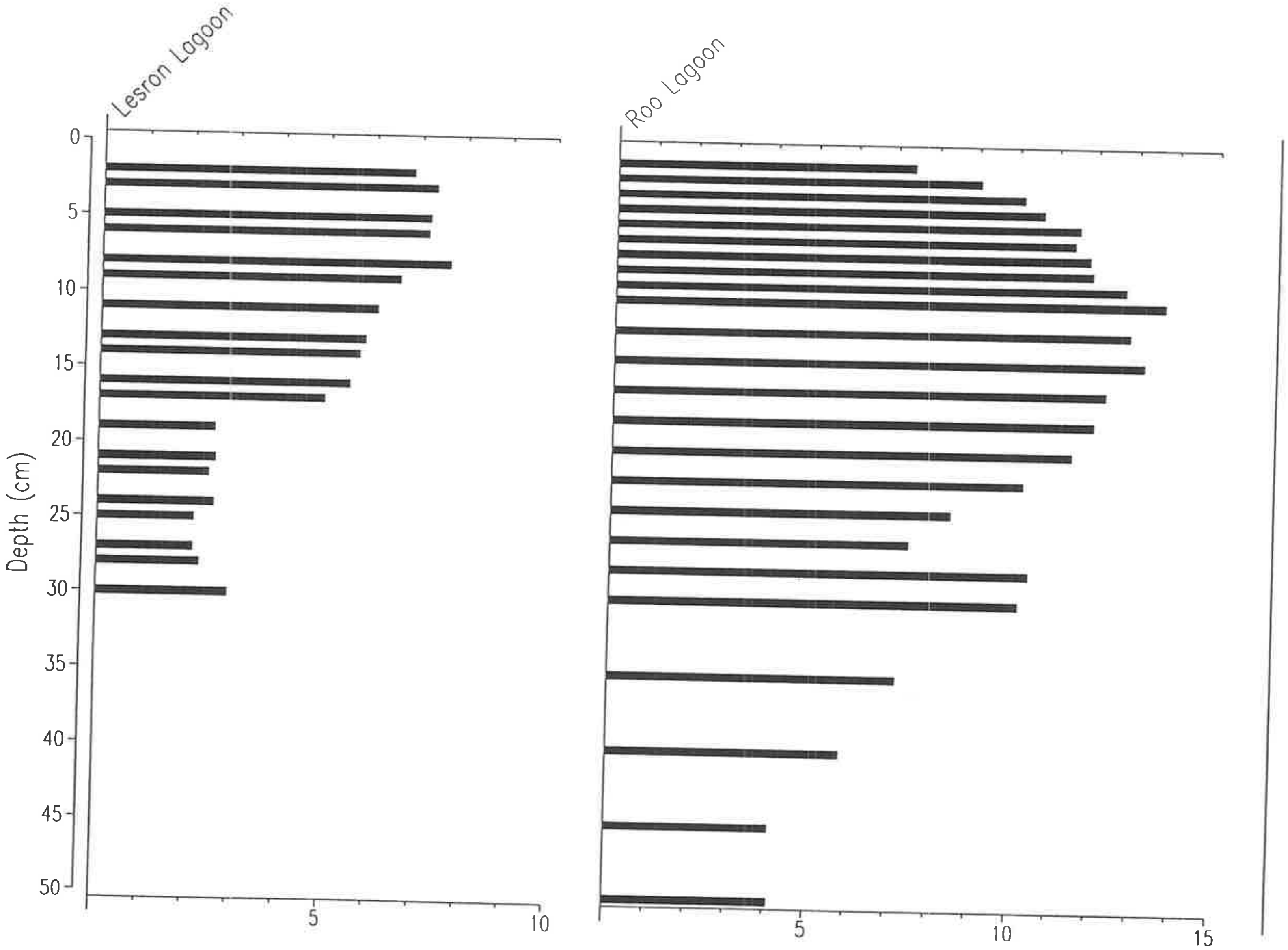
The only difference in water quality of these two lakes was the conductivity (Table 6.9). Lesron Lagoon had a much lower salinity than Roo Lagoon because it receives more surface water flushing. Roo Lagoon does not receive adequate fresh water to flush out the salts. Both lakes are highly saline, as is the whole watercourse.

The organic profiles of the sites in the Duck Island watercourse are shown in Figure 6.34. The curve of these two graphs are similar but Roo Lagoon exhibits more detail due to the higher sedimentation rate assumed to occur there. The peak of organics just below the surface of both sites indicates that the organic accumulation of the lakes has decreased recently, possibly a result of European landuse activities.

Table 6.9: Water Quality of the sites of the Duck Island Watercourse

Water Quality	Lesron Lagoon	Roo Lagoon
Conductivity (‰ µS)	111	> 200
pH	10	10
Nitrate (µg/L)	3.6	3.6
Phosphorus (µg/L)	Not detectable	Not detectable

Figure 6.34: Organic Content of sites of the Duck Island watercourse



The carbonate profiles of the two sites within Duck Island watercourse are shown in Figure 6.35. Carbonate production is higher in Roo Lagoon than Lesron Lagoon and the carbonate peak in Lesron Lagoon correlates with the first minor peak in zone one of Roo Lagoon. These two cores indicate that carbonate production has decreased since the last dry period. This is most likely due to an increase in salinity reducing the precipitation of carbonates. If this is the case, then salinity has been increasing well before Europeans settled in the Duck Island watercourse. This trend has been occurring since the last dry period and appears to be continuing. The impact of Europeans may not yet have registered at either lagoon, which is because the sedimentation rate is so slow. Thus increasing salinity and/or increasing surface water flooding appears to be a natural trend in Duck Island watercourse.

6.4 The changes in the surface water hydrology of the Upper South East of South Australia

Long term hydrological changes in the Upper South East were identified from the stratigraphy and chemical analyses of the study site sediment cores. Figure 6.36 shows the stratigraphy of all field sites. Cores from the Cortina Lakes South Lagoon, Cortina Lakes North Lagoon, Alf's Flat, Gum Lagoon Conservation Park cores and Lesron Lagoon all exhibit evidence of hydrologic changes in the form of repetitive wet and dry cycles, which were indicated by alterations of stratigraphy between sand and clay based horizons. Kangoora Lagoon, Reedy Swamp and Jaffray Swamp showed changes which were of a different nature to the other sites. It is suggested that these sites were acting independently of the watercourse changes, due to either their location with respect to the watercourse, or their source of surface water.

The organic and calcium carbonate profiles of the study site cores also illustrate long term hydrological fluctuations in the environment of the Upper South East, and are illustrated in

Figure 6.35: Calcium Carbonate Content of sites of the Duck Island watercourse

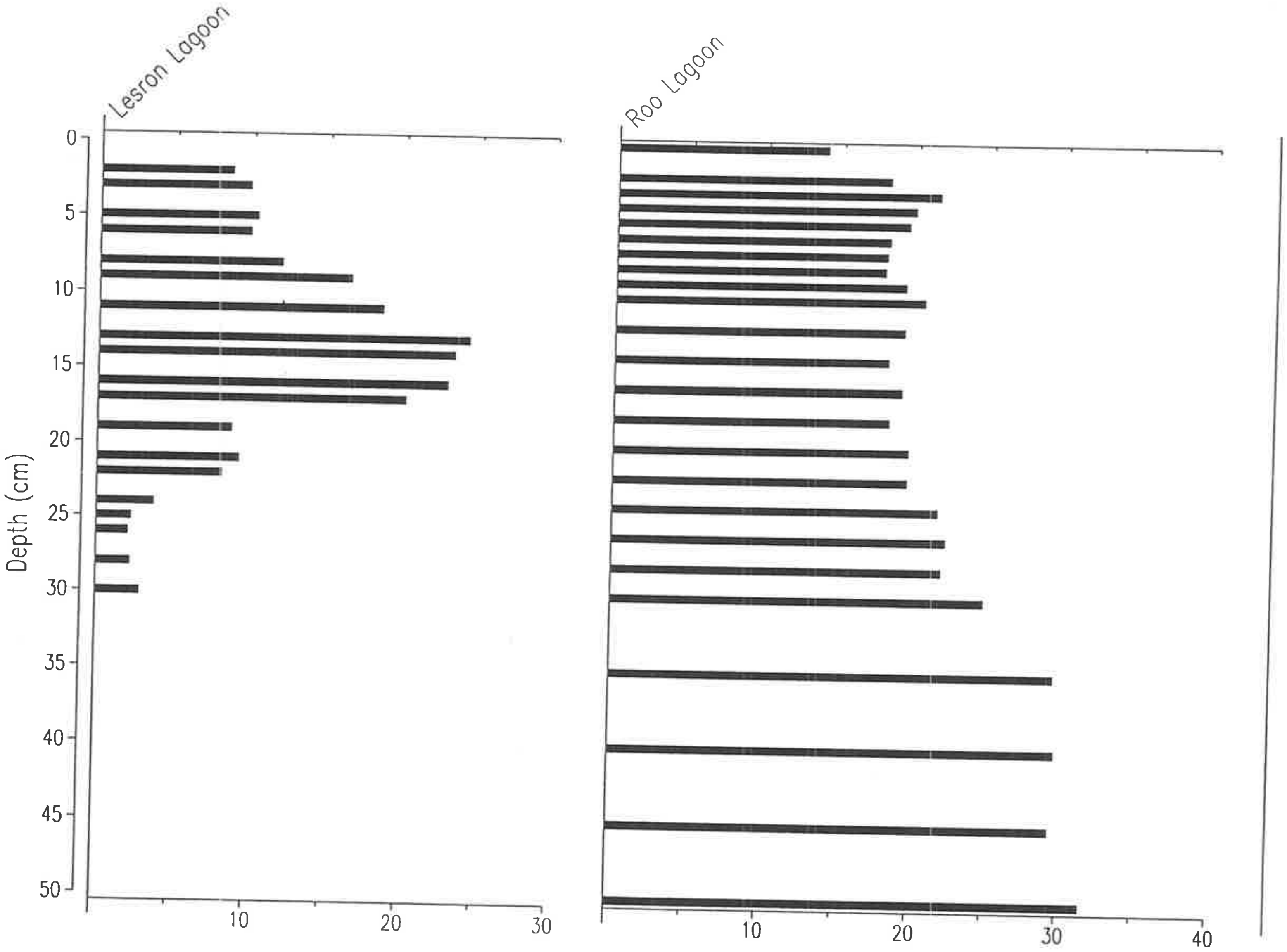
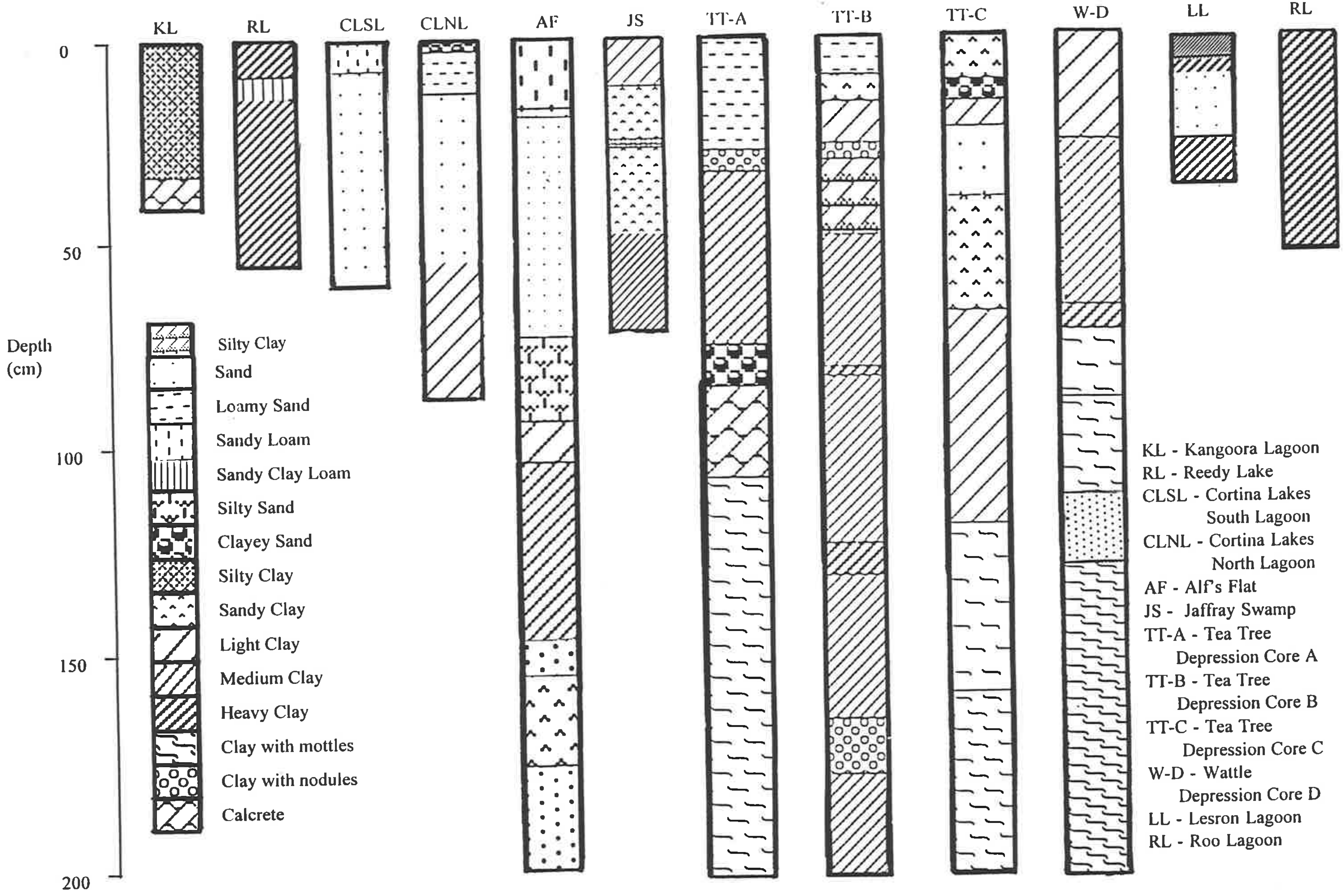


Figure 6.36: Stratigraphy of sites of the Upper South East



Figures 6.37 and 6.38, respectively. Currently, the Upper South East is within a period of climate conducive to ephemeral lake conditions, resulting in high organic and calcium carbonate precipitation. Prior to this period, the lakes appeared to have dried with little organic or carbonate accumulation occurring. Other peaks of organic and carbonate content represent hydrological periods similar to that of the modern environment: that is, a period of wet, moist conditions, but perhaps with deeper lake environments, as the carbonate content is lower than that of the most recent period. In addition, the mineralogy of the Lesron Conservation Park cores, indicated that Lesron and Roo Lagoons have been highly saline for the length of time recorded in the soil cores. Thus, it appears that the Upper South East has experienced fluctuating periods of hydrological conditions over a long period of time, and has experienced saline conditions during the length of time recorded in the Lesron Conservation Park cores.

Short term hydrological changes were revealed by the inferred salinity records in combination with dating techniques. For example, the pine pollen profiles of the study site cores are illustrated in Figure 6.39, and demonstrate the difference in the recent sedimentation rate of the sites in which pollen was preserved. This Figure indicates that sedimentation has been highest in lakes located in the southern end of the watercourses, and lowest in the terminal wetlands located in the north of the Upper South East. Thus, the source of sediment in the interdune areas must principally be from flood deposits carrying sediment loads from the southern region. Only in very large floods does surface water reach the terminal depressions to deposit flood sediment loads. Thus, the southern sampling sites contain a more detailed record of environmental change over short periods of time, while the terminal depressions (Messent and Gum Lagoon Conservation Parks) contain very long records of environmental change without detailed resolution.

Figure 6.37: Organic Content of sites of the Upper South East

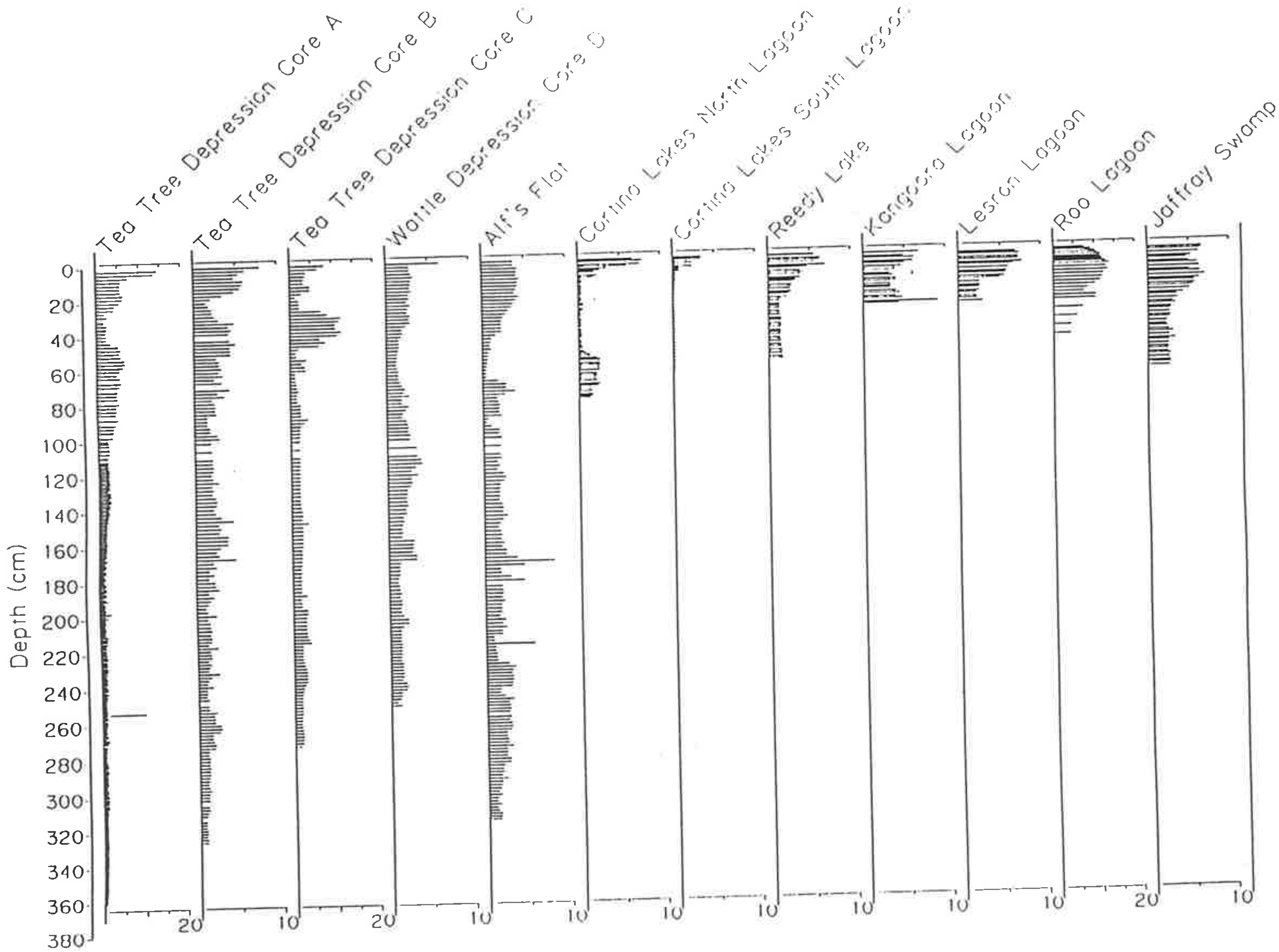


Figure 6.38: Calcium Carbonate Content of sites of the Upper South East

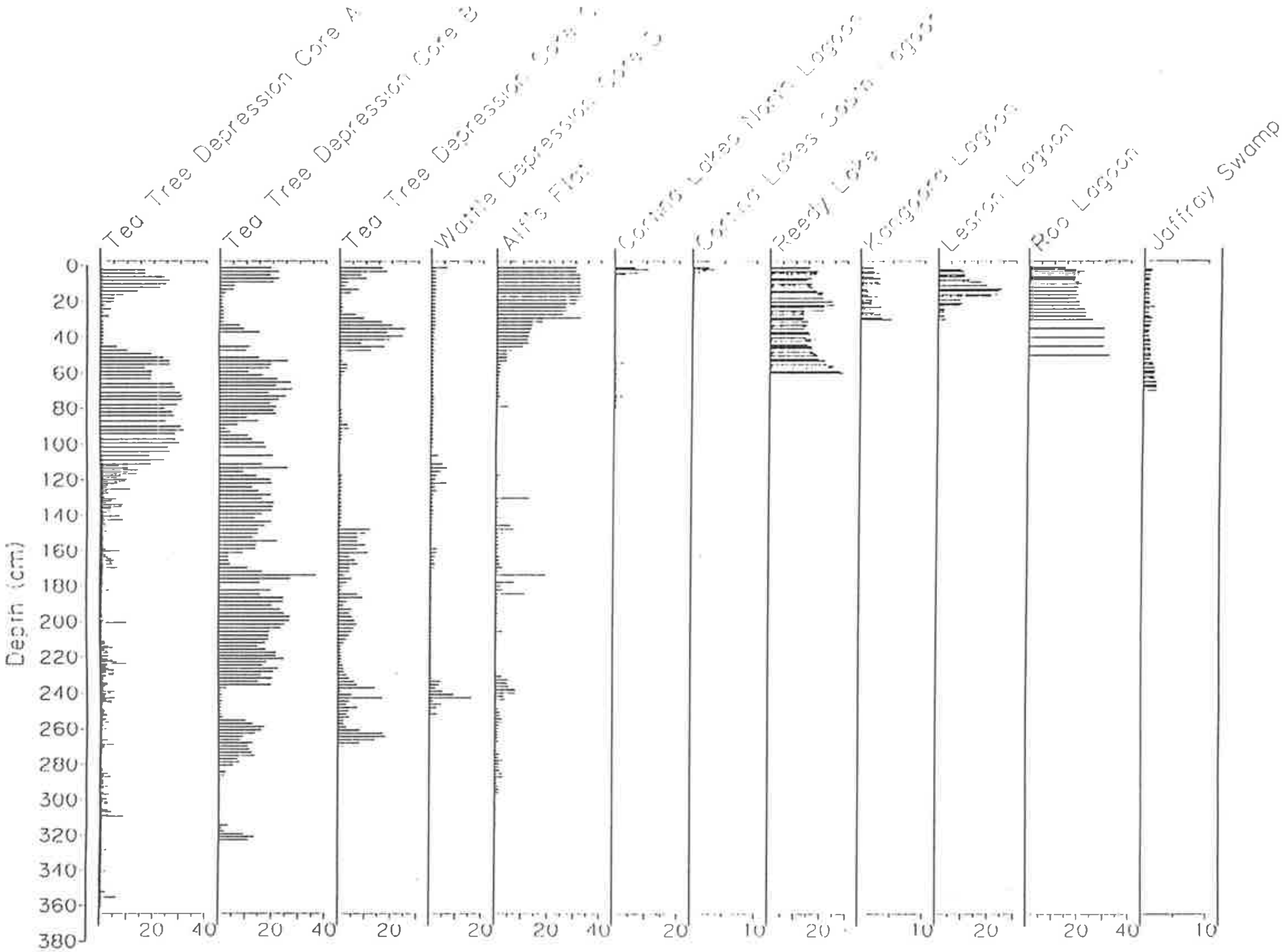
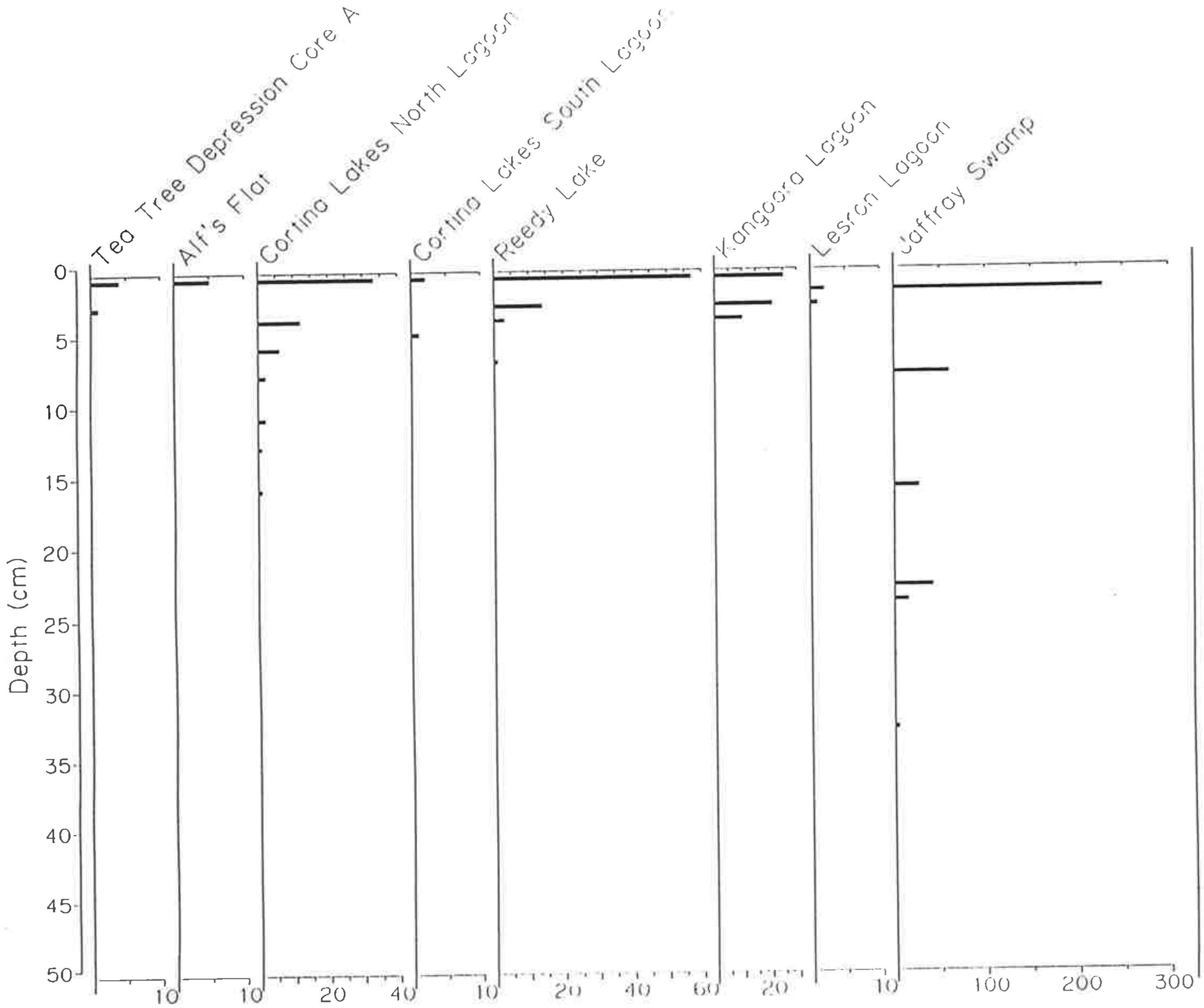


Figure 6.39: Pine Pollen Record of sites of the Upper South East

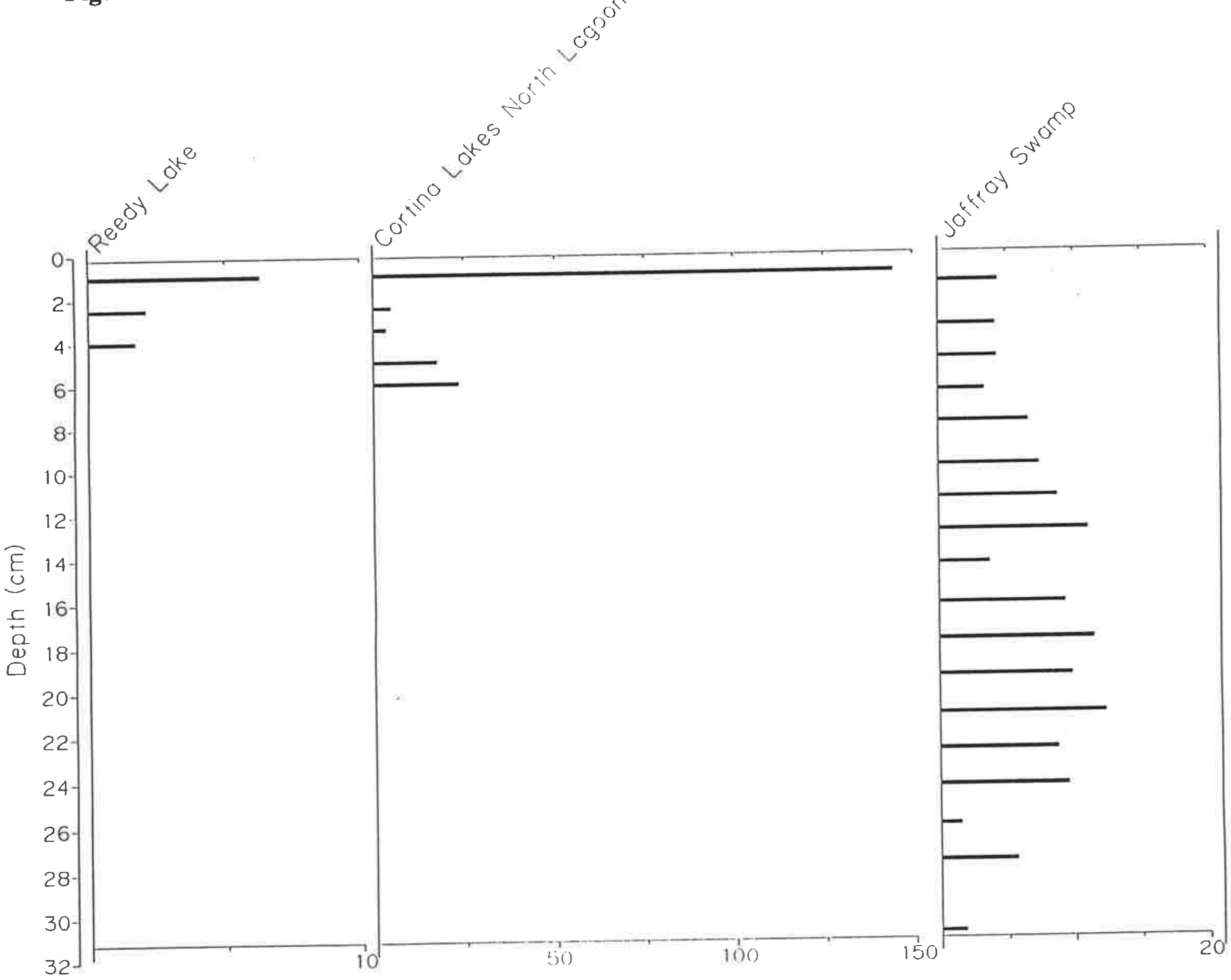


Salinisation trends of the Upper South East were identified from the inferred salinity curves of the Reedy Lake, Cortina Lakes North Lagoon and Jaffray Swamp (Figure 6.40). The Cortina Lakes North Lagoon and Jaffray Swamp salinity profiles show a trend of decreasing salinity in the surface samples. This result stands as a great contrast to the results of water sampling conducted when the cores were extracted, and public opinion which believes that an increase in the amount and rate of dryland salinisation has occurred in the Upper South East in the past few decades. However, Cortina Lakes North Lagoon currently receives greater throughflow of surface water than pre European conditions, due to drainage constructions. The increase of flushing of the wetland, has reduced the salinity of the lake water.

Similarly, Jaffray Swamp now receives greater amounts of water, and throughflow of surface water, that is flushing the swamp and causing a freshening of the surface water. In contrast, Reedy Lake shows an increase of salinity in the modern core samples. Reedy Lake, however, is a groundwater fed lake, and is more likely to be illustrating changes of the regional groundwater quality than the surface water of the Bakers Range watercourse. It is presumed that while regional groundwater salinity is increasing due to the impacts of European agricultural activities, or contemporary climate change, that the effect of drainage in the main watercourse areas has been to freshen the wetlands.

In summary then, the current hydrological environment of the Upper South East wetlands appears to be slightly different from any preceding wet period, with ephemeral conditions dominating, rather than a deep lake environment. This regime is changing with the introduction of European land use activities, but has not been clearly recorded in the palaeoenvironmental records as yet, due to the slow sedimentation rate prevalent in the Upper South East.

Figure 6.40: Inferred Salinity of Sites of the Upper South East



Thus, climatic change and human induced environmental changes, are visible in the cores examined from the Upper South East of South Australia. Table 6.10 summarises the field sites and the nature of changes detected. Most sites showed climatic change, and some sites showed evidence of European activities. It is apparent that the environmental changes related to European activities are not as dramatic as those caused by natural climatic fluctuations.

Table 6.10: Detected Climatic and Human Induced Changes in the Environment of Field Sites of the Upper South East

Field Site	Climatic Change	Human Induced Change
Kangoora Lagoon	?	?
Reedy Lake	Y	Y
Cortina Lakes South Lagoon	Y	Y
Cortina Lakes North Lagoon	Y	Y
Alf's Flat	Y	?
Jaffray Swamp	Y	Y
Gum Lagoon Conservation Park	Y	?
Lesron Lagoon	Y	?
Roo Lagoon	Y	?

7.0 DISCUSSION

The purpose of this thesis has been to investigate changes in the surface water hydrology of the Upper South East of South Australia. The aims were threefold: firstly, to identify changes of the surface water hydrology during the period of European settlement from historical records; secondly, to identify changes in the surface water hydrology prior to European settlement from the sedimentary record; and lastly, to utilise the above results to forecast the effects of current and planned management plans on the hydrology of the Upper South East of South Australia. In addition, the potential usefulness of the environmental history methodology in addressing controversial land management issues was investigated. This chapter summarises and discusses the surface water hydrological changes that have occurred in the Upper South East, by examining both the changes brought about by natural climatic fluctuations, and the changes produced by European activities. The chapter concludes with a discussion of management considerations for the future, with particular emphasis upon the surface water hydrology.

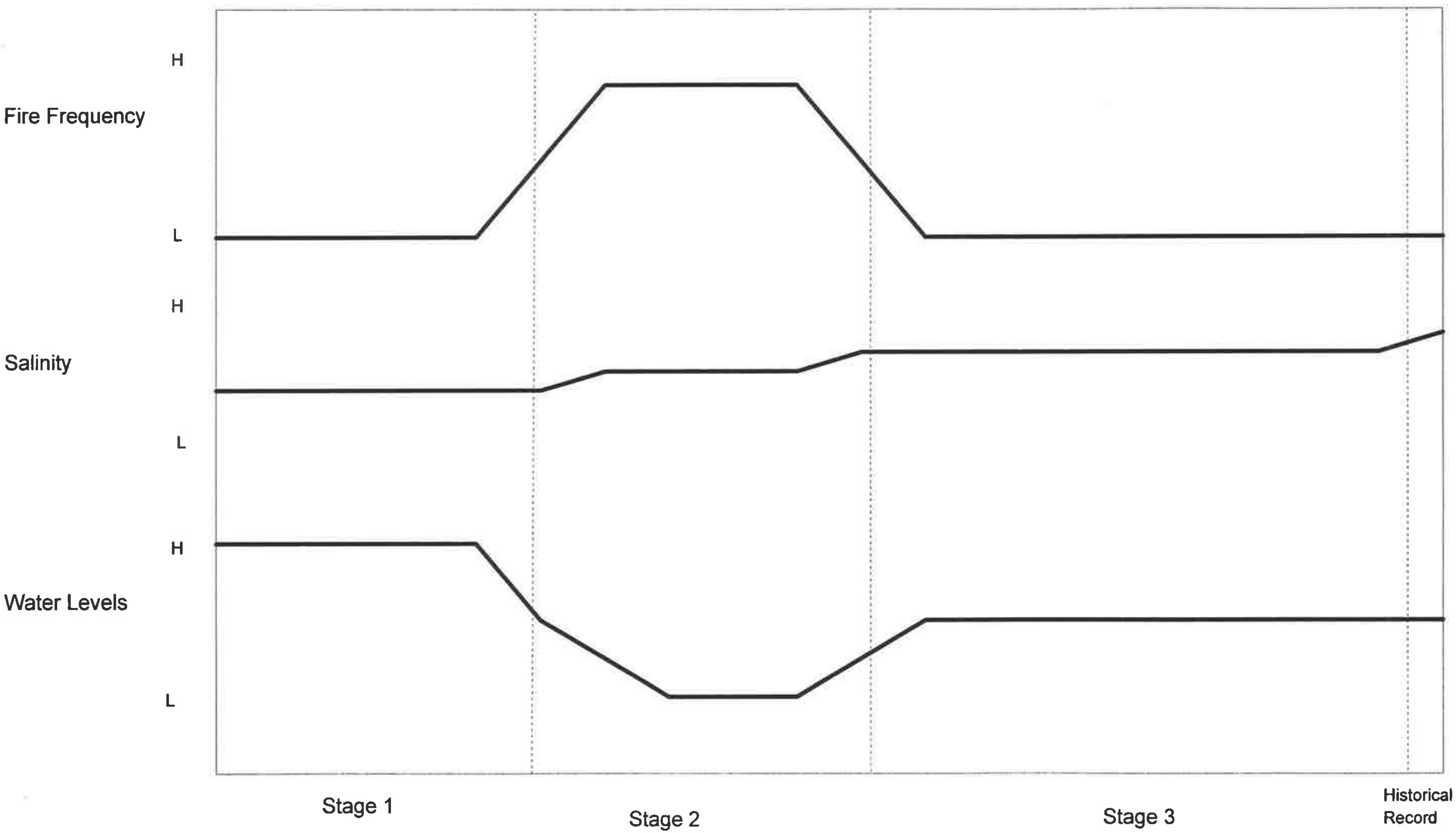
7.1 Climatic Fluctuations

The palaeoecological record of the Upper South East revealed fluctuating periods of wet and dry wetland conditions over a long period of time. It is hypothesised that the hydrological changes relate to climatic fluctuations, with changes of effective precipitation causing the change of water levels. In the most recent phase, within which the Upper South East wetlands have experienced ephemeral conditions, the effective precipitation has been moderate. In the preceding period, within which the Upper South East wetlands dried, the climate may have been drier than present, with little effective precipitation, and prior to the dry period, the Upper South East wetlands experienced lake full conditions, with high effective precipitation. The Gum Lagoon Conservation Park and Alf's Flat cores indicate that this pattern has been repeated at least several times in the Upper South East. These periods are represented by high organic content strata interspersed with sand based strata. However, it is hazardous to comment on the nature of these climatic fluctuations without more detailed palaeoecological results, which were unfortunately not obtainable in the Upper South East environment.

A reconstruction of the climate of the Upper South East was hindered by dating problems. A majority of the samples used for dating contained very low levels of organic material and high levels of calcium carbonate. Once the carbonate had been removed from the sample during pre-treatment, very little datable material remained. Thus AMS dating techniques were utilised, and proved successful for samples from which reasonable levels of carbon could be extracted. However, within samples of very low organic material contamination was high, producing nonsensical ages. It is believed that in these samples modern carbon from the surface was infiltrating the soil column, causing contamination of the older sediments. For that reason, samples with low organic material were disregarded from the dating results. It is hoped that in the future amino acid racemisation or optical stimulated luminescence (OSL) dating techniques may provide a better indication of the age of long term hydrological fluctuations occurring in the Upper South East.

It is presently difficult to construct a chronology for the Upper South East sediments, as the timing of climatic fluctuations could not be accurately ascertained for the region. Instead Figure 7.1 illustrates the stages of hydrological change revealed by the palaeoecological evidence to have occurred in the Upper South East. Ages were estimated by comparing the stratigraphy of the Upper South East cores to those of lakes in surrounding regions. The first stage depicted in Figure 7.1 represents a period within which south-east Australian

Figure 7.1: Climatic Change in the Upper South East of South Australia



lakes have commonly contained deep water levels, and is estimated to have occurred between approximately 15 000 and 13 000 years BP (Harrison, 1993). This period may be represented in the Alf's Flat, Gum Lagoon Conservation Park and Cortina Lakes North Lagoon cores as the second peak in the organic profile from the surface. This zone shows high organic production but a lack of carbonate precipitation, which is indicative of deep lake water. During this time period, the salinity of the Upper South East wetlands was probably moderate, due to the landscapes marine origins. The large amounts of surface water in the wetlands, and possible frequent flooding, prevented any build up of salinity in the wetland areas. The charcoal record from Tea tree depression core A demonstrates a low fire frequency occurred within this period. The wet climate would possibly reduce fire hazards, and the moisture content of vegetation would have been too high to support a fire of any great intensity.

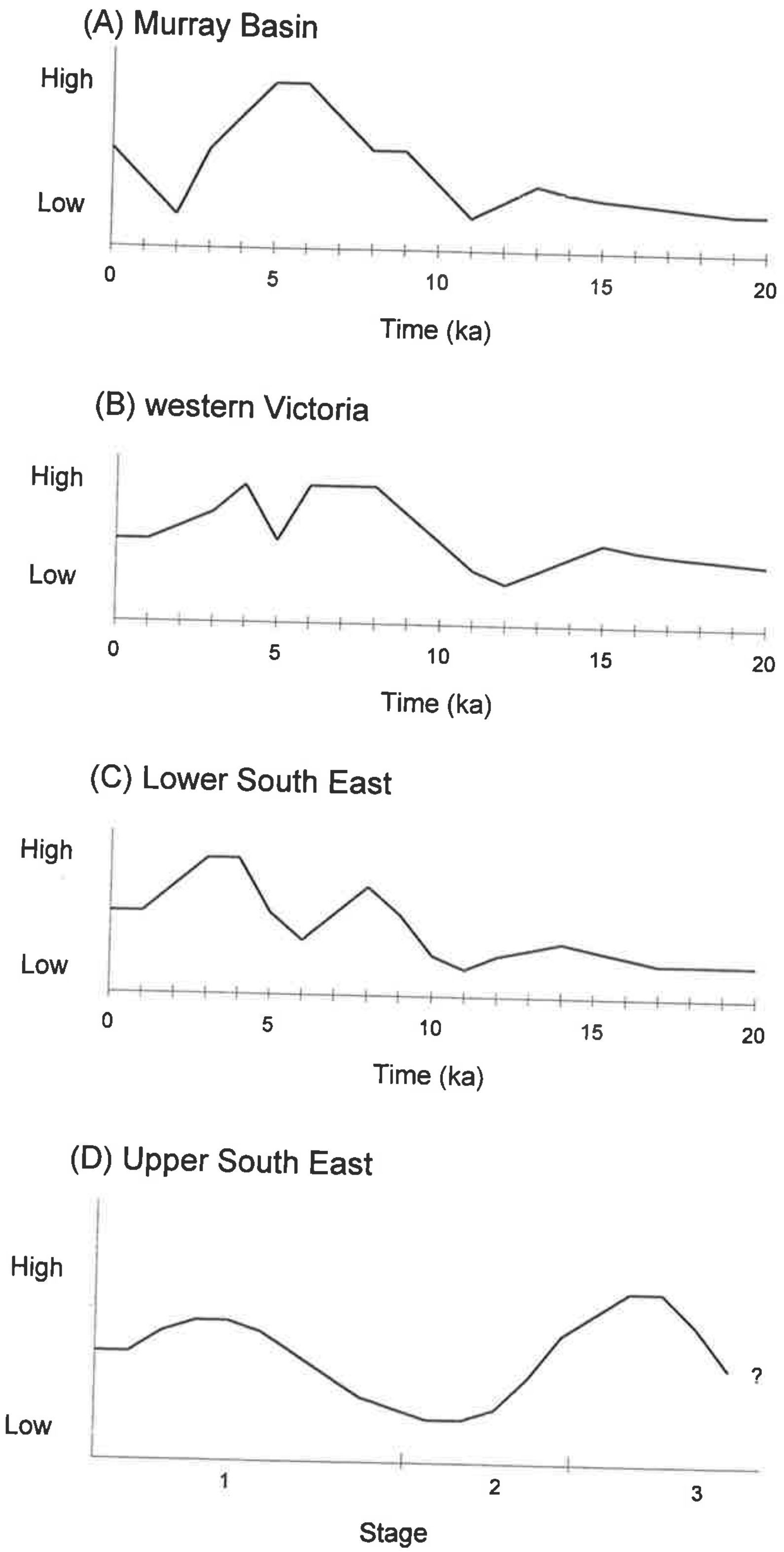
Stage two of Figure 7.1 is represented by the stratigraphic zone composed of sandy sediments. It is suggested that this horizon was deposited in the last dry period, and may have occurred between 13 000 and 11 000 years BP (Harrison, 1993). The core results indicate that the Upper South East wetlands completely dried during this period, and winds deposited unconsolidated sandy material from the surrounding stranded beach dunes into the interdunal swales and depressions. The salinity of the Upper South East wetlands are likely to have increased slightly at the beginning of this period as the wetlands dried, and again when the lakes began to refill. However, between these periods salinisation would have decreased as the groundwater table moved deeper into the soil column (Crowley, 1994). The charcoal content of Tea tree depression core A increased within this period, demonstrating an increase of fire frequency and/or fire intensity. The decrease of effective precipitation during this time may have dried vegetation increasing available fire fuel.

Also, the climate change altered vegetation composition in the Lower South East to an open Eucalypt woodland (Dodson, 1975), which generates more fire fuel than the preceding Eucalypt with heath understorey vegetation type. This vegetation change may also have occurred in the Upper South East.

Stage three of Figure 7.1 may correspond with the Holocene, which has been characterised by a warm and wet climate. During this time, the Upper South East depressions experienced long periods of inundation, most likely of shallow water or ephemeral conditions which are conducive to the production of organic material and the precipitation of calcium carbonate. Results from the cores of Reedy Lake and Kangoora Lagoon indicated that minor fluctuations of water depth may have occurred within this period, possibly due to fluctuations of effective precipitation. However, a lack of dates prevented a chronology of these fluctuations to be constructed, and so they were not included in Figure 7.1. The Lesron and Roo Lagoon core mineralogy results indicate that the increasing salinisation of the Upper South East has been a long term trend, that has probably occurred throughout the Holocene. The charcoal content of the Tea tree depression core A reduced during the Holocene, demonstrating a decrease of fire frequency, possibly related to the increase of effective precipitation.

Figure 7.2 shows a comparison between the Upper South East hydrological fluctuations and those of lakes located in surrounding regions. All lakes from which data was derived from (Lake Tyrrell, Lake Keilambete, Tower Hill, Lake Leake, Wyrie Swamp and Marshes Swamp) show a wet and dry period preceding the Holocene, and a current period of shallow and ephemeral conditions. Not apparent in the Upper South East cores, but illustrated in the other regions, are minor fluctuations of water level within the Holocene which may have been demonstrated in the results from Reedy Lake and Kangoora Lagoon.

Figure 7.2: Lake Levels of the Upper South East and Surrounding Regions



Lastly, the most recent trend of a reduction of water levels, excepting the Murray Basin lakes (Luly, 1993), is also evident in the Upper South East cores by the extraordinarily high carbonate content in zone one, which indicates a shallow and/or ephemeral water body.

Evidence corroborating with the trend of increasing salinity, found in the Upper South East core results, was found by Harmer (1996) in the Holocene record of playa lakes at nearby Lake Alexandrina. A pollen analysis of her playa lake cores indicated a trend of declining Casuarinaceae pollen which is indicative of an increase of salinity. Excepting the period estimated by Harmer to be between 2 ka and 1.3 ka, where an increase of effective precipitation caused a major decline of salinity, this trend of increasing salinisation has continued throughout the Holocene to the present day, due to a rising sea level and groundwater table bringing salts from depth in the soil column to the surface. Similarly, this was the trend found by Crowley (1994) in western Victoria, which was also evident by a decline of Casuarinaceae pollen in several west Victorian lake records.

The historical record provided no information on long term climatically-induced environmental changes. However, evidence of historical climatic change encompassing fluctuations on the scale of decades was found in the rainfall and flood records (Chapter 5.3), which demonstrated that the Upper South East surface water hydrology was dynamic. The cumulative rainfall average (Figure 5.14) illustrated a distinct dry period in the Upper South East in the 1940s that correlated with changes found in south eastern Australia by Pittock (1975). It could be presumed that fluctuations on the scale of decades have been occurring for the entire time covered by the palaeoclimatic record, but were not visible due to the slow sedimentation rate at most sites and the lack of fossils preserved that are indicative of such events. Also, early travellers to the Upper South East noted that the water level of wetlands in the region were dynamic (Chapter 5.1). Hydrological fluctuations occurred monthly, some floods appearing within days, but taking many years to dissipate. Thus, the Upper South East surface water hydrology has been exceedingly dynamic over a long period of time.

Palaeoecological evidence indicates that a large amount of environmental change has occurred in the Upper South East of South Australia. However, for the purposes of environmental management, the palaeoecological record of the region has been unable to provide resolution sufficient for a complete understanding of the ecosystem. This is due to the alkaline soils prevalent in the region which destroy fossil evidence, the slow sedimentation rate, making a fine resolution study impossible, and the difficulty of obtaining an accurate chronology from the Upper South East sediments. Thus, a historical perspective was required to determine the most recent changes in the region's surface water hydrology, as an adjunct to the sedimentological record.

7.2 European induced environmental changes

European landuse activities in the Upper South East of South Australia have produced significant environmental change within a very short period of time. Some of these changes are apparent in the sedimentological record of the lakes in the region, but most evidence was obtained from the historical record.

Several trends were found in the palaeoenvironmental results that correspond with the period of European occupation. Firstly, the sedimentological record indicates that the last one hundred years or so have seen a return to full lake conditions, with a rise in the amount of organics being produced, and a decrease in carbonate production. The cause of these trends are the drainage activities of Europeans. That is, drainage structures have resulted in deeper more permanent lakes in the Upper South East, as water is channelled into and retained within designated swamps. This has caused an increase of organic accumulation in the lakes, but has retarded the precipitation of calcium carbonate.

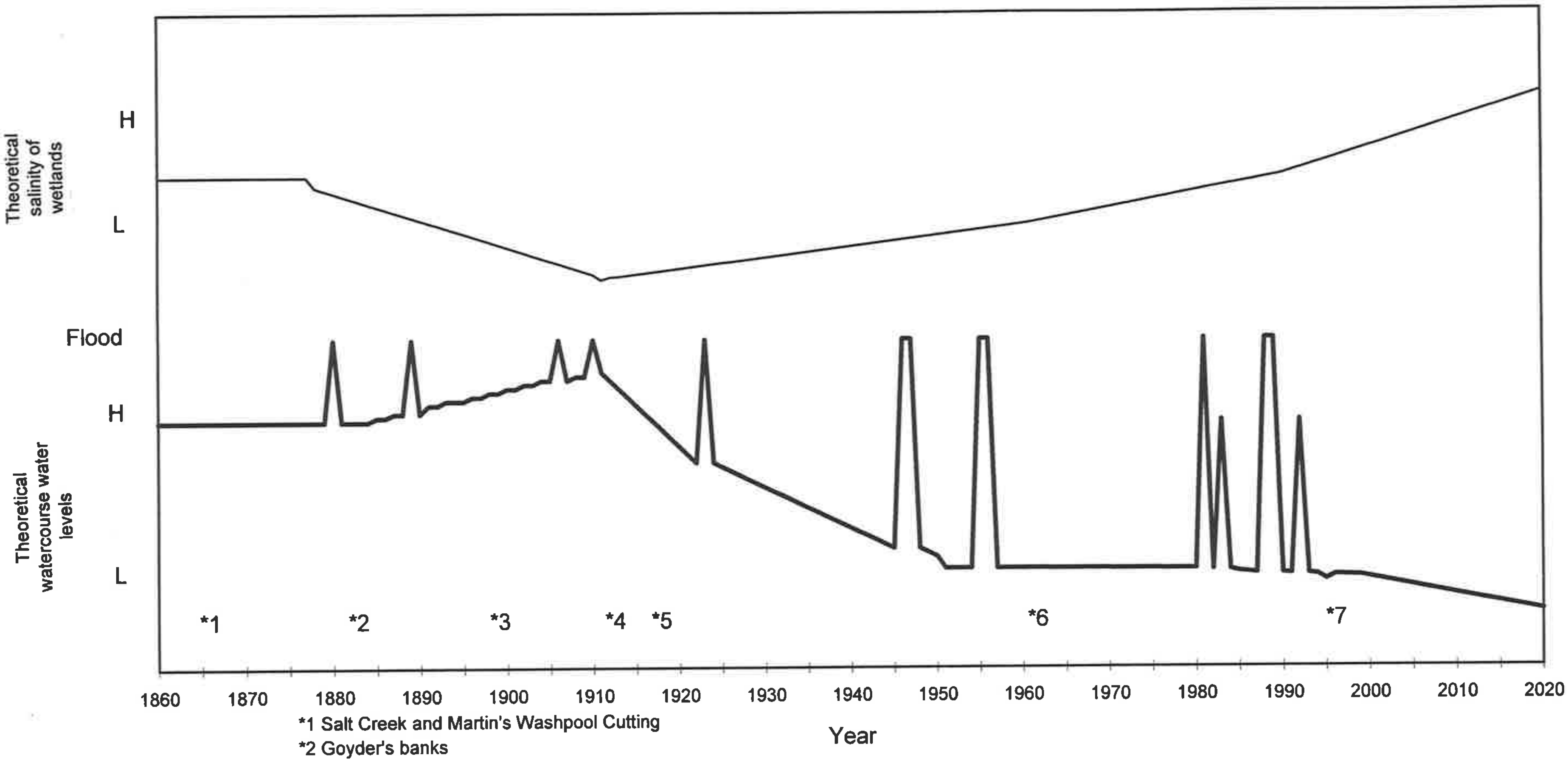
A second trend identified from the palaeoenvironmental results was a change in the inferred salinity profile, as evidenced by the Reedy Lake, Cortina Lakes North Lagoon and Jaffray Swamp core profiles. Reedy Lake indicates a regional increase of salinity that has been attributed to the salinity of groundwater rather than a change in the surface water salinity of the lake. However, by contrast, Cortina Lakes North Lagoon and Jaffray Swamp showed a trend of decreasing salinity within the period of European occupation, believed to be caused by an increase of the amount of water, and throughflow of surface water, in the wetland areas, which is controlled by drainage structures. Thus, while the region may be experiencing an increase in dryland salinisation, a natural occurrence heightened by European landuse activities, some wetlands are experiencing a decrease of salinity as a result of specific drainage activities.

The above trends were identified using the pine pollen content of the Upper South East cores as a chronological indicator of the age of the sediments. Pine pollen grains are quite large, thus contamination of older sediments by pine grains moving downwards in a soil column, is less likely to occur than contamination by modern carbon. For this reason the pine pollen record of the Upper South East cores was considered more reliable that ages obtained from AMS dating. This trend was also found by Ogden (1996) in the Murray-Darling billabongs, and was confirmed by ^{210}Pb dating.

The historical documentation of environmental change revealed many fluctuations in the surface water hydrology of the Upper South East environment in the past one hundred years. Despite the fact that the natural surface water hydrology of the region has been very dynamic, there is a distinct change of trends since European occupation. The changes have principally occurred as a result of drainage and vegetation clearance, which are associated with the development of the Upper South East agricultural industry. The trends evident within each watercourse are illustrated in Figures 7.3 to 7.7, and are described below.

The surface water hydrological changes revealed by historical information are different for each watercourse considered. Tilley Swamp contained large amounts of surface water under pre-European conditions (Figure 7.3), and it is highly likely that this swamp experienced more frequent and larger floods than the other catchments, due to a shallow groundwater table and the high water levels in the wetlands. Construction of the Salt Creek and Martin's Washpool cuttings in 1864, were the first alterations to the natural surface water hydrology. The northern wetlands of Tilley Swamp watercourse experienced drier conditions when the cuttings were made, but the majority of Tilley Swamp watercourse water levels remained the same. The construction of Goyder's Banks in 1886 increased the amount of surface water in the watercourse. The southern swamps were then flooded more frequently, and the swamps north of Martin's Washpool received greater throughflow of water as surface water was rapidly directed through the Salt Creek cutting. The amount of surface water in the Tilley Swamp watercourse was further increased in 1897 by the Wilmot cuttings. In this period (1864 to 1910), many floods occurred, as the water levels of the wetlands were already high. The volume of surface water in Tilley Swamp changed again in 1912 when Stopbanks F, H and Cutting G were constructed. These structures encouraged the movement of surface water into the Bakers Range watercourse rather than travelling the extent of Tilley Swamp watercourse. As a consequence water levels of the Tilley Swamp watercourse were reduced from natural conditions. Drains L and M were constructed in 1916 and 1918 and channelled water towards the sea rather than northward, further reducing water levels. Since 1912, the Tilley Swamp watercourse has experienced

Figure 7.3: Environmental Changes in the Tilley Swamp Watercourse



*1 Salt Creek and Martin's Washpool Cutting
*2 Goyder's banks
*3 Wilmot Cuttings
*4 Stopbanks F, H & Cutting G
*5 Drains L & M
*6 Jacky White's & Blackford Drains
*7 Southern and Central Drainage Schemes

much drier conditions than the natural hydrological regime. While the Tilley Swamp was naturally a very large and deep surface water channel, that experienced long periods of inundation, after 1912 it became almost dry and received little water from its sources, Reedy Creek and Avenue Flat. Water levels have continued to drop in the Tilley Swamp watercourse with the development of the Jacky White's and Blackford drains. A comparison of the 1980 water level with the 1860 water level highlights the true severity of the 1981 and 1988/89 floods. Without the drainage networks existing at those points in time the agricultural areas of the Upper South East would have been devastated.

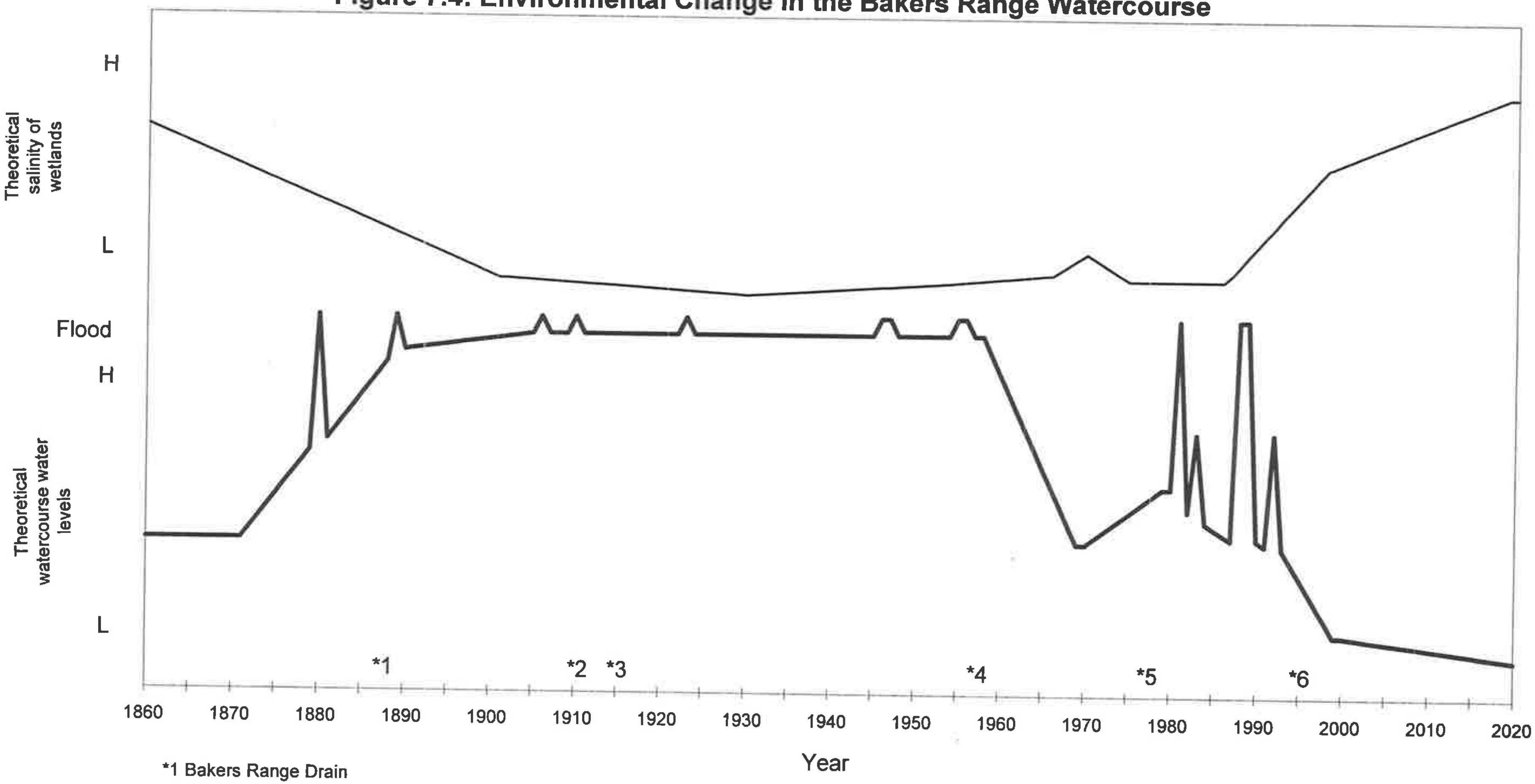
It is demonstrated in Figure 7.3 that the salinity of the Tilley Swamp watercourse has also changed within the period of European activities. As a consequence of the increase of water levels in the watercourse in the early 1900s, the salinity of surface water in the Tilley Swamp wetlands was probably reduced, the increase in surface water throughflow in addition to larger quantities of surface water diluting existing solutes. Since the construction of Stopbanks F and H, and Cuttting G, a trend of increasing salinisation has occurred as the water levels of the watercourse have dropped.

The pattern of lowering of the water levels of the Tilley Swamp watercourse, and an increase of salinisation, are expected to continue with the construction of the planned Central drainage scheme (Figure 3.6) (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993). These drains will reduce the problem of surface water flooding in the Tilley Swamp watercourse with very infrequent and perhaps only minor floods occurring. However, the wetlands of the area require frequent flooding to manage the inherent salinity problem, so will continue to degrade. Therefore, dryland salinity will increase in severity in wetland areas, because they will be deprived of a reasonable amount of surface water throughflow to flush the wetlands of salts and other pollutants.

Of the Bakers Range watercourse, no information was available on its pre-European surface water hydrology. The first mention of this watercourse occurred in 1897 when the Bakers Range drain was constructed in the Lower South East to encourage the movement of surface water from the Lower South East to the northern reaches of the same watercourse. This drain dramatically increased the level of water in the Bakers Range watercourse (Figure 7.4). The amount of surface water in the Bakers Range watercourse was further increased in 1912 when Stopbanks F, H and Cutting G were constructed, and again, in 1915-1916, with the construction of Drain E, which all encouraged the movement of surface water from the Tilley Swamp and Marcollat watercourses respectively, to enter the Bakers Range watercourse. It should have been no surprise when Alf's Flat, the terminal wetland of Bakers Range watercourse, filled with surface water in 1918 after the 1917 flood and produced a very extensive and deep lake of fresh water. At this time, the Bakers Range watercourse was receiving up to three times the amount of surface water it had previously received.

The trend towards increasing surface water in Bakers Range watercourse was reversed in 1960 with the extension of Drain M, which directed all surface water flow in the Lower South East towards the sea. The amount of surface water in Bakers Range watercourse was slightly increased in the early 1980s with a sudden and rapid development of private drains. Water levels were increased due to the uncoordinated nature of the drains which were unable to provide an outlet for the excess surface water. The construction of these drains coincided with the increased frequency of flooding in the early 1980s. Since the 1980s the water levels of the Bakers Range watercourse have continued to drop. Thus, after

Figure 7.4: Environmental Change in the Bakers Range Watercourse



*1 Bakers Range Drain
*2 Stopbanks F, H & Cutting G
*3 Drain E
*4 Drain M
*5 Privately constructed Stopbanks at Jip Jip
*6 Southern and Central Drainage Scheme

63 years of excess surface water, the northern reaches of the Bakers Range watercourse finally received only small amounts of surface water again. Whether this returned the watercourse to a more natural hydrological regime, or whether the area then experienced drought type conditions, is unknown. Field observations in Messent Conservation Park suggest that the area is currently experiencing much drier conditions from its natural regime because *Banksia ornata* are rapidly invading the lowland areas, and this species is intolerant of flooding.

Salinity of the surface water of the Bakers Range watercourse has been reduced for a majority of the period of European activities, due to the increase of surface water in the watercourse within the period 1897 to 1960. This trend has been reversed since the construction of Drain M, and the subsequent decline of the amount of surface water within the Bakers Range watercourse. A minor reversal of this trend may have been experienced in the early 1980s, when private drainage increased surface water throughflow in many of the Bakers Range watercourse wetlands.

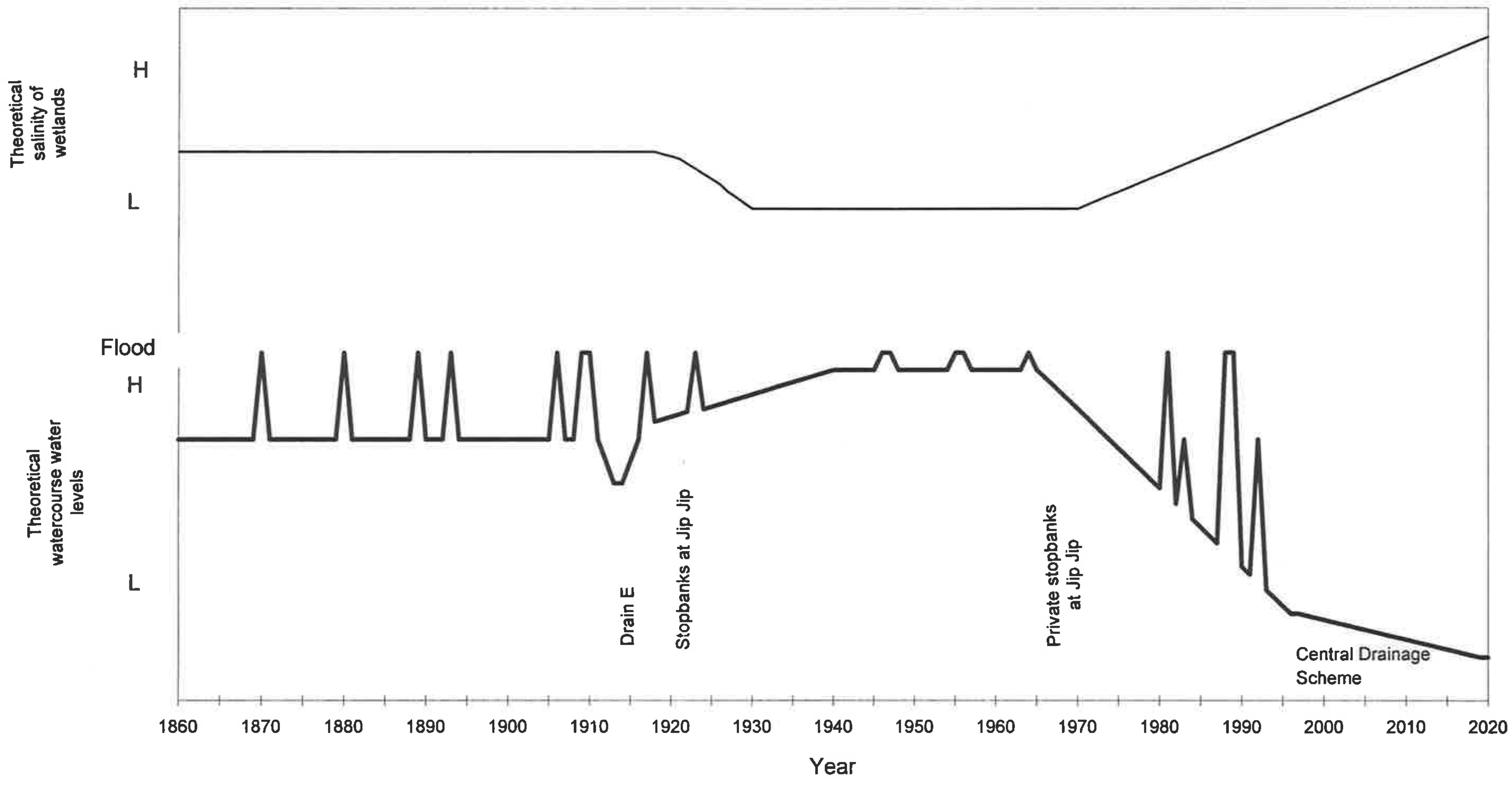
With the additions of the planned Central and Southern drainage schemes (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993), the water level of the Bakers Range watercourse is expected to continue to decline (Figure 7.4), and flooding will become a rare occurrence in future years. The reduction of surface water levels will also exacerbate the trend of increasing salinity within the wetlands of the watercourse in the long term, as the wetlands are no longer flushed of salts by surface water throughflow.

No information on the natural hydrology of the Marcollat watercourse was found, so it was presumed that the water levels of wetlands in this watercourse were moderate in the late nineteenth century (Figure 7.5). The first drain affecting the Marcollat watercourse surface water hydrology was Drain E which was constructed in 1915, and encouraged the flow of surface water from Naracoorte Creek northwards, increasing the water levels of wetlands. However, privately constructed stop banks at Jip Jip encouraged surface water to exit the Marcollat watercourse, into the Bakers Range watercourse, causing a reduction of surface water in the terminal wetlands. Coola Coola Swamp (the terminal wetland, which is located within the Gum Lagoon Conservation Park) has received little surface water since 1918. The southern reaches of the Marcollat watercourse therefore experienced greater surface water flow, but water levels in the wetlands were shallower than under natural conditions. A further decrease of water levels in the northern wetlands of the Marcollat watercourse was achieved by private stopbanks, which were constructed at Jip Jip in 1972. Thus, the Marcollat watercourse has been radically altered by European activities, as both the direction and amount of surface water in the watercourse has changed.

In contrast to the Marcollat watercourse water levels, the salinity of surface water in the Marcollat watercourse is likely to have decreased in the period 1920 to 1970, and increased since the 1970s, when the effects of vegetation clearance impacted the whole Upper South East. This trend is expected to continue.

The construction of the Central Drainage scheme is likely to significantly alter the Marcollat watercourse surface water hydrology (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993). The surface water and groundwater drains that are components of the proposed network (Figure 3.6), will reduce water levels in the southern wetlands of the Marcollat watercourse and flooding will become less frequent (Figure 7.5), but the northern wetlands will continue to remain dry. It is uncertain how the salinity of the surface waters of the Marcollat watercourse will respond to the proposed drains, it is suggested that the reduction of the ground water table may reduce

Figure 7.5: Environmental Change in the Marcollat Watercourse



salinity in dryland areas, but the reduction of surface water throughflow within wetlands may cause an increase of salinity.

Duck Island watercourse has been greatly affected by European activities. The watercourse is now inundated more frequently, and for longer periods of time, than under natural conditions, due to the effects of vegetation clearance and the associated regional rise of the groundwater table. Pre European occupation, the Duck Island watercourse experienced more frequent flooding than the western watercourses (Tilley Swamp, Bakers Range and Marcollat watercourses), as demonstrated in Figure 7.6. The impact of private drains in this watercourse have been minimal because there is no ultimate outlet for the surface water, and excess water is simply transferred from one property to the next until it is allowed to pool in some of the deeper depressions. As a consequence of the increase of surface water flooding, this watercourse has also experienced an increase of dryland salinisation, which although has been a long term and natural trend, has been exacerbated by European impact. The planned northern drainage scheme (Figure 3.8) is likely to be beneficial to this watercourse (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993). The removal of excess surface water by a surface water drain will lessen both surface water flooding and the increase of dryland salinisation.

Similar to the Duck Island watercourse, the Mount Charles watercourse has no outlet for excess surface water. Thus, while the natural hydrology of this watercourse is unknown, it is likely to have experienced frequent flooding prior to European occupation. This trend has continued within the historical record, as demonstrated in Figure 7.7. During the period of European activities, the Mount Charles watercourse has experienced an increase in the ground water table level, as a consequence of vegetation clearance. Attempts to reduce surface water inundation by the construction of private drains has not succeeded. A long

Figure 7.6: Environmental Change in the Duck Island Watercourse

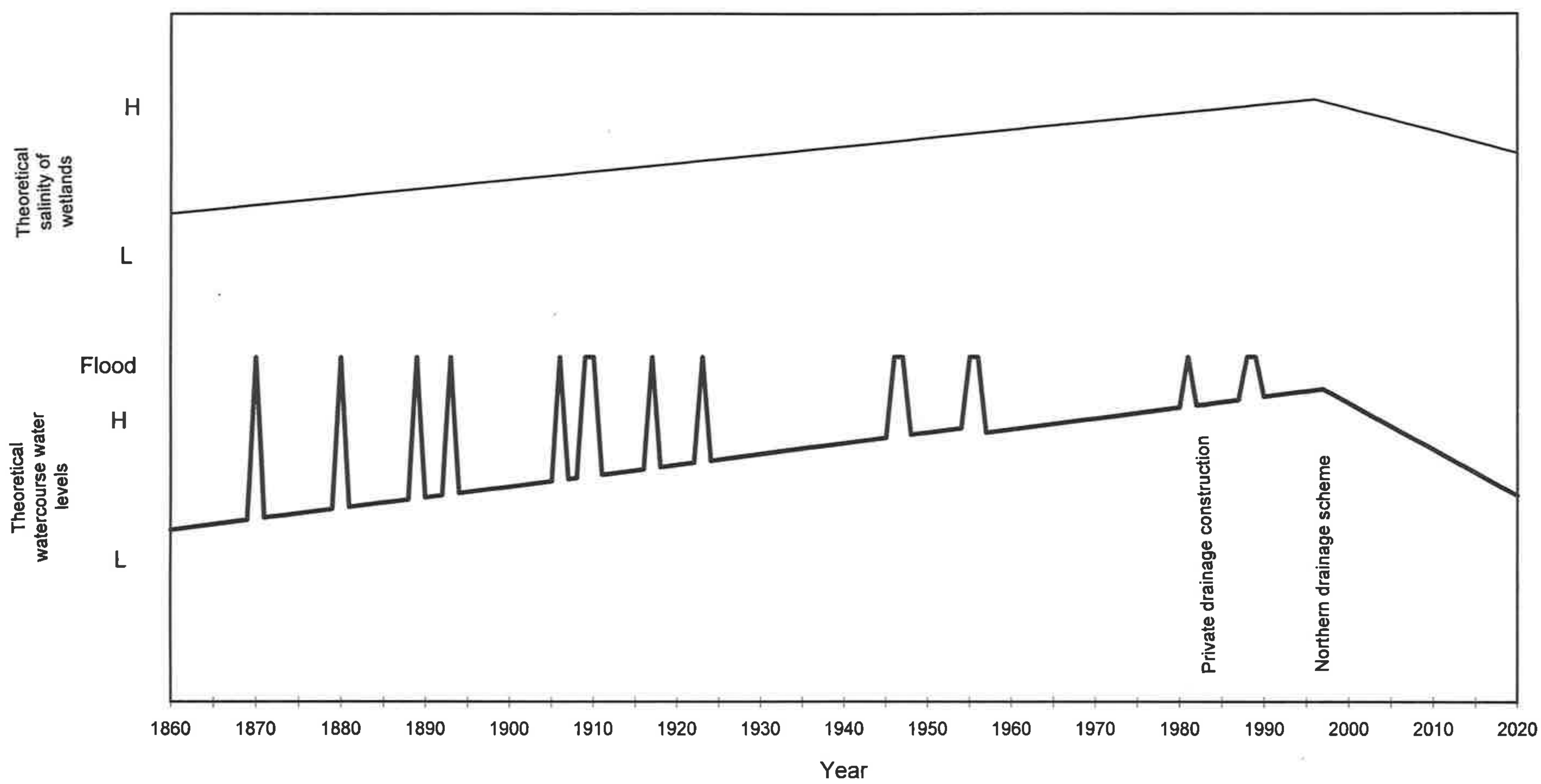
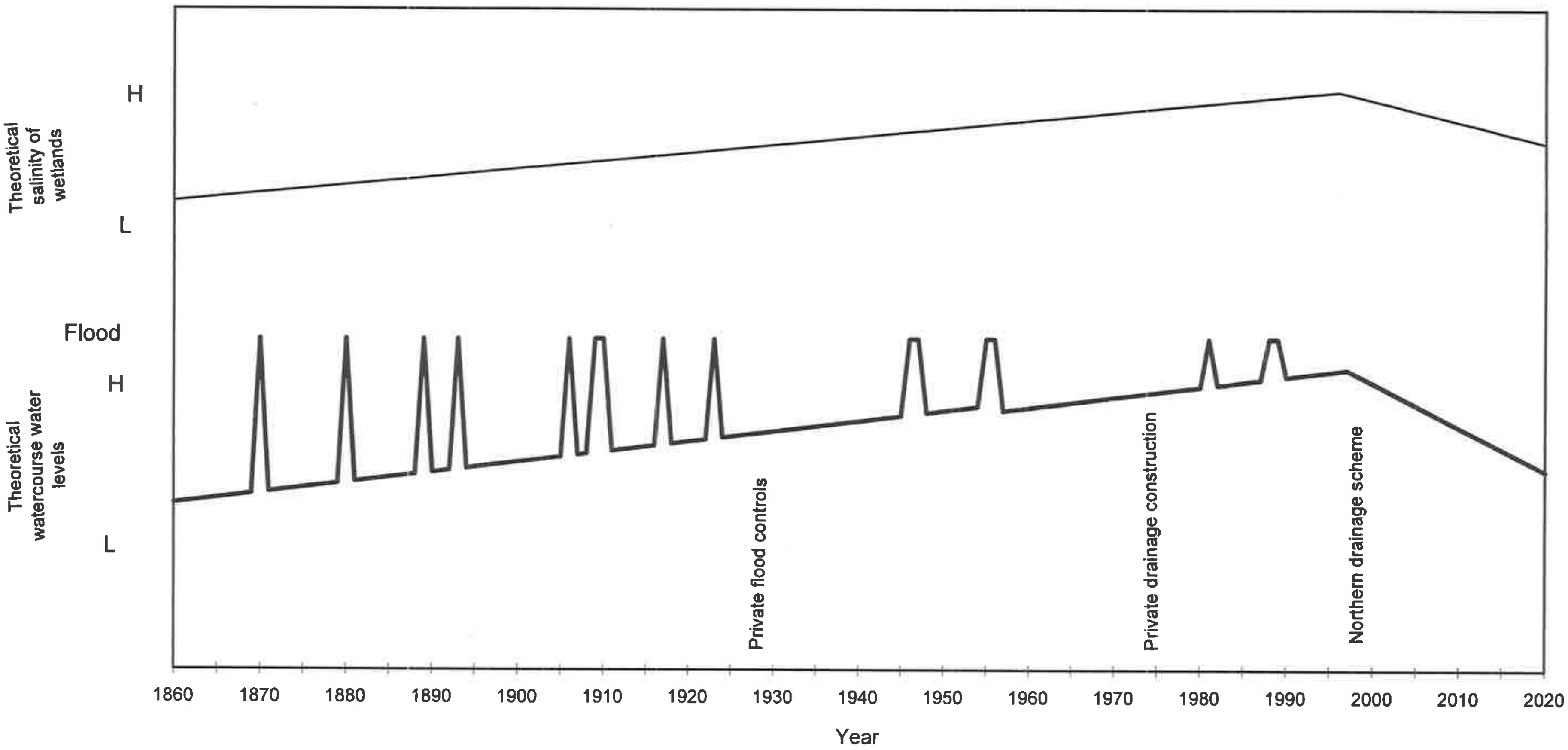


Figure 7.7: Environmental Change in the Mount Charles Watercourse



term trend of increasing salinisation was found to exist within the Mount Charles watercourse by palaeoecological results, and this trend has been exacerbated by European activities. Similar to the Duck Island watercourse, the proposed Northern drainage scheme (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993) may provide some relief to the dual problems of surface water flooding and dryland salinisation.

The surface water hydrological changes occurring in each watercourse of the Upper South East differ. Both the Tilley Swamp and Marcollat watercourses now experience drier conditions than their natural hydrological regime. The Bakers Range watercourse initially experienced much wetter conditions than its natural regime until the period following 1960, when surface water dried. It is not known how the present hydrological regime compares with that present prior to European settlement. Both the Duck Island and the Mount Charles watercourses are experiencing an increase of flood water above that of their natural hydrological regime.

The salinity changes in the Tilley Swamp, Bakers Range and Marcollat watercourses were almost the direct opposite of the water level changes but with a lag time. When an increase of water levels occurred, there was an increase in the amount of water both within wetlands, and flowing through the watercourses. The existing solutes were diluted and moved northward with the flow of surface water. Thus, the Tilley Swamp, Bakers Range, and Marcollat watercourses experienced a decline of wetland salinity in the early twentieth century when the water levels were increased by the effects of drainage. The opposite occurred in the Duck Island and Mount Charles watercourses, as the surface water had no outlet, both excess surface water and solutes have continued to increase.

Comparison of the palaeoecological results and the above historical discussion of surface water changes within each watercourse reveals that the sediment record of the Upper South East lakes has identified the periods of increased surface water and decreased salinity within each wetland, that occurred between European settlement and approximately 1950. This period is evidenced in the surface core samples as an increase of organic content and a decrease of carbonate precipitation. However, the more recent occurrence of less surface water within the watercourses as a result of drainage activities is not apparent, because insufficient sediments have been deposited in the wetlands due to the slow sedimentation rate, to reveal the most recent hydrological trends.

Thus, drainage activities have been the major cause of changes in the surface water hydrology of the Upper South East of South Australia within the period of European landuse activities. Their influence began at the end of the nineteenth century and are likely to have a continued direct influence upon the Upper South East hydrology in the future. The indirect effect of drainage upon the surface water hydrology was its ability to make available increased amounts of land for agricultural development. Thus, the land drained was subsequently cleared of native vegetation. While remnant native vegetation is now protected by the Native Vegetation Retention Act, it is estimated that the full effects of previous clearance have not yet been fully expressed within the environment, and further groundwater table rise may be expected (Bakers Range/Marcollat Watercourses Working Group, 1991).

However, a report by Foale and Smith (in prep.) found evidence against the widely held belief of increasing salinity in the Upper South East. Using the maps of Melville and Martin (1936), and a remotely sensed image of the region analysed by Cann *et al.* (1992), they prepared a map illustrating salinity changes. Results indicated that many areas that are currently classified as saline were already saline in the 1930s, such as downstream Tilley Swamp watercourse, northern Bakers Range watercourse and Duck Island watercourse. Some areas have increased in salinity (western Tilley Swamp watercourse, Didicoolum Flats and the Mount Charles watercourse), and the Bakers Range watercourse near the Cortina overflow and southern Tilley Swamp watercourse have decreased salinity values. Thus the Foale and Smith (in prep.) results indicate that salinity changes in the Upper South East are complex within the period of time affected by European activities. The well publicised regional increase in dryland salinity, is not apparent in the environmental history for all areas of the Upper South East.

The historical record shows that development of the Upper South East occurred rapidly, without monitoring of the resultant environment changes. Large scale environmental changes have occurred as a result of drainage construction and native vegetation clearance. Initially, construction of the Lower South East drains, in the early 1900s, increased water levels in the watercourses to a level that may have been similar to the conditions experienced between approximately 15 000 and 13 000 years BP, when lake full conditions and frequent flooding prevailed. More recently, conditions have ameliorated, excepting the major wetlands, into which drainage water is currently channelled. It is expected that current management strategies will produce a new hydrological regime as yet unexperienced in the Upper South East. Upland areas will be permanently dry, with few minor flood events occurring. Major wetlands will continue to contain deep water that is channelled from adjacent areas, but the movement of surface water along the watercourses will cease. Thus, it is expected that proposed management plans will continue the degradation of remaining wetland areas.

7.3 Future management

The third aim of this thesis was to forecast the effects of current and proposed management strategies on the environment of the Upper South East. Several options were outlined in Chapter 3.2, but here only two of the options will be discussed; firstly, the 'do-nothing' option where the hydrology of the Upper South East is not further altered; and, secondly, the favoured strategy currently being implemented that includes drainage, revegetation, a Wetlands Waterlink and on-farm measures.

The 'do-nothing' option was found to be unsuitable by the Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993), on the grounds of the unsustainablility of agricultural productivity. This strategy predicted continued groundwater table rise, resulting in an increase of flooding and salinisation, which would affect both remnant native vegetation and agricultural areas. The impact upon fauna was less well studied but was expected to be high. Thus, this option was discarded because of the likely drastic influences upon the natural and social environment.

Results from the environmental history of the Upper South East, indicate that without further alterations of the surface water hydrology, the water level of the Tilley Swamp, Bakers Range and Marcollat watercourses will remain low as drains in the Lower South East continue to channel water towards the sea. Major wetlands along these watercourses, into which excess surface water is currently channelled, will continue to contain deep water, but with little surface water throughflow. Water levels in the Duck Island and Mount Charles watercourses will continue to rise. Wetlands within these watercourses will receive an increase of water resulting in deeper lakes and surrounding areas will be inundated more frequently and on a more permanent basis.

The salinity of all watercourses will continue to rise, both within the wetlands and the areas connecting major wetlands. Without a large amount of surface water flowing through the watercourses, salts and pollutants will continually accumulate in the wetlands, causing a rapid increase of salinisation and pollution, which may have a negative impact upon native flora and fauna.

These predicted environmental changes reverse the Holocene surface water hydrology of the Upper South East which was revealed in this study. That is, the wetlands were adapted to a constant throughflow of surface water with periodic flooding. European activities have altered the surface water hydrology so that the major wetlands are now deep, permanent lakes, and other areas of the watercourses are permanently dry. The 'do-nothing' option would continue the post European trend of decreasing surface water throughflow, increasing lake water depth in major wetlands, but increasing salinisation. This would be a negative trend for the remaining natural wetlands. Especially the Duck Island and Mount Charles watercourses, which were naturally frequently flooded and more saline than the remaining portion of the study area.

Thus, the environmental history of the Upper South East indicates that intervention of a positive kind must be taken to prevent further degradation of both agricultural and natural areas. Current agricultural practices will not be able to successfully continue under a 'do-nothing' scenario, particularly within the Duck Island and Mount Charles watercourses.

The favoured management strategy (Chapter 3.2) being implemented by the South Australian government will also cause further surface water hydrological changes in the Upper South East. The management plan aims to reduce the amount of surface water inundation, especially in agricultural areas, but restore natural surface water flows through the remaining wetland regions using the Wetland Waterlink. It also aims to reduce the increase of dryland salinisation in the long term by revegetation and a change of agricultural techniques to adapt to the more saline environment.

Proposed drains, that are components of the Southern drainage scheme, run east to west, emptying into the sea via the Henry Creek. These drains will divert all surface water moving from the Lower South East away from the Upper South East. The Central drainage scheme then moves surface water rapidly northward along the interdune areas. The effect of these drains upon the Tilley Swamp, Bakers Range and Marcollat watercourses were illustrated in Figures 7.3, 7.4 and 7.5, and will cause further reduced surface water flows. Interdune flats along these watercourses will not receive surface water as frequently, or in the same volume, as during any stage of European settlement. Designated wetlands will receive a greater amount of surface water but less through flow, as drains channel runoff toward the swamps and allow surface water to pond. These drains will have a similar effect upon the wetlands within the Tilley Swamp, Bakers Range and Marcollat watercourses as the 'do-nothing' option, that is, increasing salinity and decreasing flood frequency. The effect upon dryland areas is likely to be beneficial as the reduction of the ground water table by the drains will reduce flooding and salinisation. The Wetland Waterlink is aimed to overcome the predicted change in the watercourse wetlands. However, it will be unable to overcome the reduction of surface water received by the Upper South East since the construction of Drains L and M in the 1960s.

Surface water drain construction in the northern reaches of the Upper South East will have a large effect upon the Duck Island and Mount Charles watercourses. These catchments currently have no outlet for surface water and are therefore greatly affected by the rising groundwater table. Providing an outlet for surface water through the Salt Creek will reduce flooding in these watercourses and possibly reduce the spread of salinisation (Figures 7.6

and 7.7). Currently, tea-tree (which is a species resistant to periodic flooding and high salinity), is dying in these watercourses. A dramatic positive change could be expected in these northern watercourses with the proposed management strategies, if over drainage does not occur.

The expected environmental changes from current management strategies will cause another period of radical change, which may be quite different from any so far experienced in the surface water hydrology of the Upper South East. Prior to European occupation, the native flora and fauna of the Upper South East, was adapted to a large amount of surface water flowing through the watercourses, and periodic flooding. Without this freshening of surface water, salinisation has become degradational to the Upper South East environment. Currently, native flora and fauna of the Upper South East are under great stress from the dramatic and rapid environmental changes caused by European land use activities. Many species are at the edge of their ecological tolerance and may not be able to adapt and evolve to further environmental change. Current management strategies may tip the ecological balance in favour of introduced species and cause the decline of remnant native vegetation and associated fauna, simply because non indigenous species are better adapted to European agricultural practices.

The wetlands waterlink is aimed to overcome the current degradation of the once extensive and unique Upper South East wetlands. Utilising a complex network of drains and retaining structures, the Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993) planned to rejuvenate remaining wetlands by reinstalling the 'natural' hydrological regime. The method by which the wetlands waterlink would be managed was a component of the Upper South East Management Plan that required further data collection and research (Environmental Impact Assessments Branch, 1994).

This study shows that the wetlands waterlink must recreate periods of drought and flood, and produce large amounts of surface water flowing from the Lower South East towards the Upper South East terminal wetlands. To produce such a hydrological regime it will be necessary to divert surface water, from Drains L and M, towards the Upper South East. This water must be continually channelled northwards along pre existing drainage lines. The resultant water depth in the wetlands, or whether current drainage lines follow natural surface water paths (Foale and Smith, 1991), are not important to ensure the conservation of the wetlands. It is the periods of flood and drought, and the movement of surface water through the hydrological system that is crucial to their survival. Outlets for the surface water in the Tilley Swamp, Bakers Range and Marcollat watercourses are unlikely to be required, as currently the terminal wetlands have been dry since the mid-1950s and require an increase of flood water.

The Duck Island and Mount Charles watercourses must be included in the wetlands waterlink to provide beneficial management strategies for the remaining wetlands in these watercourses. If the wetlands waterlink does not include them, then it is likely that the wetlands will take second place to agricultural priorities, and hence be allowed to continue to degrade. As these wetlands have a unique hydrology (they are naturally saline and frequently flooded), and are highly vulnerable to further degradation, their conservation must be prioritised.

It is possible that the wetlands waterlink may have degradational effects upon the surrounding agricultural areas, due to the groundwater table mounding effect, which may increase the impact of dryland salinisation in marginal areas. Massive revegetation is required to surround the designated wetlands to reduce this impact. In addition, the revegetation will also provide a buffer for the wetlands from agricultural pollutants.

The agricultural areas of the Upper South East may benefit from drainage and revegetation, but the cost to the natural environment may be too high a price to pay. More attention on the concept of the wetlands waterlink and revegetation within the watercourses is required. Also, more studies must be conducted on the ecological tolerances of indigenous species to accurately predict their likely reaction to the new proposed hydrological and salinity regime. It is recommended that a more thorough monitoring system be installed in the Upper South East in the near future. Instrumental data on soil saturation, stream flow, surface water and groundwater chemistry and flood extent at a variety of locations within each watercourse need to be known. Since 1992 a bore well water table and ground water salinity network has been constructed that is producing interesting results. But the environmental conditions that occur prior to a flood need to be more thoroughly identified to aid the prevention of agricultural deterioration and improve management of wetland areas.

7.4 Effectiveness of "Environmental History" in the Upper South East of South Australia

It was obvious in the Upper South East that neither a historical nor a palaeoecological analysis was likely to provide adequate information for management purposes. The region was settled too recently for written records to provide any useful information on long term environmental fluctuations. The environment, however, was not perfectly suitable for fine resolution palaeoecological analysis with alkaline soils and a slow sedimentation rate. However, the region required a reconstruction of the history of environmental fluctuations in order to understand ecological processes that were occurring, whether they were natural or a product of European influence.

Obtaining the environmental history of the Upper South East has been useful from a number of perspective's. It has provided the history of changes in the surface water hydrology of the region over a long period of time. It has shown that the Upper South East has responded to climatic oscillations in a manner similar to surrounding regions. It has illustrated that the recent dynamic nature of the hydrology is not a recent phenomena but has persisted over the period of the Holocene. In combination the historical and palaeoecological records have illustrated that European activities have had a large impact upon the Upper South East surface water hydrology, but not in the presumed manner. For example, initially European activities increased surface water and decreased salinity in the Tilley Swamp, Bakers Range and Marcollat watercourses. It has only been in the past twenty five years that European activities have decreased surface water levels and increased dryland salinisation to a level beyond the Holocene hydrological regime. It has also shown that the Duck Island and Mount Charles watercourses were naturally wet and saline, and although these conditions have been exacerbated by European activities, a reversal of that type of environment would further devastate the natural ecology of the watercourses.

The environmental history of the Upper South East has indicated that the current management strategies may be ideal for dryland agricultural areas in the short term, but thus far, the hydrological needs of the wetlands have been unknown and therefore neglected. The specific needs of each watercourse in the Upper South East was not examined in the EIA in sufficient detail. Now that the hydrological history of the Upper South East is known, these must be incorporated into the management plan. The watercourses of the Upper South East are an integral part of the region, and thus essential to the long term survival of the Upper South East environment.

Without this study on the environmental history of the Upper South East future changes that are now expected to occur would remain unknown. The opportunity to take these changes into consideration in the process of the development of future management strategies would not be available. For that reason alone, the concept of environmental history could become very important in regions where controversial and conflicting management decisions must be made. This is especially the case in Australia where historical records are short, incomplete and usually non quantitative.

8.0 CONCLUSIONS

The environmental history of the Upper South East of South Australia has revealed hydrological fluctuations that have occurred as a result of both climate and human influences. The climate reconstruction, which was primarily based upon palaeoecological evidence, demonstrated that the Upper South East wetlands have experienced a wide range of hydrological environments. Results clearly indicate three different hydrological periods: firstly, a wet period in which major wetlands contained deep and permanent surface water (estimated to have occurred between 15 000 and 13 000 years BP); secondly, a dry period (estimated to have occurred between 13 000 and 11 000 years BP) which was characterised by a dry, and windy environment that dried wetlands and caused sands from adjacent dunes to fill existing depressions; and thirdly, the most recent period (possibly the Holocene), in which wetlands have experienced ephemeral lake conditions. Some fluctuations of water level may have occurred during this period but could not be placed within a more accurate chronological framework. In addition, palaeoecological evidence indicated that the Upper South East experienced saline conditions throughout the most recent period, but large amount of surface water flowing through the watercourses, and periodic flooding, flushed excess salts from the wetlands and prevented dramatic increases of salinisation.

European agricultural activities have also caused changes in the surface water hydrology of the Upper South East. Changes revealed by the historical record, in addition to the palaeoecological record, were primarily caused by drainage activities and vegetation clearance. Initially drainage increased the amount of surface water, and decreased the salinity within watercourses of the Upper South East, due to the channelling of excess surface water from the Lower South East into the Upper South East. In this period (1860 to the mid 1950s) lake full conditions occurred, which may have been similar to the period estimated to be between 15 000 and 13 000 years BP. Since approximately the 1960s, the Upper South East has been deprived of surface water inflow from the Lower South East as large groundwater drains, such as Drains L and M, channel surface water towards the sea. Consequently, the amount of surface water within the watercourses has been reduced and salinity has increased. Excess surface water within the Upper South East has been channelled into, and retained, within major wetlands causing an increase of lake water depth. This new hydrological regime has been unable to cope with the inherent salinity problems because there is inadequate surface water throughflow to flush excess salts from the watercourses.

Planned management strategies (Upper South East Dryland Salinity and Flood Management Plan Supplement Working Group, 1994) will benefit dryland areas of the Upper South East only. The wetlands waterlink, a scheme aimed to retain and improve the natural attributes of the watercourses, lacked adequate information on the Upper South East surface water hydrology to ensure conservation and preservation of the wetlands. This study shows that the wetlands waterlink must recreate periods of drought and flood, with large amounts of surface water flowing through the Tilley Swamp, Bakers Range and Marcollat watercourses. To accomplish this surface water from Drains L and M will need to be diverted towards the Upper South East. The wetlands waterlink must also include the Duck Island and Mount Charles watercourses, as these unique environments are highly vulnerable to further degradation. Without adequate management the wetlands within these watercourses will continue to degrade because importance is currently placed upon the agricultural areas only, which have conflicting requirements to that of the wetlands. To prevent the wetlands waterlink impacting nearby agricultural land uses, the designated wetland areas must be revegetated to reduce the effect of groundwater table mounding.

Throughout the Holocene, the Upper South East watercourses have been a unique wetlands area composed of a rich diversity of flora and fauna. Currently, the wetlands play an important role as a breeding ground for avifauna but are threatened by increasing dryland salinisation, a product of a new hydrological regime caused by European land use activities. Frequent flushing of the wetlands is required to prevent further degradation of the wetlands, which are crucial to the conservation of the Upper South East environment.

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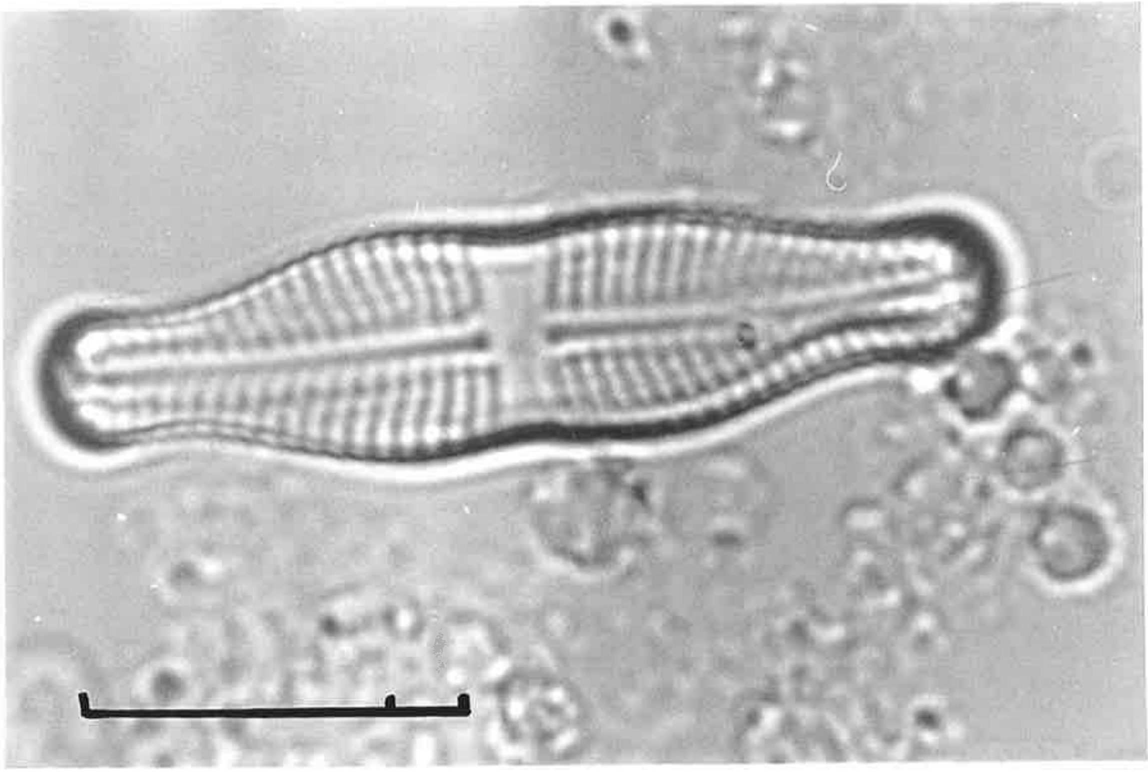
10.0 APPENDICES

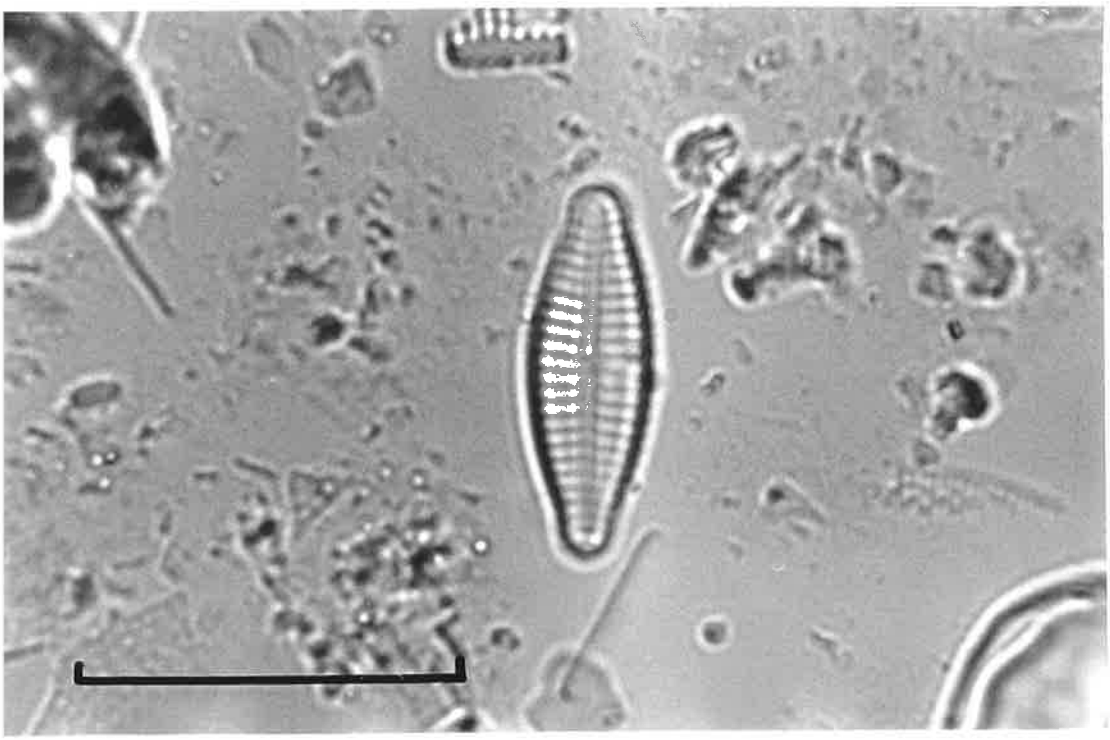
10.1: Diatoms of the Upper South East of South Australia

1μm

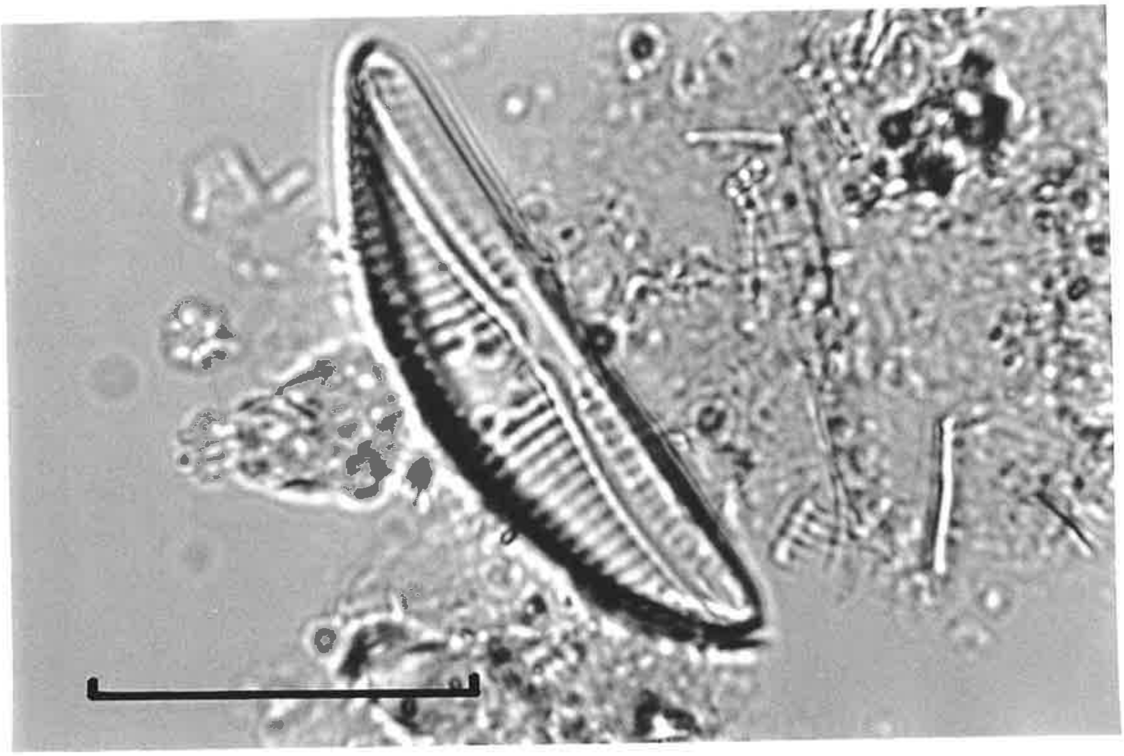
Achnanthes coarctata



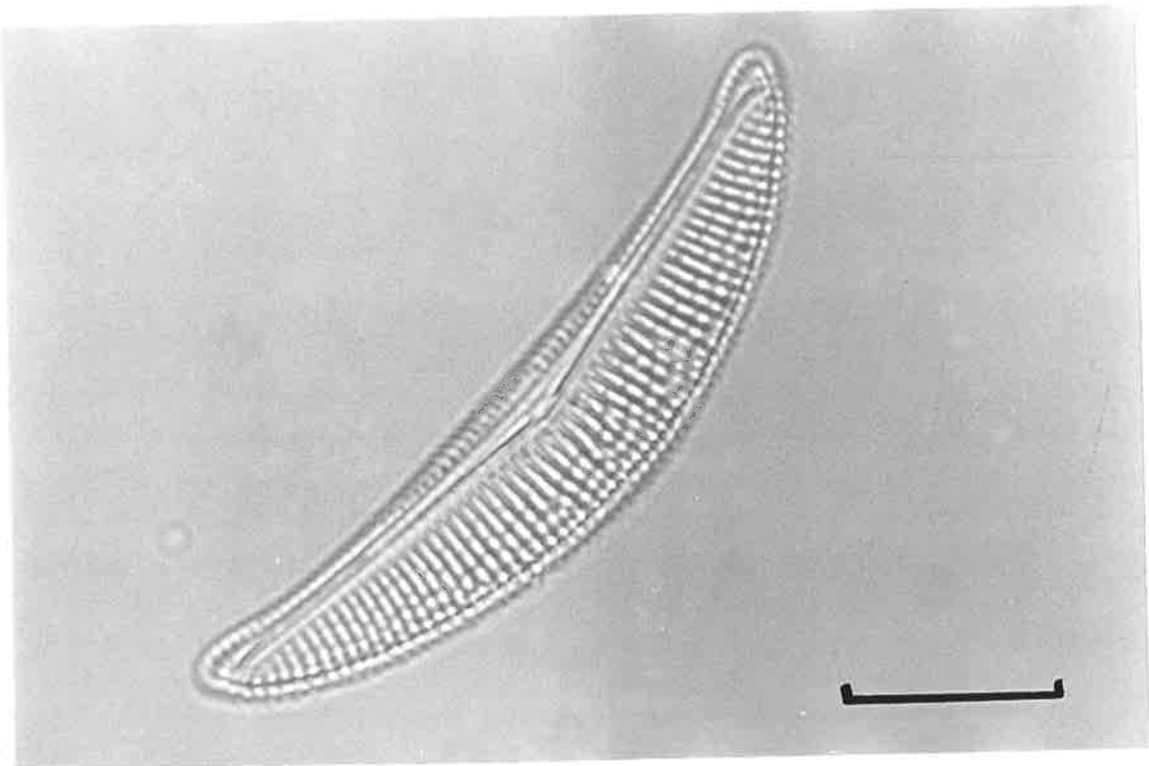
Achnanthes delicatula



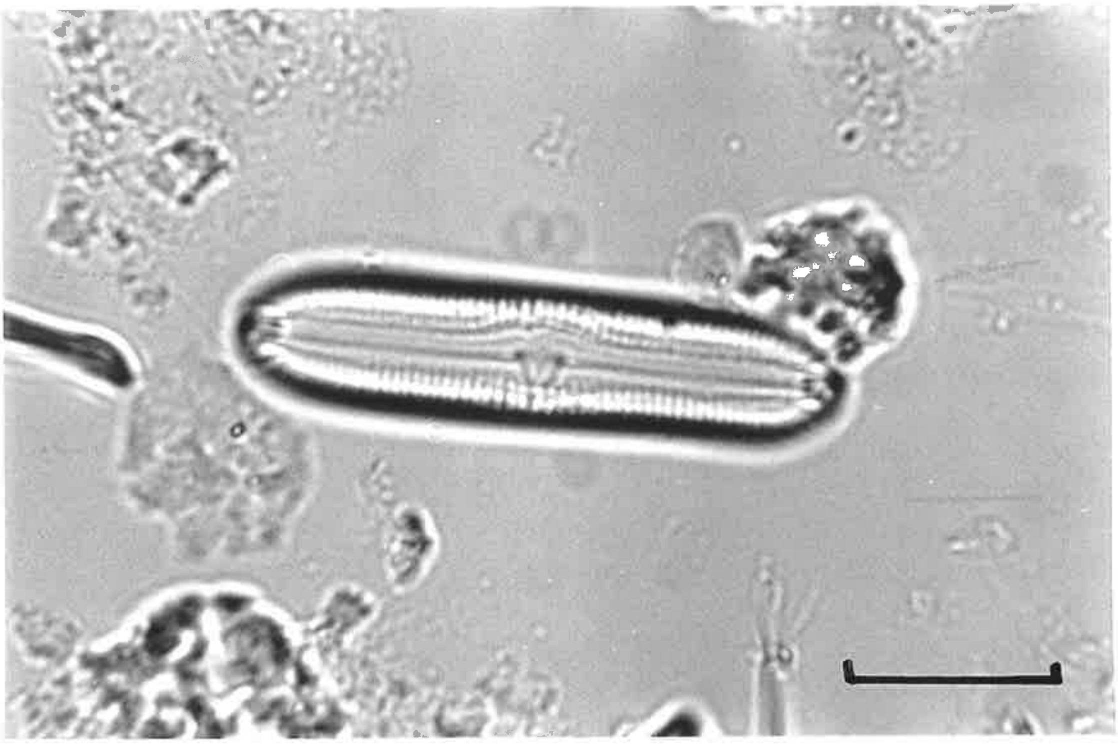
Amphora veneta



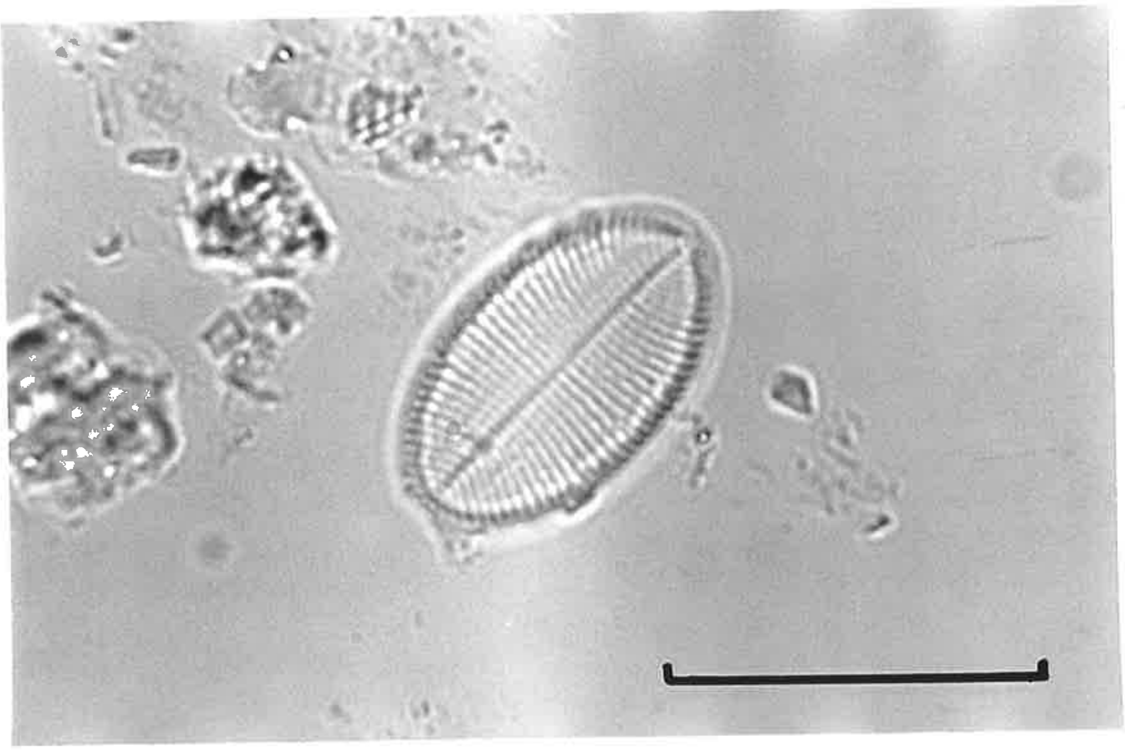
Amphora ovalis



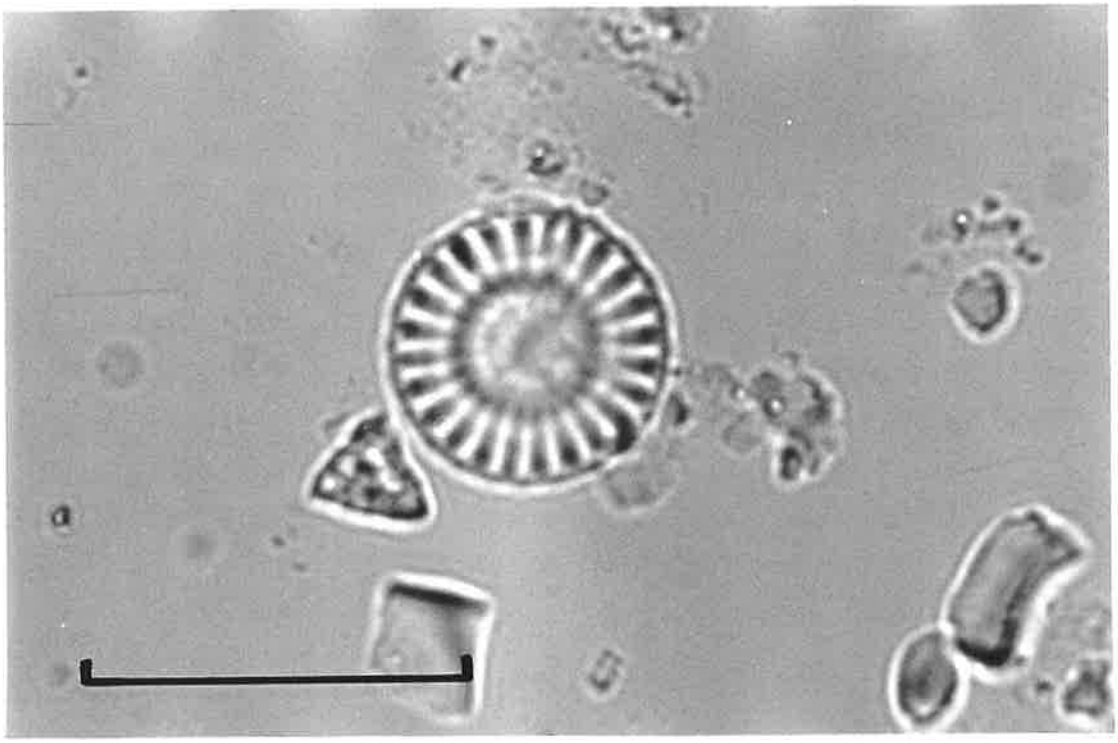
Caloneis silicula



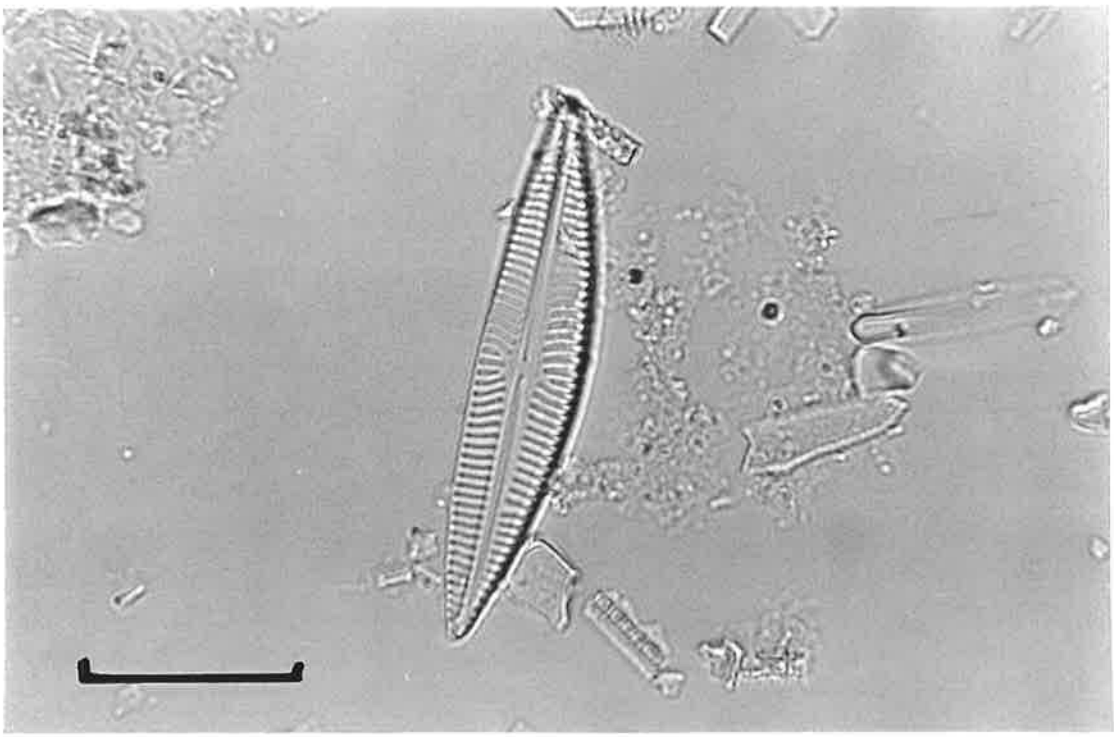
Cocconeis placentula

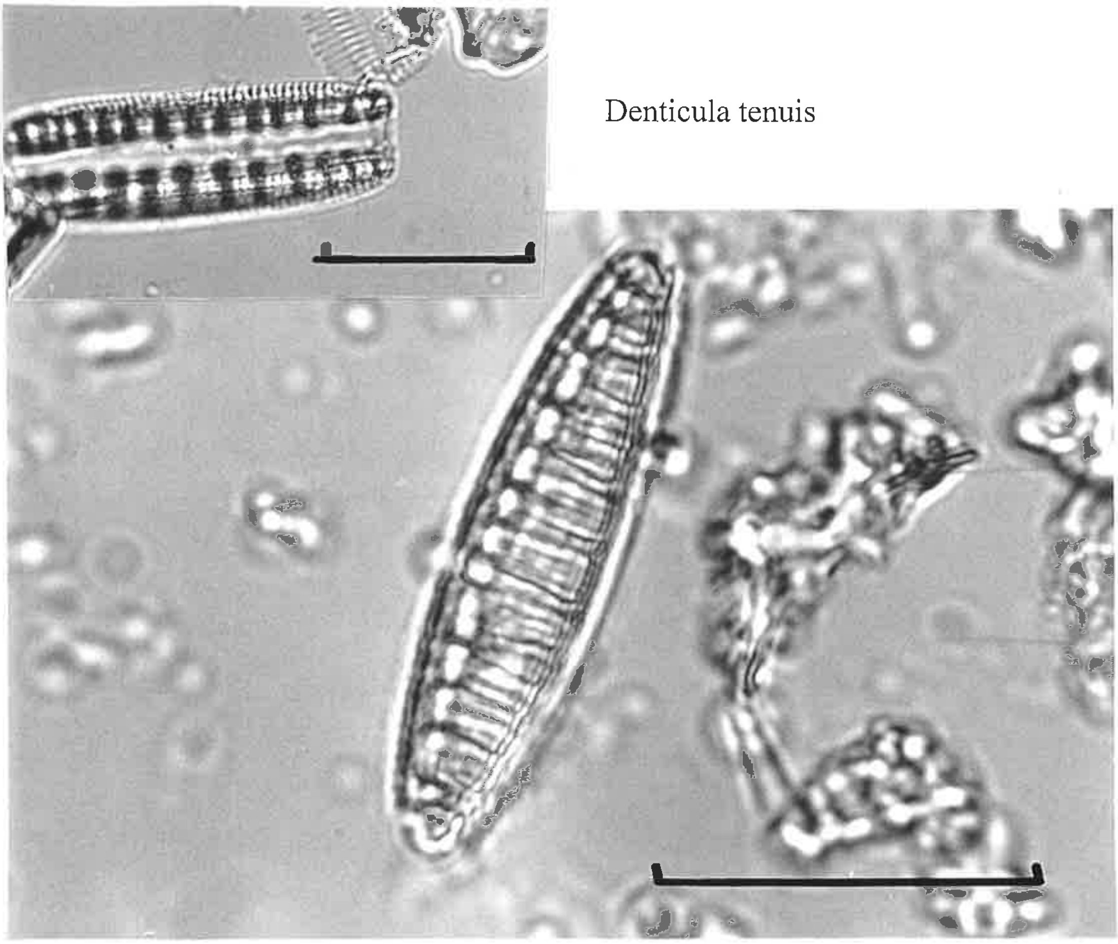


Cyclotella meneghiniana



Cymbella pusilla

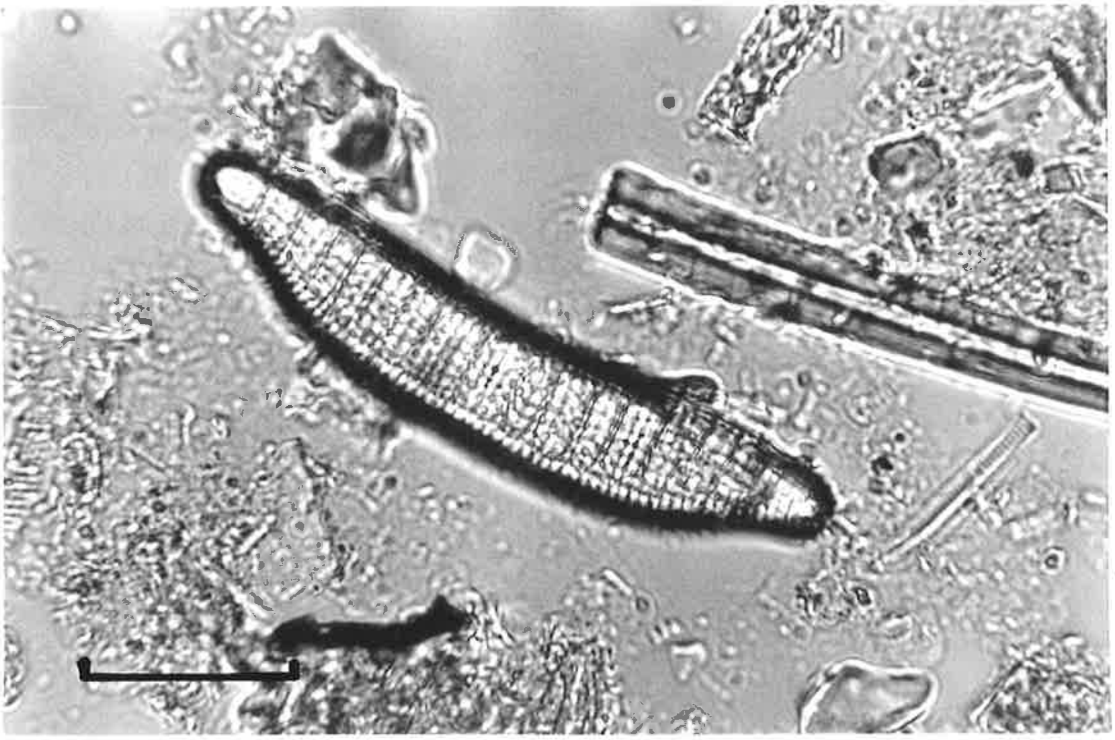




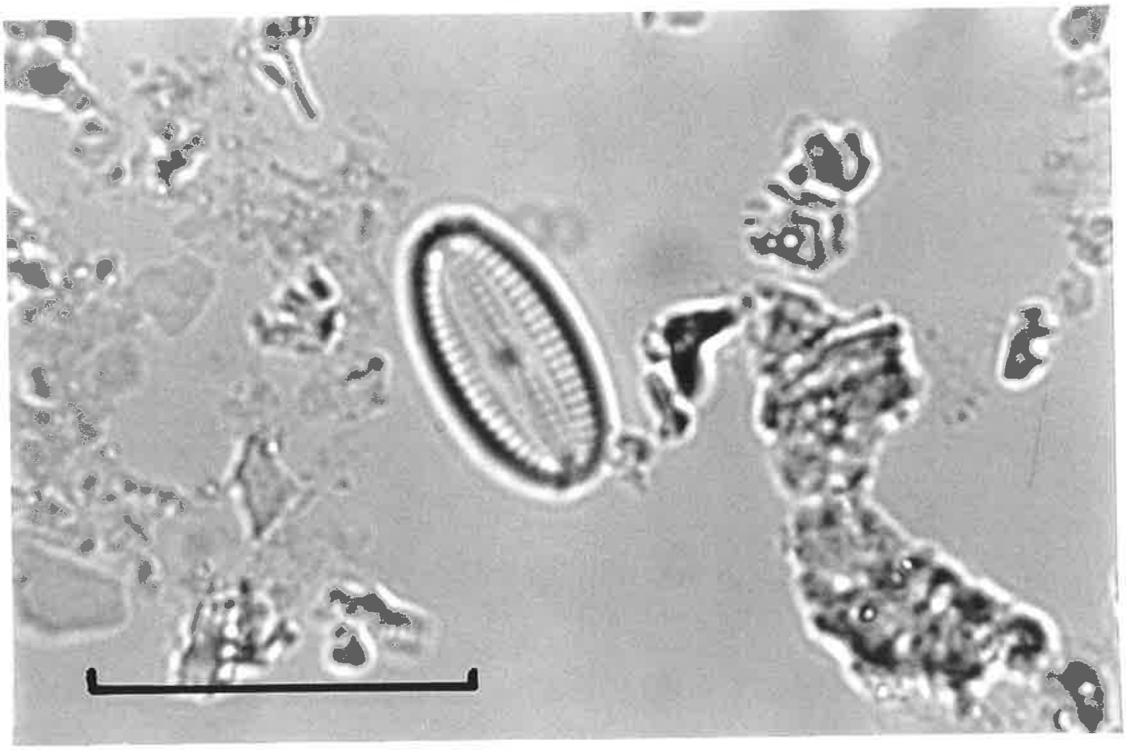
Denticula tenuis

Diploneis smithi

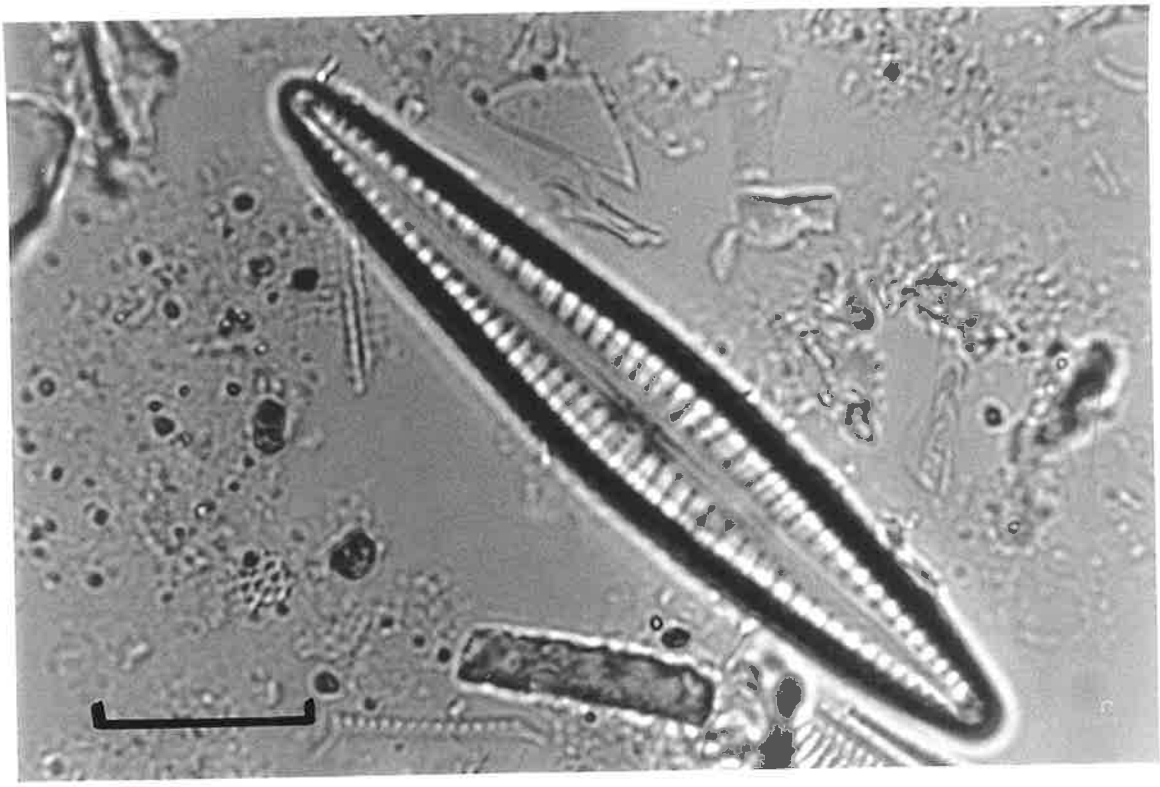
Epithemia adnata



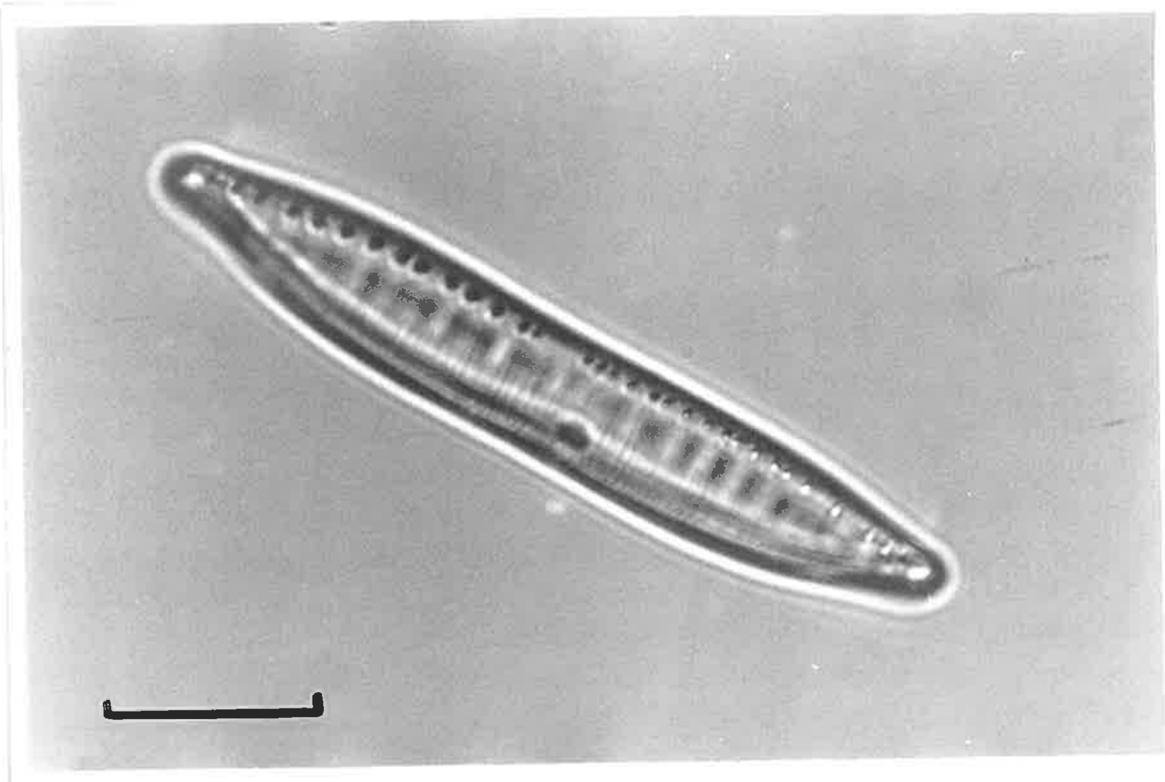
Fallacia tenera



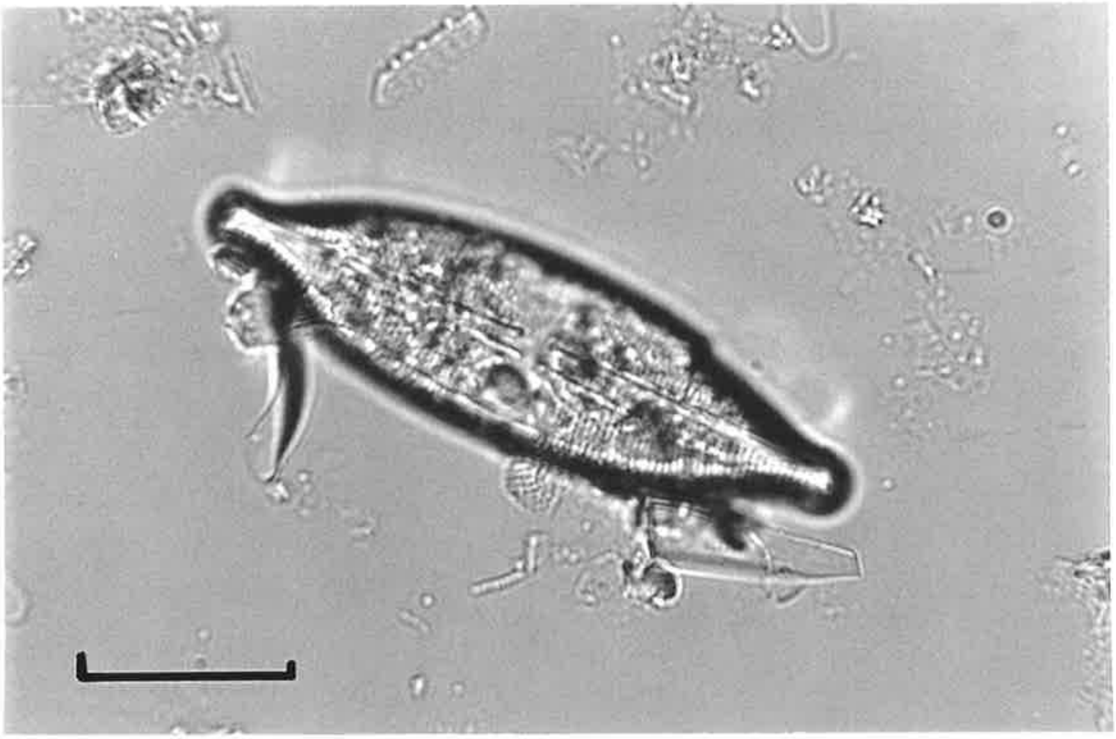
Gomphonema gracile



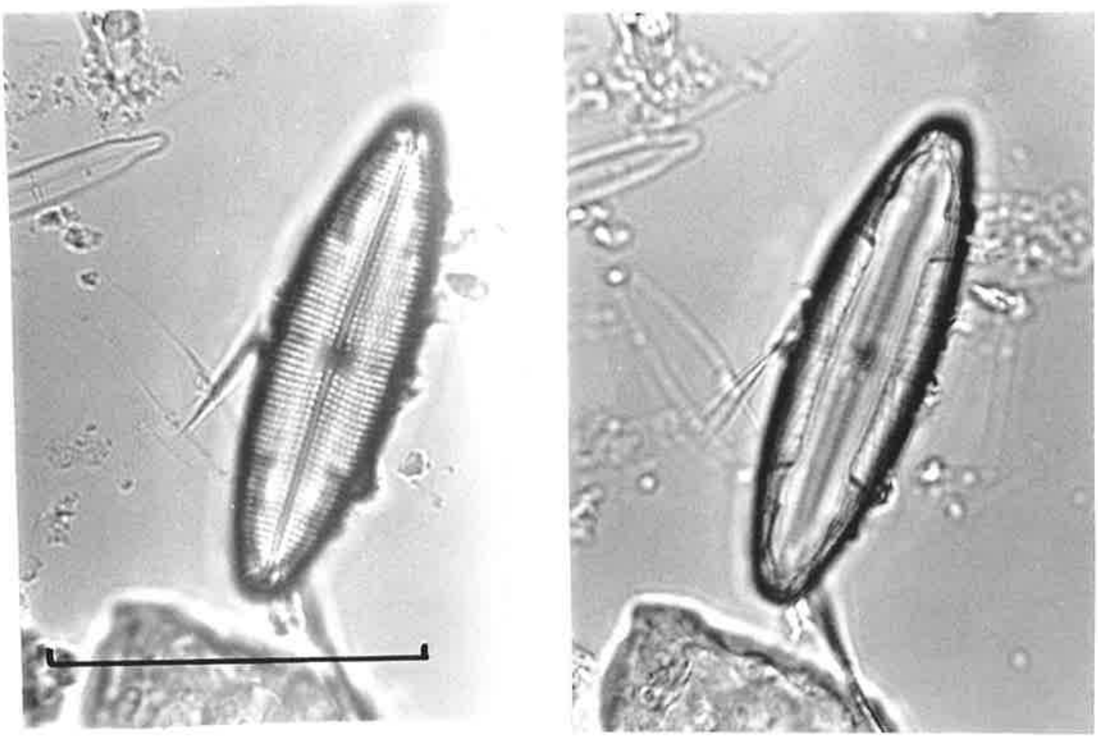
Hanzschia amphioxys



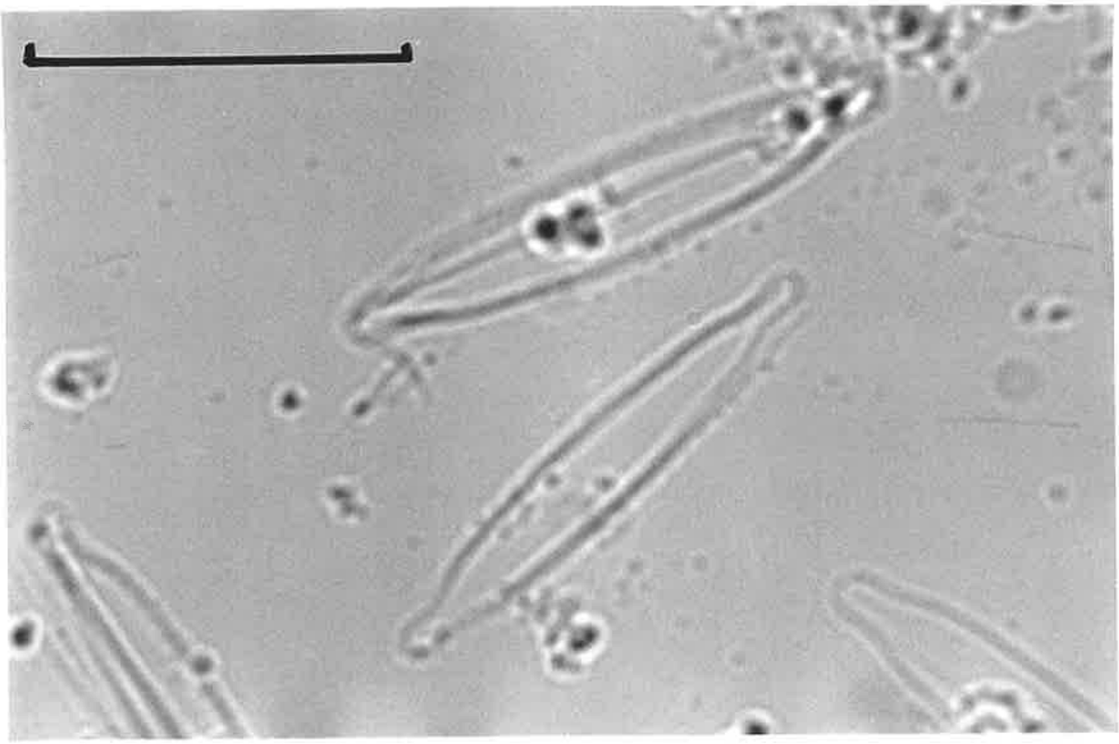
Mastogloia baltica

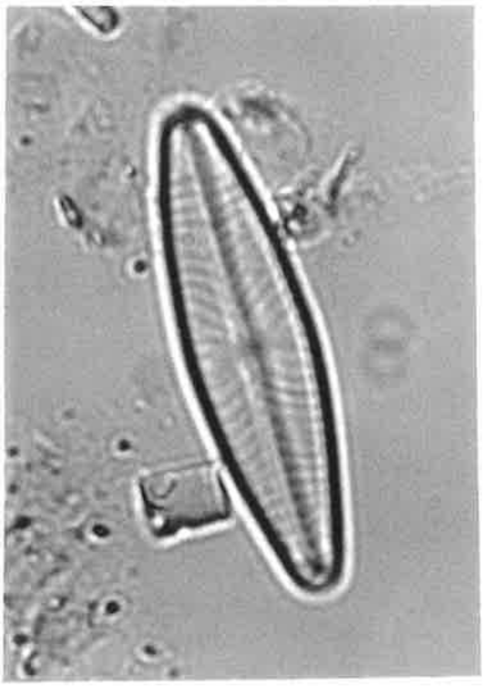


Mastogloia smithi



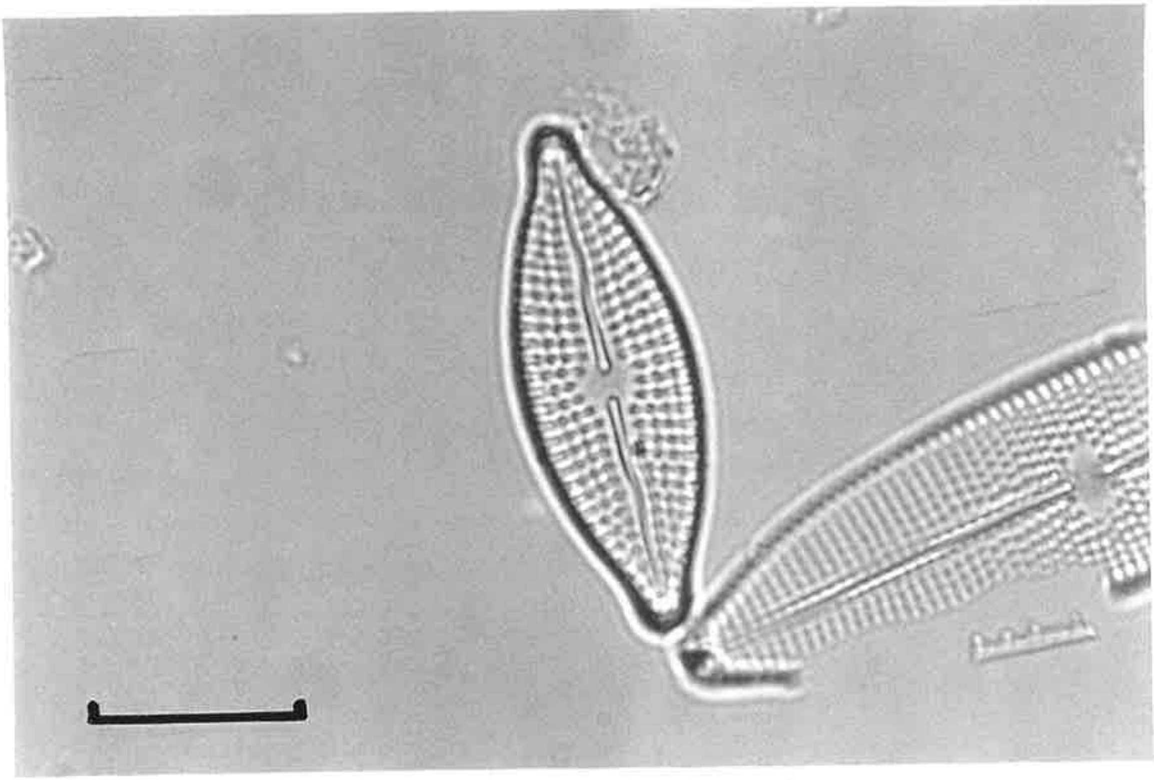
Navicula bulnheimii



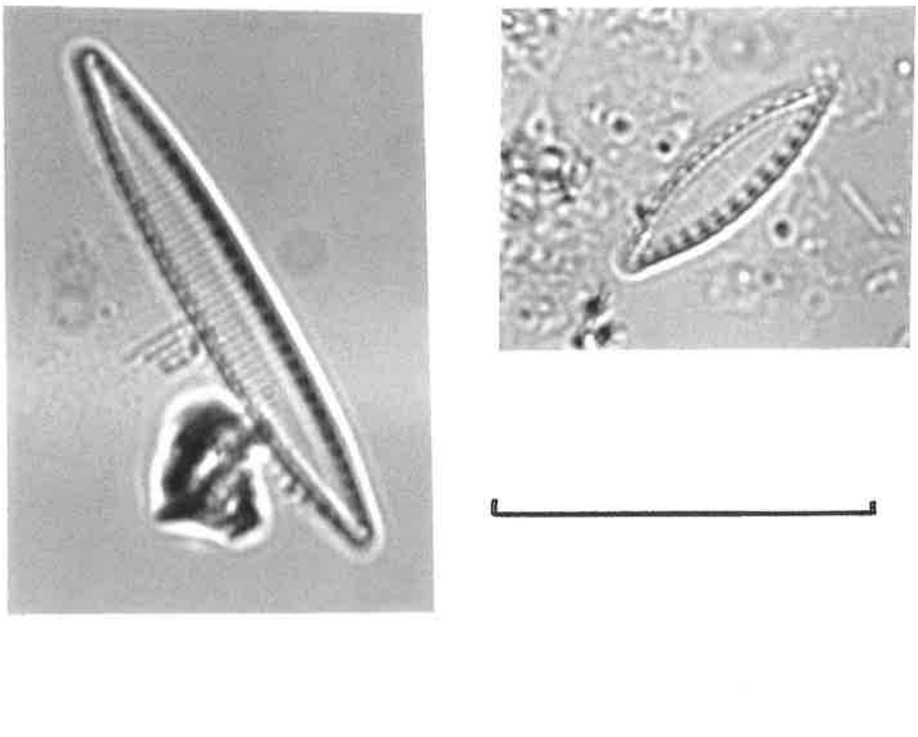


Navicula cincta forma minuta

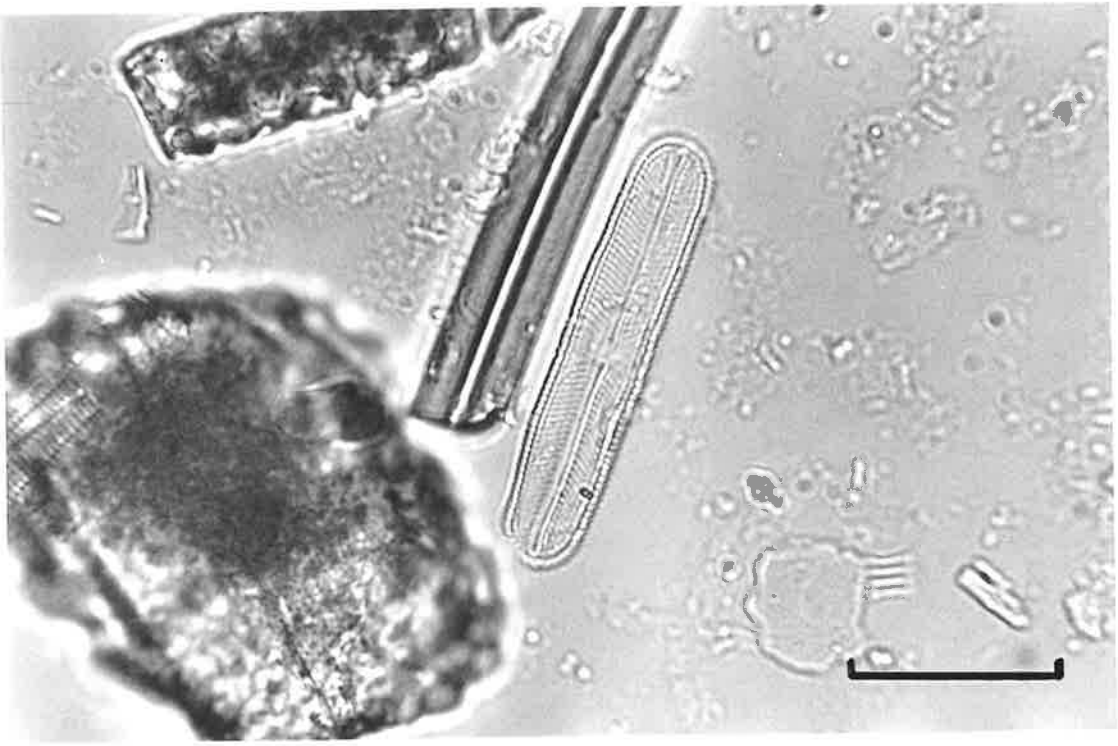
Navicula tuscula



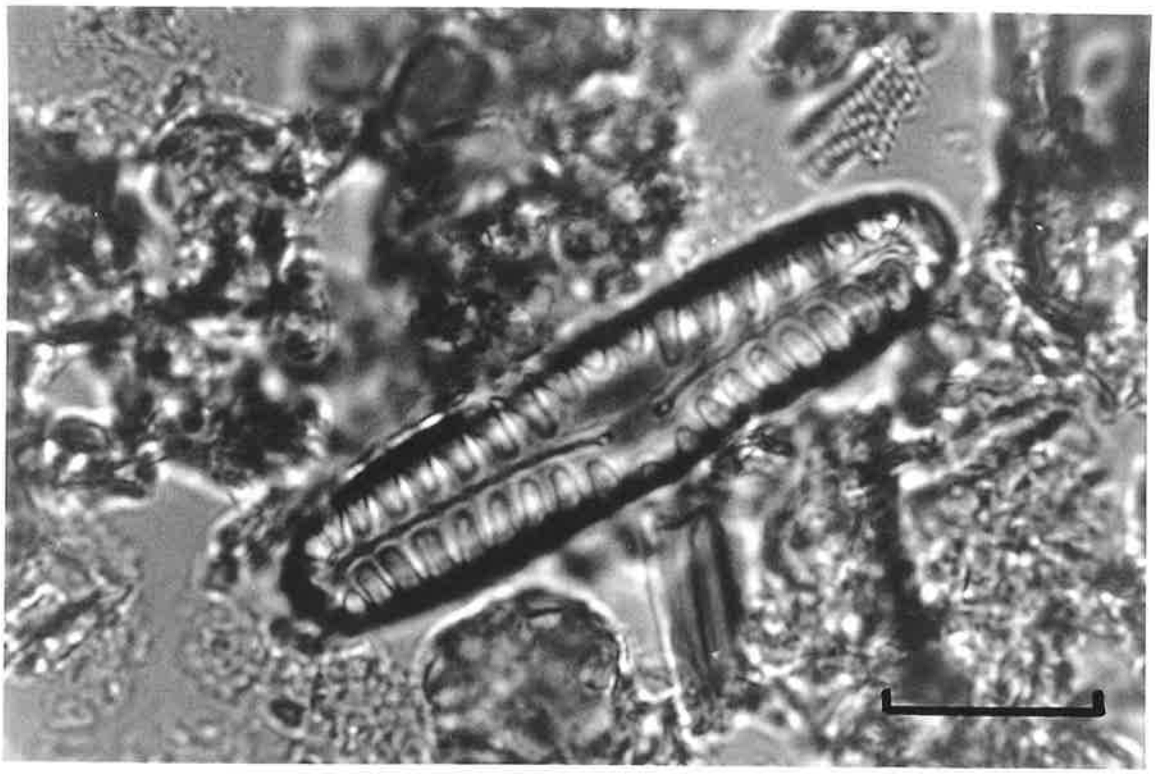
Nitzschia liebetruthii



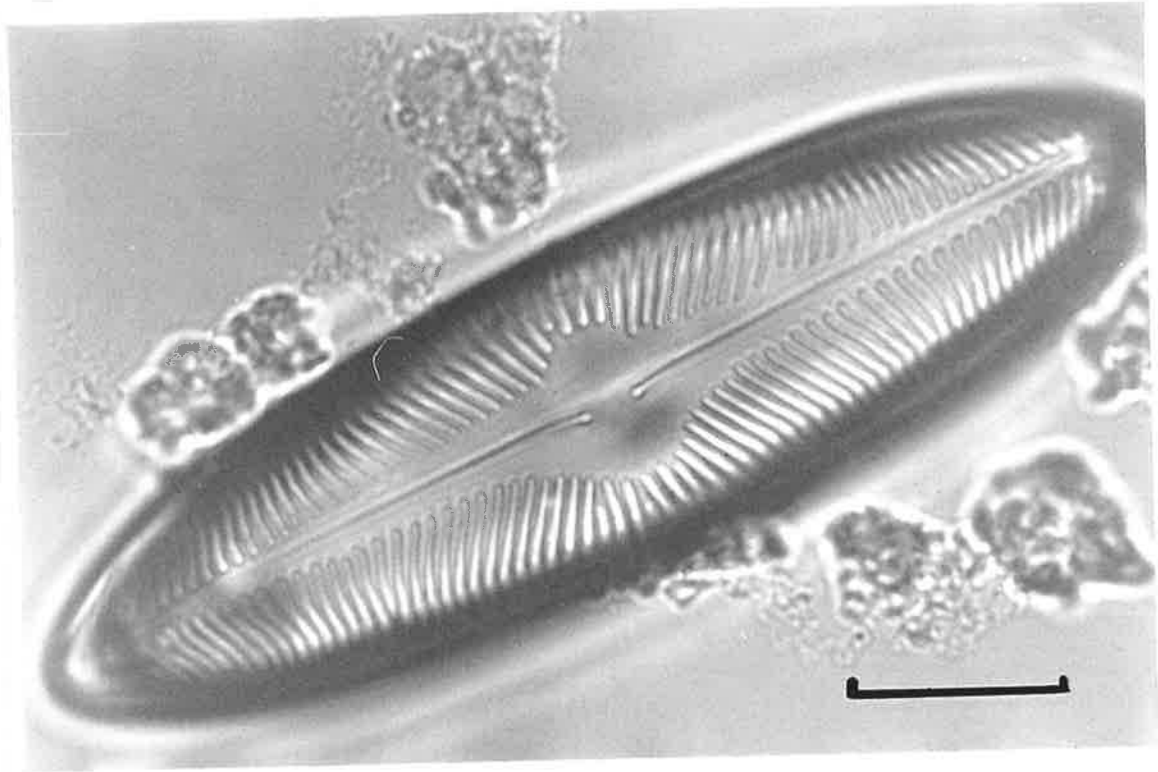
Pallacia pupula



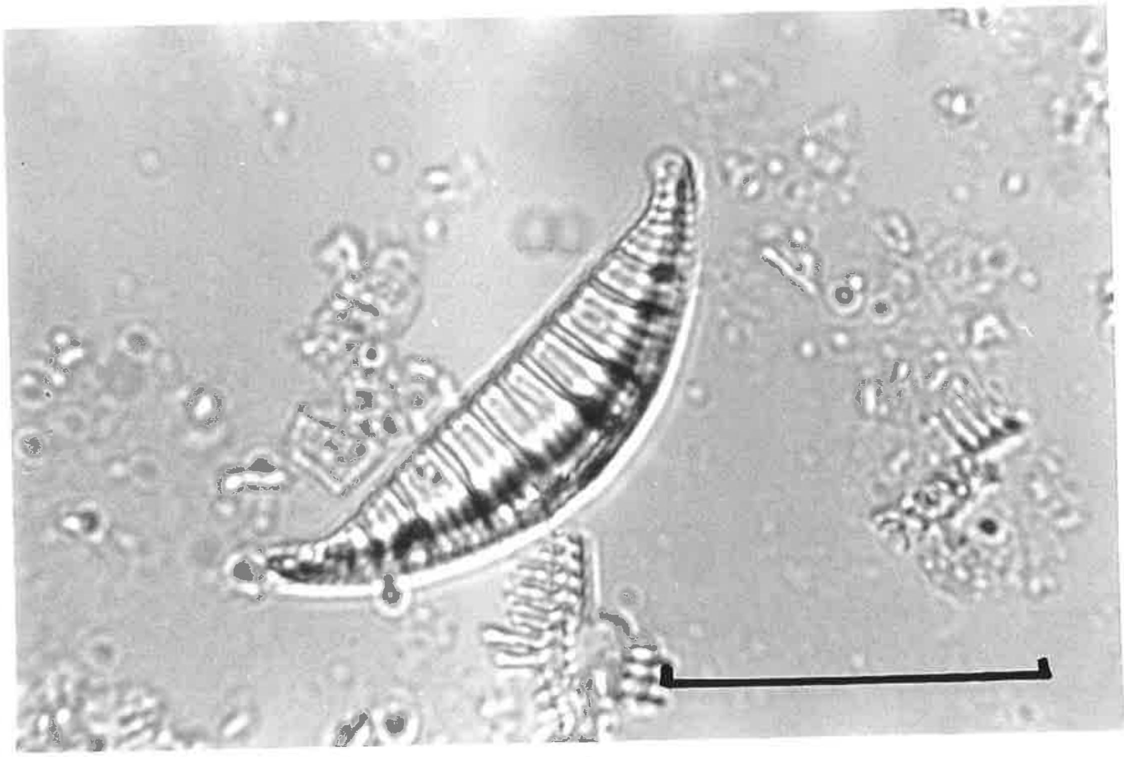
Pinnularia borealis



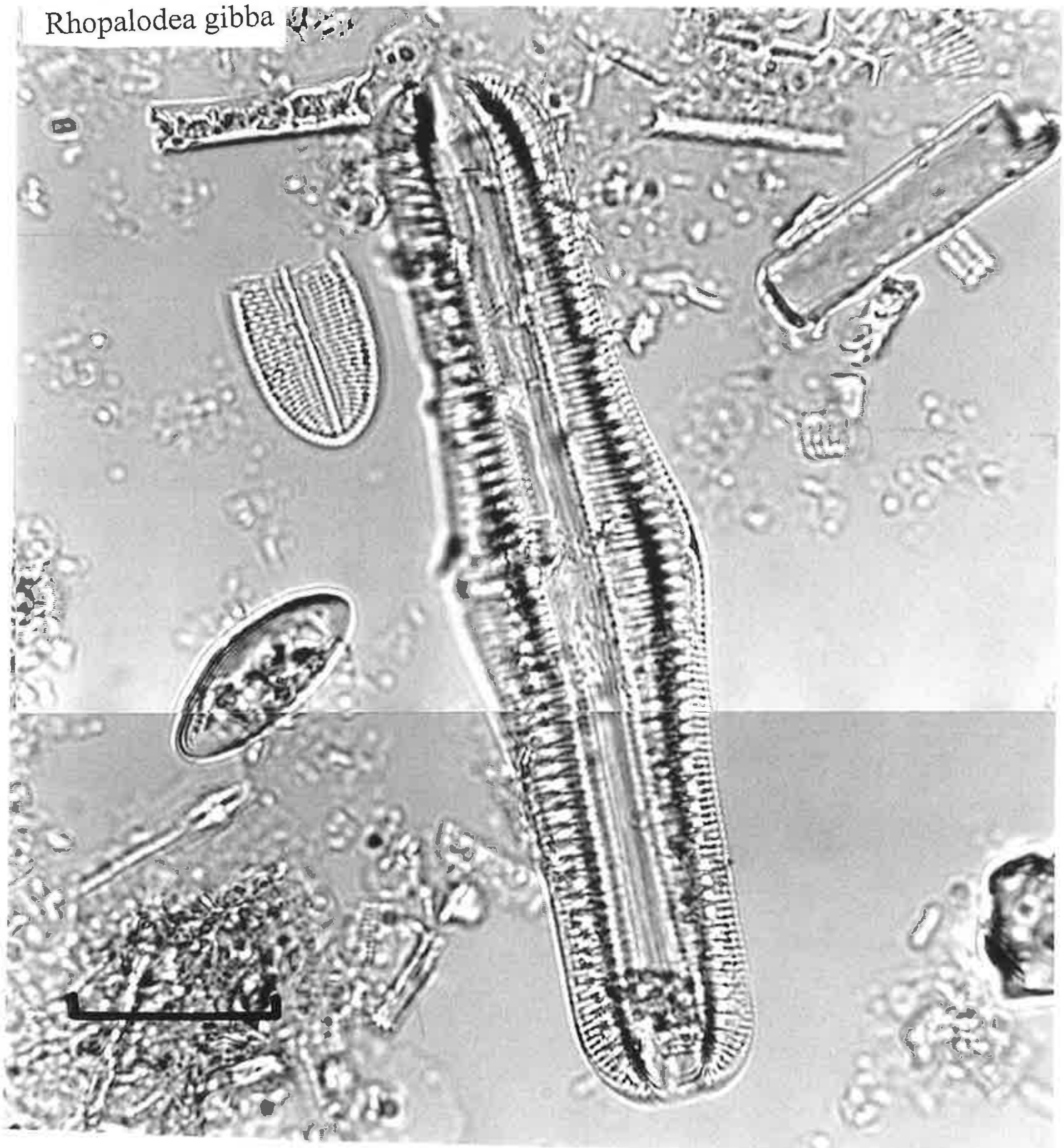
Pinnularia elegans



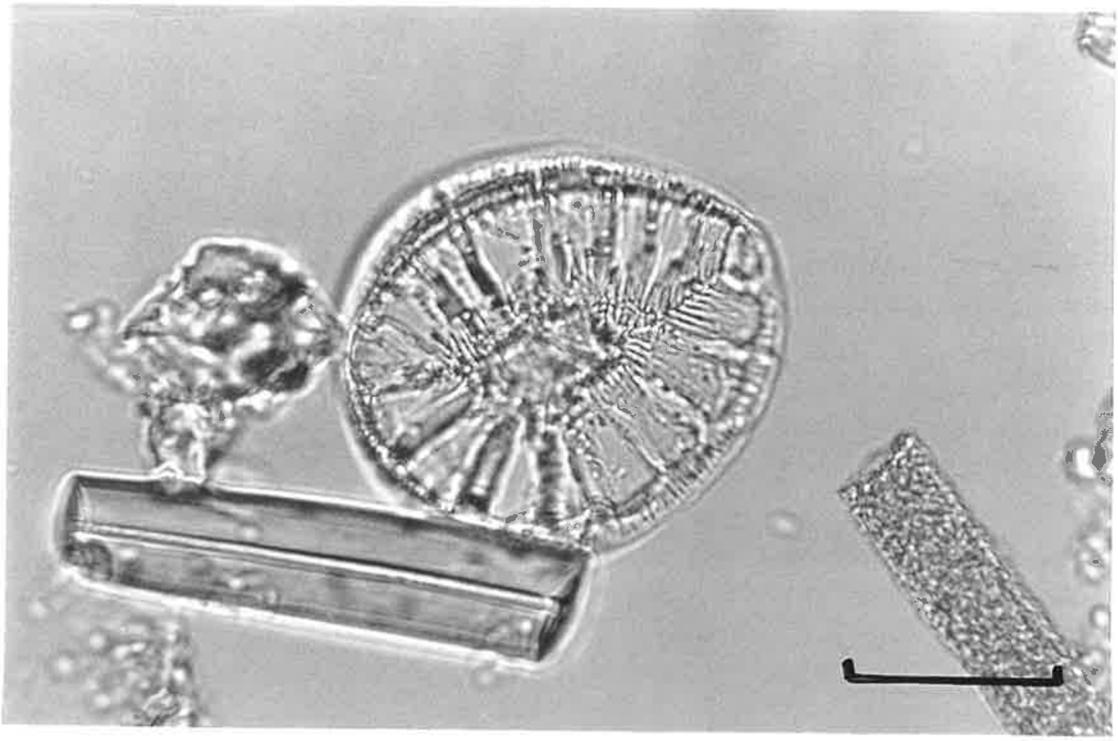
Rhopalodea brebissoni



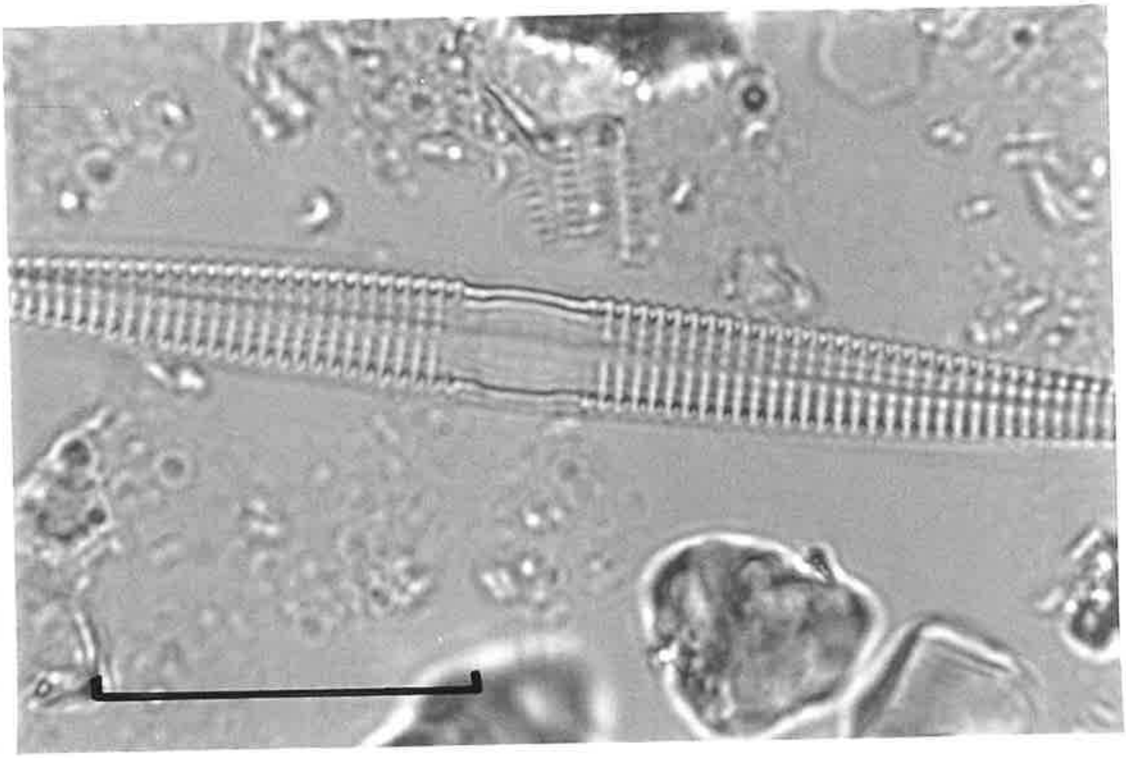
Rhopalodea gibba



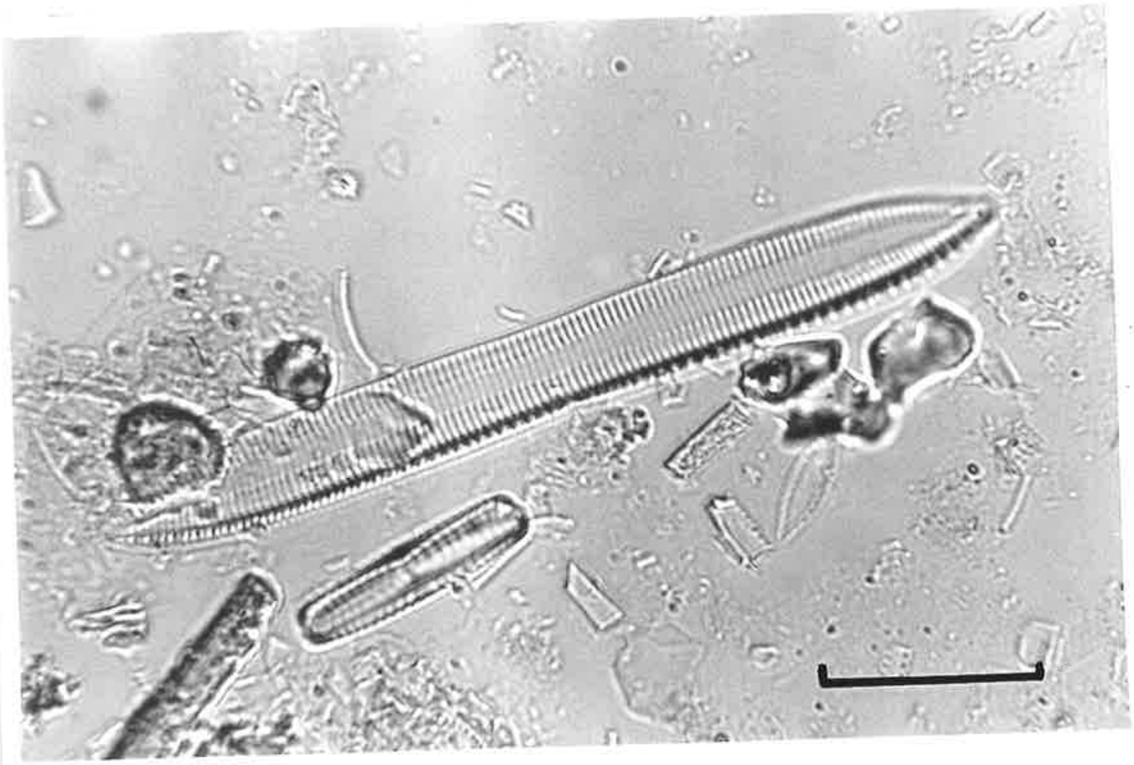
Surirella brebissonii



Synedra pulchella



Tryblionella hungarica



10.2: Methods Used in the Analysis of Reconnaissance Samples

As described in chapter 4, many palaeoecological methods attempted on recconaissance core samples could not be successfully applied to the Upper South East sediments. The purpose and methods of these procedures are described below.

10.21 Pollen Analysis

It was anticipated that pollen in the surface layers of sediment would be preserved, and would indicate the period of European settlement. Unfortunately, pollen were degraded severely by the alkaline soil, and selective preservation of the more robust specimens was occurring. Pollen analysis was conducted at the pollen laboratory of the Division of Archaeology and Natural History, Australian National University. The amount of pollen in a select sample was observed after each processing step to ensure that pollen was not being destroyed or removed from the sample, which it was not. The pollen record was therefore considered an unreliable fossil record, and was not utilised as a palaeoecological procedure. The procedure of Atkin (1994) was followed in the reconnaissance samples.

1. Seven grams of fresh sediment was transferred to a glass beaker.
2. The sample was treated with 10% hydrochloric acid (HCl). This procedure removed carbonates from the sediments. HCl was continually added and left until all bubbling ended.
3. The sample was then treated with 40 % hydrofluoric acid (HF) which was left cold overnight. This process removed silicates from the sample including fine clays.
4. The sample was treated again with 10 % HCl, this time in a hot water bath, for ten minutes. This treatment was conducted after the HF treatment to keep the dissolved silicates in solution, so they could be thrown out.

5. The sample was treated in 10 % potassium hydroxide (KOH) solution in a hot water bath for a maximum period of 20 minutes. This step removed lignited and humic acids. The KOH was washed out immediately after treatment as pollen grains degrade in an alkali environment.
6. Samples were sieved through a 180 micron sieve. This sieves out coarse sand and large organic particles. The particles were washed through the sieve with a fine nozzle water bottle until approximately 50 mls of solution was contained in a conical flask. The contents of the conical flask were poured back into the 50 ml plastic centrifuge tube.
7. Before acetolysis the sample was dehydrated with glacial acetic acid as the acetolysis mix is extremely reactive with water. This pretreatment consisted of a wash or two with glacial acetic acid followed by centrifuging.
8. The sample was treated with approximately 0.1 mls of acetolysis for 1 to 10 minutes in a hot water bath (depending on the sample). This strong oxidation reaction removed organic material, coloured the pollen and removed the inside of the grain which made identification easier.
9. After acetolysis the sample was washed again, twice, in glacial acetic acid.
10. The sample was washed twice in absolute ethanol to dehydrate the sample.
11. The sample was washed twice in tertiary butyl alcohol (T.B.A.). This is miscible with silicone oil, but not water or ethanol.
12. The pollen were transferred from the centrifuge tube to a vial using T.B.A. The tube was centrifuged and the T.B.A poured off.. A measured amount of silicone oil was added with a syringe (0.2 mls). The sample was stood in the drying oven until all the T.B.A. had evaporated off. Once the slide was warmed the cover slip was placed on the sample. When the sample had spread to within about 3 mm of the edge of the coverslip

the edge was touched with molten wax. When the wax had surrounded the sample it was removed from the hotplate and placed on a cool surface until the wax solidified. Excess solid wax was wiped off with a spatula and the slide cleaned using petroleum spirit.

10.22 Ostracod Analysis

Ostracods are normally preserved very well in lake sediments if there is a sufficient concentration of alkaline earth elements present to prevent the decomposition of the calcareous part of the carapace. Unfortunately, they were not preserved in sites of the Upper South East in sufficient numbers to be utilised as palaeoenvironmental evidence of environmental change. Ostracods were extracted using the method of Löffler (1986) in the reconnaissance samples.

1. A minimum volume of 5 cm^3 of sediment was utilised to obtain a representative figure of ostracod remains, which was transferred to a 50µm filter and carefully washed. For the investigation of appendages an ever smaller mesh size (20µm) was used.
2. The inorganic gyttja were washed frequently, until only the remains of organisms were left. The residue was investigated under a binocular microscope with reflected light.

10.23 Cladocera Analysis

Chydorids are organisms that mainly live in the littoral zone of lakes, but their exoskeletal remains are transported offshore and deposited in deep water lake sediments. The relative abundance of chydorid skeletons are a good descriptor of the overall community in a lake, at that point in time. They are most useful in indicating past conditions and in helping to provide insight into the response of aquatic ecosystems to external changes in climate and watershed processes. Cladocera remains were not found in the sediments of the Upper South East lakes, perhaps because the salinity of the surface water was too high. The method of Ogden (1996) was followed for the reconnaissance samples.

1. 1 cm^3 of fresh sediment was washed in 100 ml of 10% KOH in a 250 ml beaker. The solution was heated, with gentle agitation, at temperatures below boiling until the sediment was completely deflocculated (approximately 30 minutes).

2. The sample was spun in a centrifuge, the supernatant decanted, then resuspended in distilled water to remove the KOH, spun down again and decanted.

3. The sample was then washed in HCl, which was added very slowly as the cladoceran remains are easily damaged.

4. The material was transferred to a plastic beaker, HF added, and left cold overnight.

5. If coarse mineral matter was still present the sample was sieved through a 0.5 mm screen

6. A couple of drops of formalin were added to discourage bacterial growth to the final residue, and then the sample was mounted on a slide using silicone oil.

10.24 Chironomid Analysis

Chironomids are of special interest in palaeolimnology because their larval head capsules are preserved in the sediment and the chironomid faunas of former lake stages can be reconstructed using the head capsules as evidence. Chironomids were also not found in the sediments of the Upper South East lakes. In reconnaissance samples an attempt to extract chironomid remains was made using the method of Hofman (1986).

1. A sample of 5 to 10g was used, and was placed in 10% KOH in a hot water bath to achieve deflocculation.

3. 10 % HCl was added to the sample to gently dissolve carbonates.

4. The sample was sieved through a 200 μm sieve, retaining both fractions.

5. The sample greater then 200μm was examined under a microscope at 20X and the head capsules counted and preserved if found.

6. The sample less than 200μm was examined at 30X to examine the smaller head capsules.

10.25 Trace Element Analysis

Reconnaissance sediment samples were processed by AMDEL Industrial Services (South Australia) for analysis of copper and cadmium content. It was expected that these compounds would indicate the period of European settlement as these were added as trace element and superphosphate additions to agricultural land. Unfortunately, it appeared that copper and cadmium were affected by the widely fluctuating water table in the soil column and showed no patterns relevant to the environmental history of the region.

10.26 Sediment Size analysis.

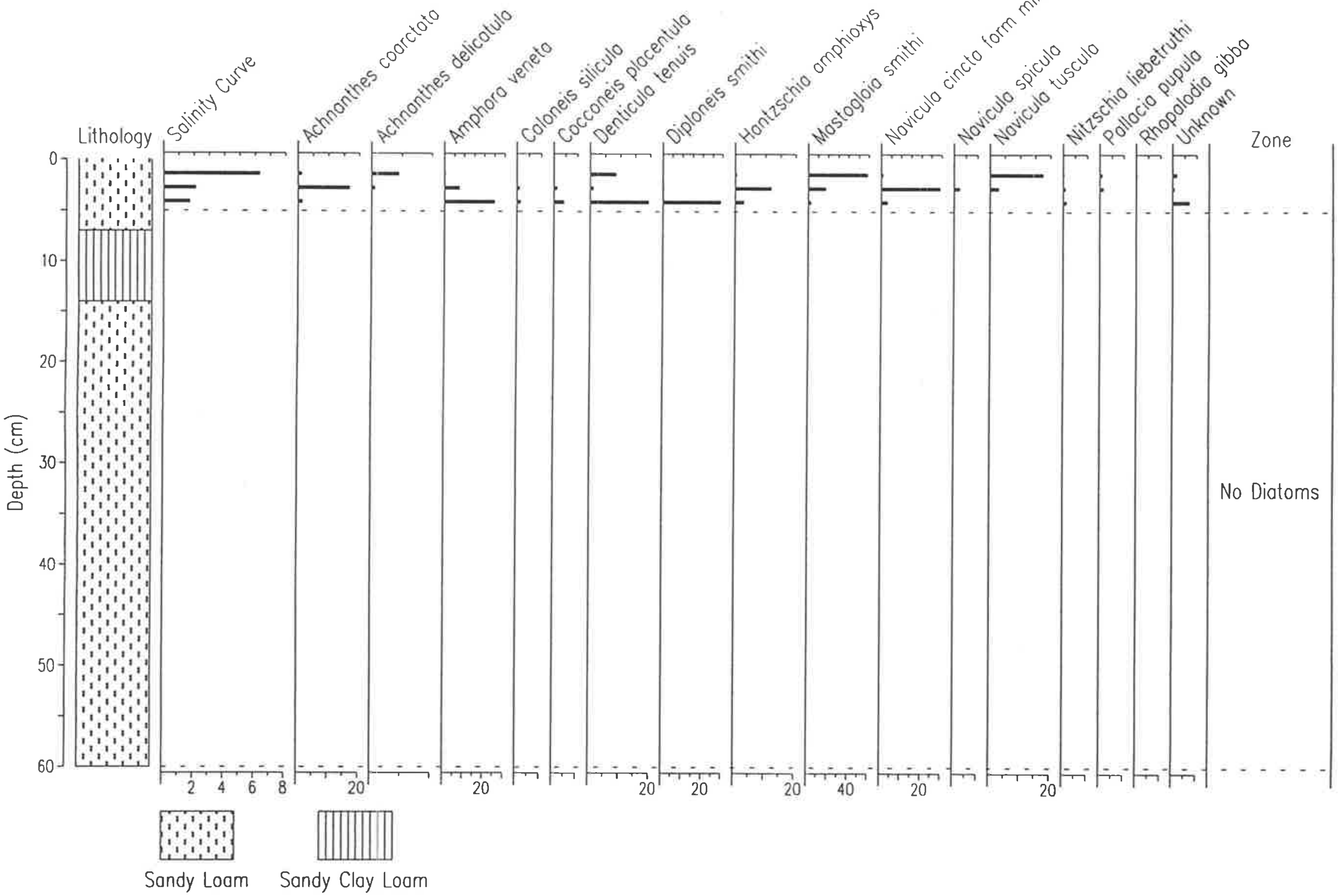
Both dry sieving and a hydrometer method were used to gain information on sediment size parameters. Dry sieving was conducted with a sieve shaker and sieve set composed of a 63μm, 125 μm, 250 μm, 1 mm and 2 mm size sieves. A 200 gram sediment sample was first oven dried and desegregated then placed in the top sieve (2 mm) and the sample left to "shake" for 10 minutes. At the completion of the sample time the sample remaining in each sieve was weighed. The sieve set was carefully cleaned before the next run.

The hydrometer method, devised by Bouyoucos (1926, 1927, 1928 and 1953) and improved by Day (1950 and 1953), was used to further distinguish size classes in the sample less than 63μm. The hydrometer method is based on the premise that particles of different size will settle from suspension at predictable rates. The density of the sediment-water solution was measured at intervals and the progressive decrease in density correlated with the size fractions that have settled past the measuring depth in the intervening times. The method used was outlined by Lewis (1984).

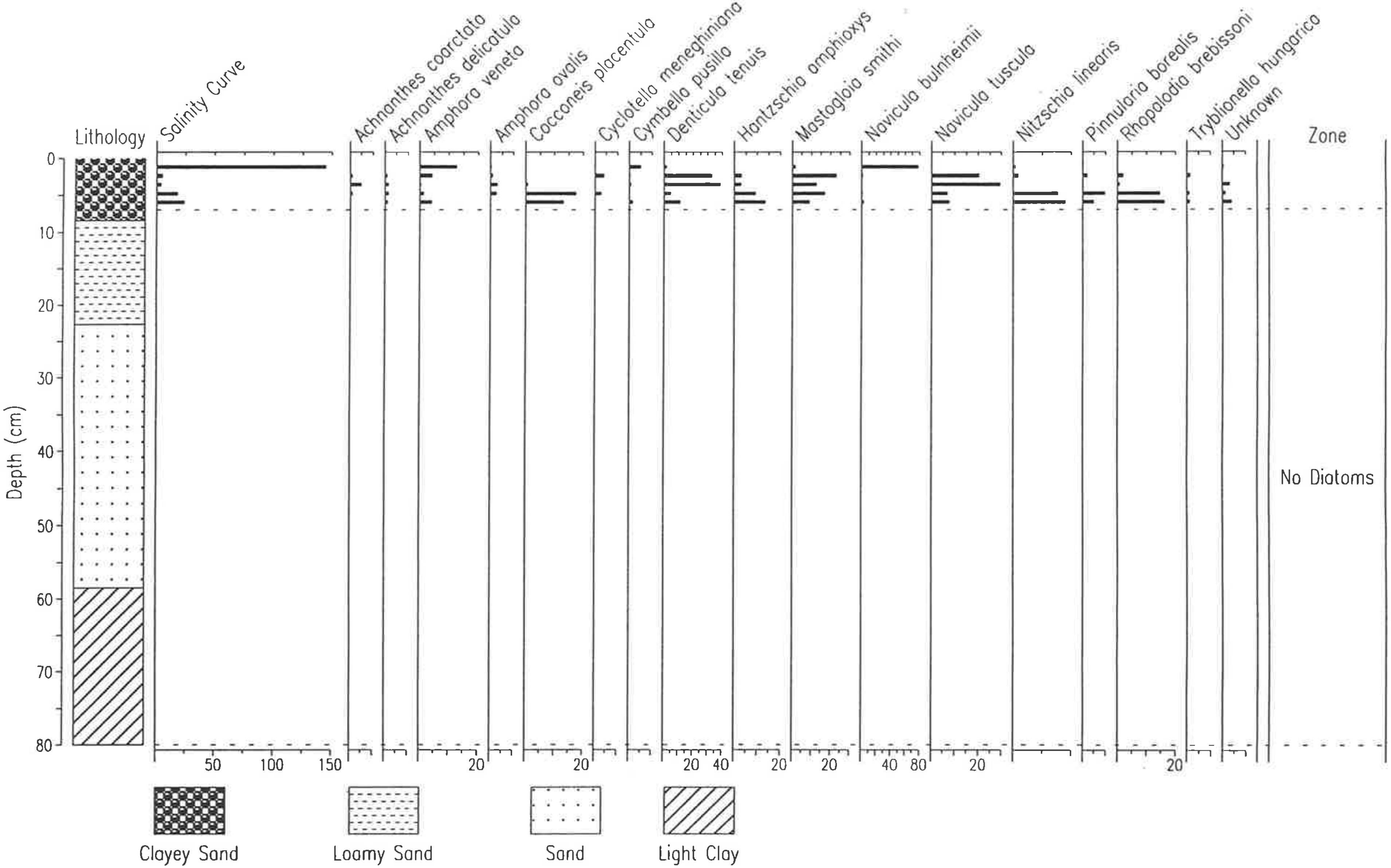
Sediment size analysis of the Upper South East sediments did not provide useful information of the environmental history of the region because the sediment rate was too low to provide sufficient resolution of events occurring in the sampled wetlands.

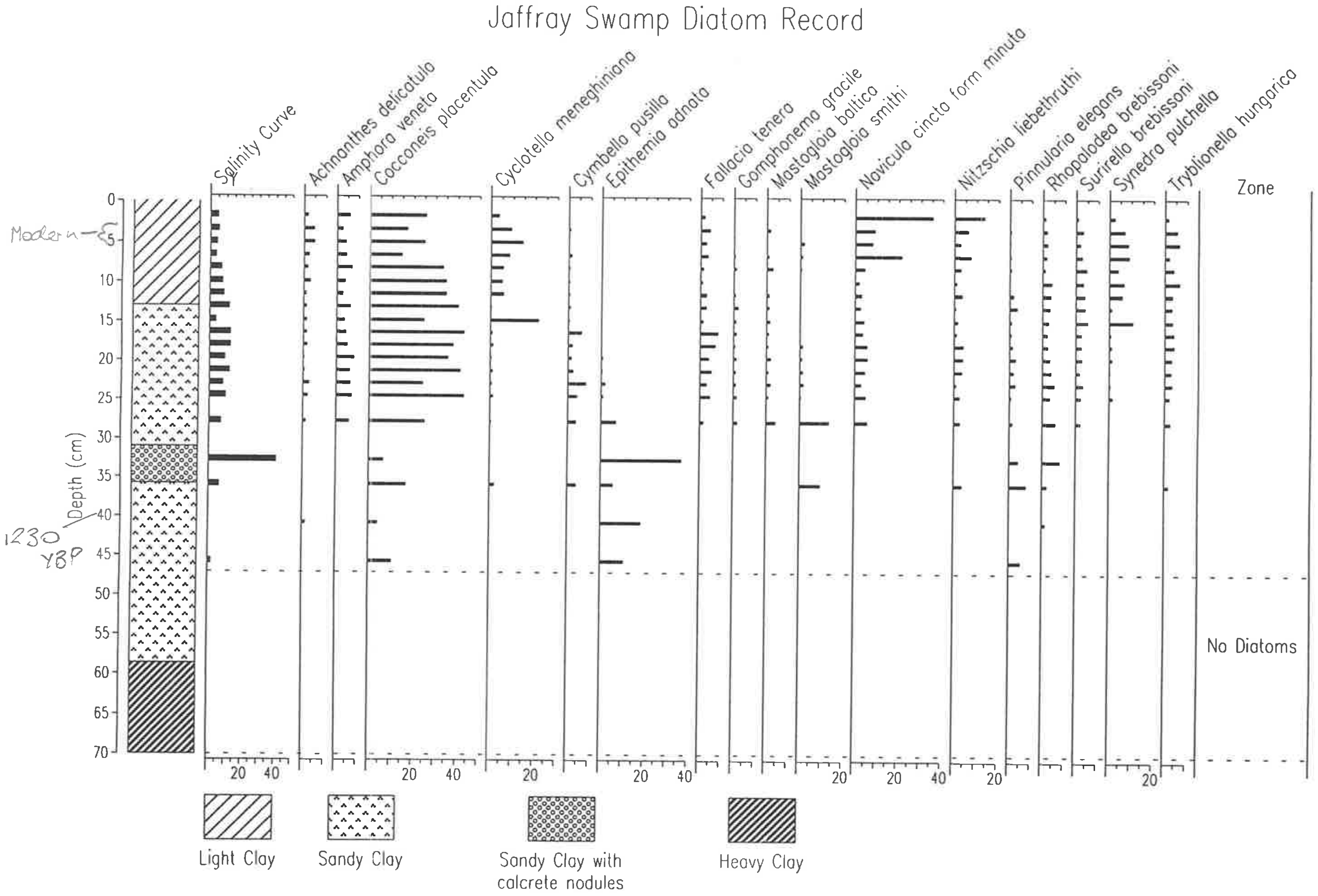
10.3: Diatom Records Of Study Sites Of The Upper South East

Reedy Lake Diatom Record



Cortina Lakes North Lagoon Diatom Record




Jaffray Swamp Diatom Record
Salinity Curve
Achnanthes delicatula
Amphora veneta
Cocconeis placentula
Cyclotella meneghiniana
Cymbella pusilla
Epithemia adnata
Fallacia tenera
Gomphonema gracile
Mastogloia baltica
Mastogloia smithi
Navicula cincta form minuta
Nitzschia liebethruthi
Pinnularia elegans
Rhopalodea brebissoni
Surirella brebissoni
Synedra pulchella
Trybionella hungarica
Zone
No Diatoms
Depth (cm)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
20
40
Modern
1230 YBP
Light Clay
Sandy Clay
Sandy Clay with calcrete nodules
Heavy Clay