Pipe Dreams:

The Mannum-Adelaide Pipeline and its effects on the aquatic environment of the Upper River Torrens Catchment, South Australia.

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ABSTRACT

In order to assess nutrient and sediment pollution in the upper River Torrens catchment a palaeoenvironmental investigation from sediments in Gumeracha Weir was undertaken. The geochemistry of core samples from Gumeracha Weir, was compared to suspended sediment samples taken from tributaries upstream of the weir, samples of Murray River water and also from sites with various land use types scattered throughout the upper River Torrens catchment.

Sediment accumulation rates in the Gumeracha Weir appear to have increased in the last 50 years. A major source of sediments in Gumeracha Weir is the River Murray, via water being diverted into the river through the Mannum-Adelaide pipeline. A second important source, associated with high silica sediments deposited in high energy flows, originated from in the Torrens catchment. No single type of land use, (eg roads or pasture) could be identified as the source of these sediments.

Through diatom analysis a history of changes in water chemistry was also established. The results indicating that there has been a significant increase in pH from approximately pH 7.6 units in samples pre-pipeline to an average of pH 8.4 units at present. The decline in *Rhicosphenia abbrevata* indicates that turbidity has also increased markedly since the commencement of River Murray water input.

It was therefore determined that the divergence of River Murray water into the upper River Torrens catchment has consequently added to an increase in both sediment and nutrient concentrations of the River Torrens.

DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by any other person, except where due reference has been made in the text.

I give my consent to my dissertation being available for photocopying and loan.

Signed: [signature] **Date:** 12th November, 2004

ACKNOWLEDGMENTS

I guess this is my version of an Oscar's speech. So firstly I'd like to thank God and The Academy. But seriously there are many people without whom this thesis would not have been achieved.

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CHAPTER 1 INTRODUCTION

1.1 Australian Rivers as Lifelines

Rivers are a critical lifeline of the Australian natural and social landscape. Many of our most productive wetland and estuarine ecosystems are dependent on the provision of freshwater and nutrients delivered by rivers. Many people are dependent on rivers to supply them with water for a range of purposes including for drinking, irrigating, and recreational activities. Our dependence however, is also the reason why many of Australia's rivers are now in a state of disrepair. It is for this reason that the health of Australian rivers needs to be given high priority,

The "State of the Environment 2001" report (SoEC, 2001) indicated that the conditions of Australian river systems are deteriorating while pressure is increasing. Two of the main factors that have been attributed to these declining conditions are the increase of nutrients and sediments into waterways. Cyanobacterial or "blue green algal" blooms are one of the greatest concerns for water quality as they frequently produce toxins that are harmful to both humans and animals and also negatively impacts upon the native aquatic flora and fauna of river systems (SoEC, 2001). One of the main reasons for these concerns is that the problem is so wide spread, it is suggested that all bar a very few river systems in the Murray-Darling Basin have high enough nutrient levels to support algal blooms (SoEC, 2001). Suspended sediments which contribute nutrients to Australian streams also increase turbidity which, on the one hand can suppress a variety of autotrophic organisms, while competitively advantaging cyanobacteria with the ability to regulate their buoyancy (SoEC, 2001).

1.2 The River Torrens

The River Torrens in South Australia is faces similar problems to other Australian river systems (Schultz et al., 2000). Concerns over the health of the River Torrens due to recent cyanobacterial blooms has lead to the realisation that the River Torrens, and the water resource it provides, needs to be managed in a more sustainable manner. The phytplankton growth is associated with excess fluxes of nutrients within the River Torrens, particularly an increase in the concentration of the limiting nutrient phosphorous.

There are a number of programs currently underway for the improvement of the River Torrens. The 'Watercourse Rehabilitation program", one of these initiatives, incorporates on ground works across 94 km of waterways. These works include fencing the riparian zone to exclude stock, the removal of woody weeds and exotic trees, creek bed stabilisation, erosion remediation and revegetation using local provenance indigenous species (Fisher *et al.*, 1999). These initiatives have been taken on in an attempt to limit the flux of nutrients and sediments to the river system. However, they are limited in their success as, at present there is considerable speculation as to the source of these nutrients and sediments. This is a concern that in management programmes such as this as, while improvements may be gained, that key sources of the problem may be overlooked and therefore remain unaddressed.

One potential source that is not a main focus at present is the inputs of River Murray water into the River Torrens catchment via the Mannum to Adelaide pipeline (see for example, Schultz et al., 2000). River Murray water has very high nutrient and fine suspended sediment loads, which, among other things, may be causing the River Torrens to become more turbid and eutrophic.

Through the study of sediments within the River Torrens it is believed a greater understanding can be gained of the origin of nutrients and sediments in the river system. Armed with this knowledge a more appropriate and successful management approach can be taken to rectify the River's health.

1.3 Biomonitoring

The short instrumental record and the unreliability and incomplete nature of anecdotal evidence means that the documentation of environmental change within our catchments is a challenging task. The recent emphasis on chemical and biological monitoring of waterways has enabled the Commonwealth of Australia (SoEC, 2001) to assess the national trends from 1996 to 2001. However, it is clear that much of the impact of modern people on rivers and lakes began early in the settlement period, well before appropriate instrumentation. As such, the SoEC's observations only provide a brief snapshot of change and provide little in terms of understanding natural condition or variability. One approach that can remedy the pioneer community's lack of foresight and facilities is palaeoecology. Contained in sediment sequences are 'fossils' of the chemical and biological indicators widely used in modern monitoring protocols. The integration of the modern and fossil lines of evidence offers a unique capacity to understand change and the true impact of our activities on natural river systems.

1.4 Aims and Objectives

This study will examine a sediment sequence from the uppermost reservoir in the River Torrens, Gumeracha Weir. This contains sediment that has accumulated before and after the commencement of the operation of the Mannum-Adelaide pipeline (1954) and should therefore reveal changes to the Rivers condition as a result of River Murray water input. The establishment of a chronology for a core extracted from Gumeracha Weir will provide a time line within the sediments to enable them to be correlated with recorded events in the River Torrens system.

This palaeolimnological approach will provide a history of the water quality in Gumeracha Weir, through the use of palaeo-indicators, fossil diatoms. Geochemical analysis of the core sediments and those collected within the catchment and from the River Murray, will enable the principal source of the sediments that have accumulated in the weir to be identified.

So, the aims of the project are:

1. to identify the main sources of nutrients and sediments entering the River Torrens
2. to reveal changes in the sediment and nutrient load in the upper River Torrens catchment through time
3. to determine the extent to which nutrients and sediments are impacting upon the health of the river system.

CHAPTER 2 LITERATURE REVIEW

2.1 Aquatic Ecosystem Health

2.1.1 Changes in Aquatic Ecosystems

Aquatic ecosystems are complex and susceptible to change. They are a combination of the interactions between the biota living within them and the physical nature of the aquatic environment, which itself is influenced by the catchment (Boulton and Brock, 1999). Changes in one or more of the characteristics that make up an ecosystem can alter the types of organisms that live within it. These changes range from human-induced alterations in water quality, water flow, sediment and nutrient inputs to natural climatic change. Direct anthropogenic impacts include, for example, the removal of aquatic plants or riparian vegetation. However indirect changes are just as, if not more, capable of impacting upon aquatic ecosystems (Boulton and Brock, 1999). These changes range from land clearance or changes in land use practices, including the removal of vegetation within the catchment, to changes in river flow and the input of nutrients and sediments, through to the import and export of water to or from the catchment. These modifications can be classified as disturbances. The magnitude of disturbance, and the resilience of the system to disturbance, will influence the degree to which aquatic ecosystems are affected.

2.1.2 Riverine ecosystems

Riverine ecosystems can be classified on the basis of photosynthesis: respiration ratios. Heterotrophic systems exist when respiration is greater than photosynthesis, normally due to the system being limited in either nutrients or light. A stream is classified as autotrophic rather than heterotrophic if photosynthesis exceeds respiration. For this to occur there must be adequate light and nutrients in the river ecosystem. The availability of light is often influenced by climate, riparian vegetation and turbidity. Nutrients or energy come from an array of different sources, both natural and anthropogenic. Natural sources include allochthonous, chemical energy produced outside the stream from organic matter, or autochthonous, for example, internal, stream or lake photosynthesis by water plants and algae (Boulton and Brock, 1999). Nutrients can also enter the aquatic ecosystem through other means, these are discussed in more detail below. If the net input of nutrients exceeds the rate to which they are lost, either through deposition, consumption or outflow, then they increase. Ongoing increases in nutrient loads can generate responses within the system, which impact negatively on the system's health (e.g. excessive growth of attached plants and algae, cyanobacterial blooms).

2.2 Processes that degrade Wetland Health

2.2.1 Nutrient Enrichment

There are two main ways excess nutrients can enter a river system, either from 'diffuse sources', or from 'direct' or 'point' sources. The former is where nutrients enter the system either through runoff, infiltration processes or subsurface flow (Boulton and Brock, 1999). The latter, 'point source', is an influx of nutrients coming from specific locations, such as nutrient-rich tributaries, sewage treatment plants, drains or water that has been diverted from another source. One example of this is the Mannum-Adelaide pipeline which diverts nutrient enriched water from the River Murray into the upper reaches of the River Torrens (Davies *et al.*, 1992). A second example is that of the releases from the Bird-in-Hand sewage treatment plant, which are responsible for very high concentrations of nitrate and phosphate in Dawesley Creek, South Australia (Markich and Jefree, 2002).

enormous costly to control. In recent times, there has been an increasing recognition that "native" phosphorus in eroded from gullies and stream banks can be the dominant nutrient source in Australian catchments (Wallbrink *et al.*, 2003; Wallbrink, 2004). In many case, resultant "solutions" revolve around treating symptoms (such as copper sulphate dosing of cyanobacterial blooms) rather than the problem's source.

Two approaches have been suggested for the control of the symptom of algal blooms arising from the eutrophication of reservoirs. The "bottom-up" theory suggests that by controlling nutrient levels, such as phosphorous which can cause water bodies to become eutrophic, the health and equilibrium of aquatic ecosystems can be maintained (OECD, 1986). The difficulties in identifying the sources of nutrients have lead to an increased focus on "top down control" (Matveev, 1998, Matveev and Matveeva, 1997, Matveev *et al.*, 1994). . This is a form of biomanipulation based on the premise that reductions in phytoplankton can be achieved through increase in zooplankton population biomass. Zooplankton, in turn, can be controlled by planktivorous fish who themselves are controlled by changes in the population of predatory fish. Hence, if there are large populations of zooplanktivorous fish, the extent to which zooplankton can control phytoplankton growth, is limited. As a result cyanobacterial outbreaks may occur. The top-down approach observes that if abundances in piscivorous fish are augmented, then, this will control the population size of zooplankton eating fish, which will inturn allow zooplankton numbers to increase, increasing control on phytoplankton biomass (Matveev, 1998, Matveev and Matveeva, 1997, Matveev *et al.*, 1994). This idea, while theoretically simple, has enormous practically complexity (e.g. success of fish recruitment in often degraded habitats) and is largely unsubstantiated in Australian systems (Harris, 1999).

2.2.2 Sediment and Turbidity

In simple terms, rivers move sediment from upland and deposit them downriver. Three types of sediment loads that are transported along a river. These are dissolved load, suspended load and bedload, each of which is influenced by energy flows, gradients and diversions along the river. Dissolved loads refer to particles that have been dissolved into the water stream and are primarily derived from chemical weathering of rocks within catchment areas. Bedloads are larger particles, sand and gravel and sometimes even rocks or boulders. These particles are carried along the stream's riverbed to a point where the energy flow has decreased to such an extent that these particles can no longer be shifted (Goudie, 2001). The volume of deposited materials, alluvium, is generally greater lower sections of the river (Young, 2001). Much of the coarser material is deposited in the upper or middle reaches of a stream. Lower sections of river systems usually carry smaller particles in the sediment load as these are more easily transported along gentle slopes(Goudie, 2001).

Turbidity influences the dynamics of a river system in numerous ways. It is mostly brought about by an increase in the suspended sediment load of a water body. High turbidity increases surface water temperature as the sediment traps the solar energy. This however reduces the water temperature at depth as particles stop light from penetrating through the water column. High turbidity limits instream photosynthesis to the upper few centimetres in many rivers therefore confining autotrophic productivity to a shallow photic zone(Boulton and Brock, 1999). Turbidity also makes it difficult for organisms on, or near, the riverbed to survive as interstices in the river gravel are filled. Primary production of micro-organisms is limited by the levels of light in the water as is the successful germination of some aquatic plants (Young, 2001). Aquatic plants may also be buried or smothered by sediment and high fluxes of sediment also makes it difficult for periphyton to grow as they can be physically removed or smothered by suspended sediment (Boulton and Brock, 1999).

A significant proportion of phosphorus transported in Australian waterways is attached to soil or organic particles (Dyer *et al.*, 1996). As such, sediments are a major source of nutrients in lowland rivers. Anoxia at the sediment–water interface can release phosphate from the sediment-bound internal load (Boulton and Brock, 1999). Additionally, benthic algae can access nutrients in the sediments and make them bioavailable (Biggs, 1996). So, an increase in the release of sediments into the river can act as an increase in the bioavailable nutrient load.

2.2.3 Reservoirs and Sedimentation

In order to manage water resources on a continent with extremely high rainfall-runoff variability (Finlayson and McMahon, 1988), Australia stores more water *per capita* than any other nation (McLennan, 1996). As the conditions of rivers change, so does that of reservoirs. Weirs, dams and reservoirs trap sediment flowing in from rivers, rather than letting the sediment flow down the river system naturally, therefore sediment accumulation rates can become high in reservoirs (Caitcheon *et al.*, 1995), in contrast to natural lakes (Clark and Wasson, 1986a). The high volumes of sediment trapped decreases the water holding capacity of the reservoir or dam. This can result in the need for dredging to remove excess sediment that has accumulated, as has been the case on numerous occasions for sections along the River Torrens in South Australia.

It has been acknowledged that in South Eastern Australia, the filling of reservoirs is not generally a problem (Davis, 1996). In arid and semi- arid catchments, however sediment accumulation due to erosion has resulted in decommissioning of key systems (Clark and Wasson, 1986b). Research conducted on the Eildon Reservoir in Victoria, demonstrated that large scale events can contribute to sediment accumulation, and are often the cause of bulk sedimentation in standing waters. Half the storage capacity lost within some Victorian reservoirs was a consequence of one major event, the 1939 fires (Davis, 1996).

High sediment accumulation, at its most extreme, is also believed to impact upon the quality of water in reservoirs, as it brings a greater influx of nutrients into the system. The shallowing of a standing body of water due to sediment accumulation, brings the bottom closer to the epilimnion. Consequently, nutrients that are released from the sediment enters this zone, causing eutrophication. This process is referred to as ontogeny and can lead to problems associated to eutrophication (Larson, 1996). This is especially so, because, epilimnetic zones are generally characterised by higher temperatures and greater intensities of light (Boulton and Brock, 1999), which inturn encourages photosynthesis and reproduction.

The sediments trapped in impoundments also have attached nutrients, particularly phosphorous. This can lock away the attached nutrients, however, if a mechanism exists, it can act as a store from which nutrients can be periodically re-released into the water column. This, sometimes substantial, internal load can provide an ongoing source of phosphate to drive the ecology of a reservoir for many years (Caitcheon *et al.*, 1995). As such, eutrophication can also occur from nutrients being released into the water body of a river system through these internal processes.

2.2.4 Determining Sediment Sources

Aquatic sediments have many sources but are greatly influenced by the geology and topography of the system catchment (Williams, 1983). Other sources contributing to sediment changes in river systems include diversion of water from different sources and the farming and soil management practices of people using land in the catchment.

In many rivers channel bank erosion is the major cause of sediment inflows into the river system (Caitcheon *et al.*, 1995). A South Australian example is that of the River Torrens where riverbanks are extremely unstable in the upper reaches. It has especially been noted in the Kersbrook, Miller and Hannaford creek sub-catchments and along the River between Mount Pleasant and Gumeracha Weir (Burston *et al.*, 1997). In the upper reaches of this area, it has been estimated, through ^{137}Cs and ^{210}Pb ratios, that subsoil contributes up to 82% of sediment that accumulates in weirs (Gell *et al.*, 1999).

Sediment sourcing techniques can be used to identify the province of sediment that has accumulated in a reservoir. Three examples are, the use of measuring radioactive elements otherwise known as "fallout tracing", "mineral magnetics" which measures the mineral magnetic properties of sediment grains (Wallbrink and Fogarty, 1998) and the third, "major element tracing" measures the geochemistry of major elements found within the sediment (Dyer *et al.* 1996). These techniques are used for research in many disciplines, but traditionally by geologists and geomorphologists. Fallout tracing, which measures the concentrations of fallout ^{137}Cs and ^{210}Pb, is best suited to measuring the depth of erosion, rather than the special origin of the sediment. This technique was used to determine the sources and transit times of suspended sediment in the Murrumbidgee River in New South Wales (Wallbrink *et al.*, 1998). Analyses were conducted on sediment samples from three sediment sources, uncultivated lands, cultivated lands and subsoil material from channels and gullies. The results of these samples were then compared to suspended sediment samples taken from the main river channel. The researchers were able to determine, among other things, that channel banks and gully walls contribute >80% of the suspended sediment load in the river (Wallbrink *et al.*, 1998).

The other two techniques are used to trace the original location of deposited sediments. For example, suspended sediment flowing into the main river channel from major sub-catchments tributaries upstream can be compared to sediment that has been obtained from within the main stream itself, and then for example, to that trapped in weirs. From results obtained, such as geochemical similarities between the sediment accumulated in the weir and those of the main channels, it is possible to establish which tributaries or sources are contributing the greatest volumes of sediment to the weir. This has great implications for management as, having the ability to identify the principle sediment sources, management can be targeted so that the greatest benefit accrues from management efforts (Gell *et al.*, 1999).

2.3 Monitoring ecological change

2.3.1 Bio-indicators

There is an increasing emphasis on the use of biological indicators to assess ecosystem health. These are used as direct measures of ecological health (e.g. biodiversity) or, because they are present in the environment for periods ranging from weeks to years as integrators of changes to water quality over long time periods (Reid *et al.*, 1995). There are a range of different types of biota that can be studied to asses water quality and chemistry. These include fish, macroinvertibrates, algae and microbes (Norris and Norris, 1995).

Biological indicators such as diatoms, are very good indicators as they are sensitive to environmental change and therefore assemblage changes in diatom taxa can signify small changes to the aquatic environment. With the development of diatom indices, it is possible to establish both the water quality and chemistry due to benchmarked variations in taxon responses and tolerance. These indices have also made it possible to establish the sensitivity of taxa to anthropogenic disturbances (Chessman *et al.*). Moreover, using diatoms, it is possible link modern biomonitoring programs to fossil studies in order to assess the (biological) success of remediation efforts (Juggins *et al.*, 1996; Flower *et al.*, 1997).

2.3.2 Palaeolimnological Studies

Palaeolimnology refers to the study of the history of waterbodies. Palaeolimnological techniques are useful in understanding changes in nutrient levels where monitoring data is lacking (Hall and Smol, 1999). In terms of sediment tracing, such studies are important since large proportions of reservoir sediment (and potentially nutrient) loads may be deposited in short periods of the reservoir's history. For example, in some cores from Burrinjuck Reservoir, more than post-1945 half was deposited in time periods totalling no more than a week (Tibby, 2001).

Palaeolimnological techniques vary from regional approaches involving the study of flora and fauna remains to reveal past conditions of the area based on knowledge of the local or regional ecological requirements of the taxa (Cameron *et al.*, 1999), to sedimentological approaches that can be used globally. The former can be achieved through the use of bio-indicators such as diatoms. This is because the silicate shell of diatoms is an ideal palaeo-indicator tool as they preserve well in sedimentary layers allowing comparison with known ecological requirements of the organisms (Gell *et al.*, 1999). So, as modern diatoms respond to nutrient concentrations, fossil diatom sequences can be used to create reconstructions of nutrient history (Tibby, 2001, Reid *et al.*, 1995). Such data serves to reconstruct the history of erosion and nutrient pollution within a site's catchment (Gell *et al.*, 1999b).

Palaeolimnological studies carried out recently have indicated that there may be a parallels between written and verbal histories of events in the area and the events recorded in the sedimentary record (Tibby, 2001). The study of sediment cores to reconstruct the rate and deviation of change through time can assist management decisions by revealing possible causes of change and the nature of a site's water pre-disturbance water quality. This state (or states) can then be identified as targets for restoration efforts.

CHAPTER 3 STUDY AREA

The principle study site of this project is Gumeracha Weir and the River Torrens catchment above the weir. The weir was opened on July 5th 1918 (Hammerton, 1986) and is situated in the study area, the upper River Torrens catchment, South Australia. There are many physical attributes to the study area that influence both the River Torrens as a whole, and more directly to the upper reaches.

3.1 River Torrens

The River Torrens remains an important water supply for the city of Adelaide (TCWMB 2002). It originates to the north east of Adelaide near Mt Pleasant in the Mt Lofty Ranges and flows in a south-westerly direction across the plateau of the ranges and through a gorge on the western scarp of the Mount Lofty Ranges. It then flows through metropolitan Adelaide to the Henley Beach outlet where it discharges into the Gulf of St Vincent. The catchment spans approximately 504 km^2 and incorporates many sub-catchments and tributaries. It may be separated into two distinct areas based on their topography, hydrology and land use - the lower and upper reaches (Figure 3.1) (Schultz *et al.*, 2000). The upper reaches are the focus of this study while the lower region will be excluded from further discussion as it has no direct impact on the chosen area.

3.1.2 Upper Reaches of the River Torrens

The Upper region incorporates the 30 km stretch of the River from its source to Kangaroo Creek Reservoir (KCR) covering an estimated area of 270 km^2 (Illman and Gell, 1998). There are thirteen sub-catchments with nine occurring above Gumeracha Weir (Figure 3.2). All contribute to the water, sediment and nutrient influxes to the River Torrens.

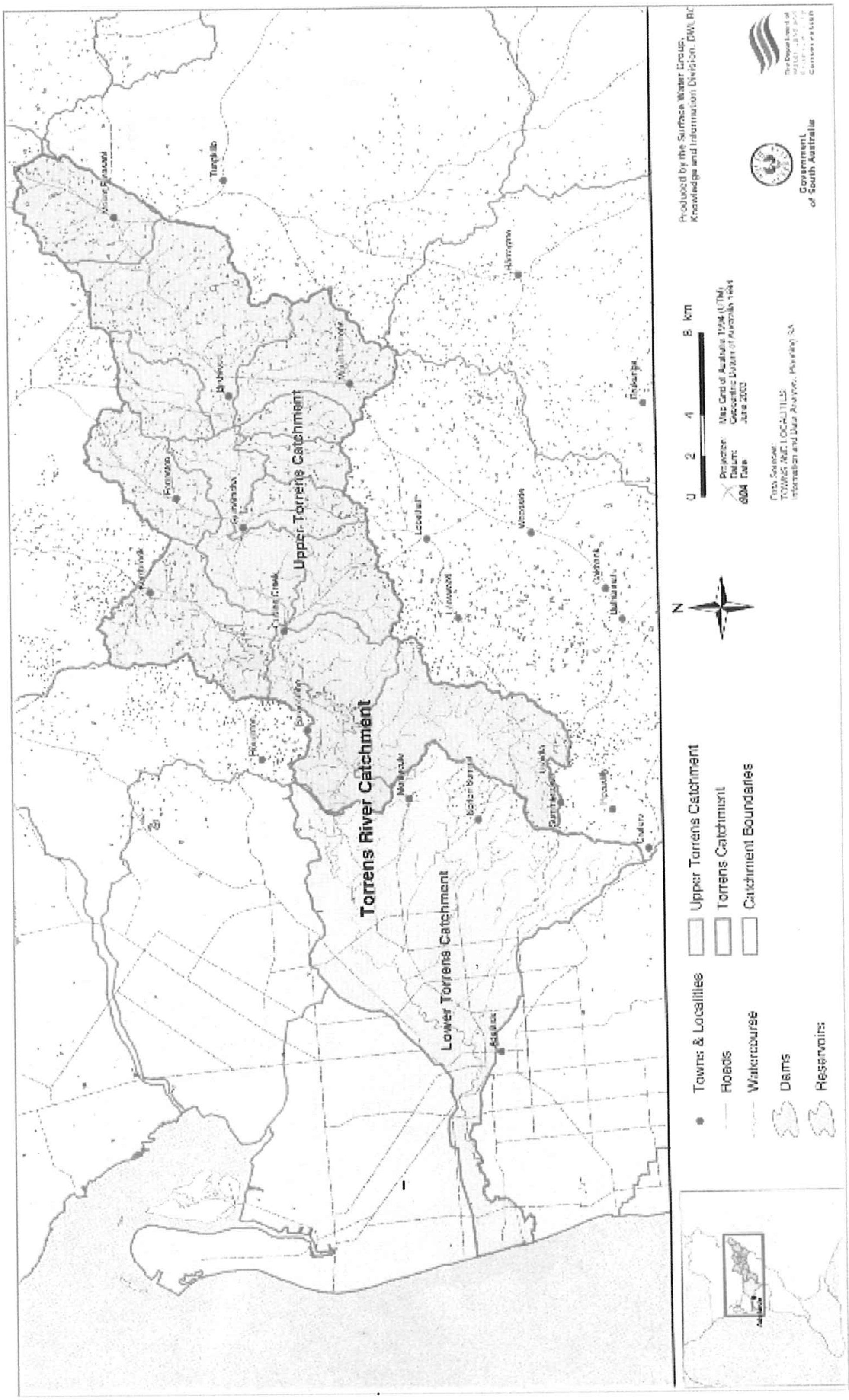


Figure 3.1 Upper and lower sub-catchments of the River Torrens Catchment. Adapted from Heneker (2003)

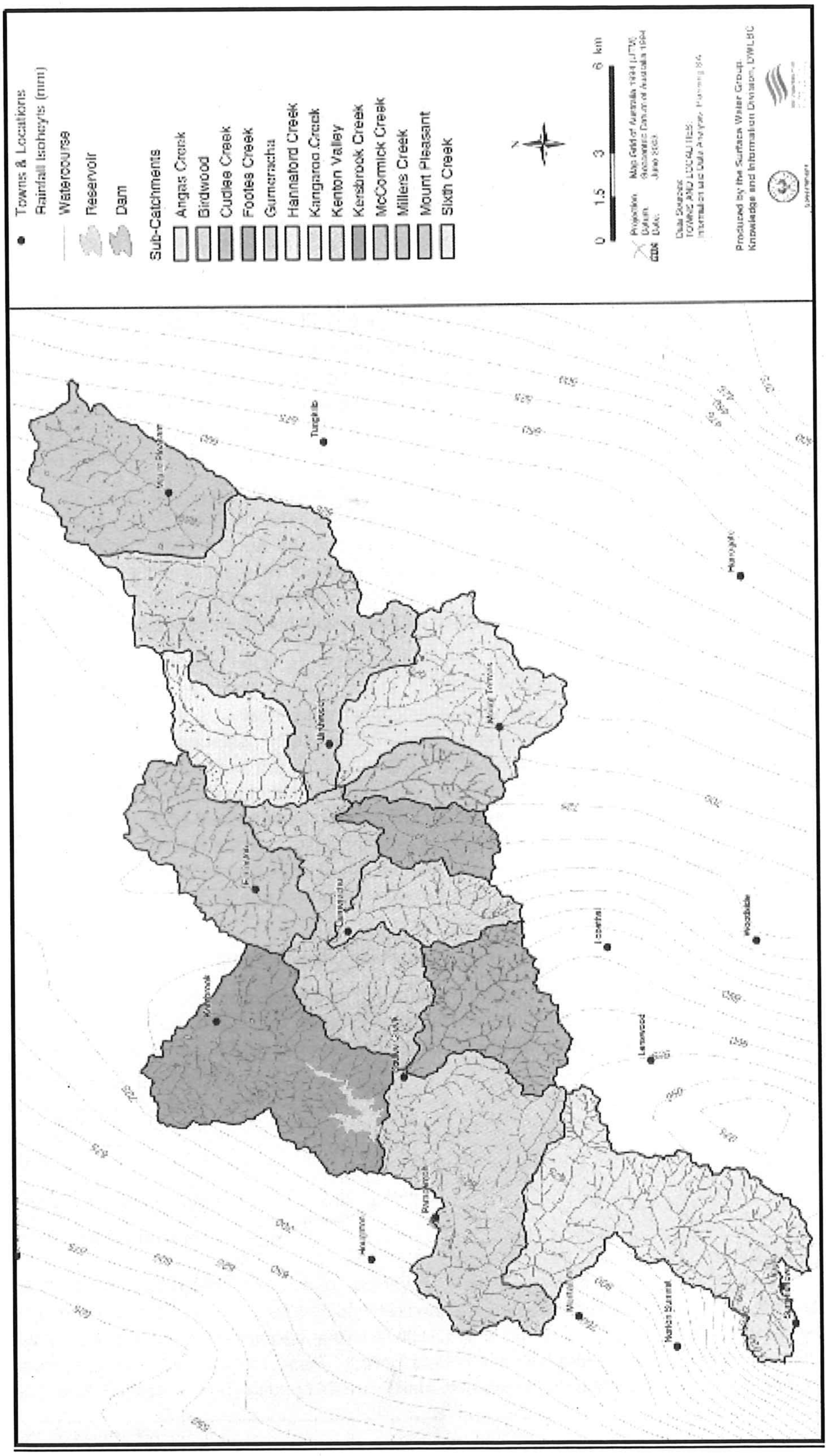


Figure 3.2 Sub catchments of the Upper River Torrens Catchment. Adapted from Heneker (2003)

3.2 Mt Lofty Ranges

The Upper Reaches of the River Torrens are a feature of the western slopes of the Mt Lofty Ranges. Thus the geology and climate of the ranges *is* that of the river and substantially contributes to the river's hydrology.

3.2.1 Geology

The Mount Lofty ranges contain rock formations dating from the Cambrian and pre-Cambrian periods (Daily *et al.*, 1976) that are aligned in a generally north-south orientation above the Adelaide plain with wide lowland sections to the east and west (Corbett, 1977). The Mount Lofty Ranges and its rivers are of debatable age and history, however studies have shown that the precursor to the modern River Torrens existed from the early Tertiary period. The lower reaches of both the ranges and river have been impacted by glacial and sea movements over the millennia, whereas the upper reaches have been moulded more by the interactions of the Eden, Burnside and Para faults (Twidale, 1976). These were responsible for the uplift of the Mt Lofty ranges to the height that provided the geological basis for the river's current existence (Figure 3.3). The river has been shaped by its environment in sections where it follows local bedrock for extended sections. It has also played a part shaping its own surroundings by exposing large areas of geological interest including eroded limestone valleys and ridges (Twidale, 1976). Geology also has an impact on the sediments in the river system with local rocks and landforms providing material that is deposited downstream (Williams, 1983)

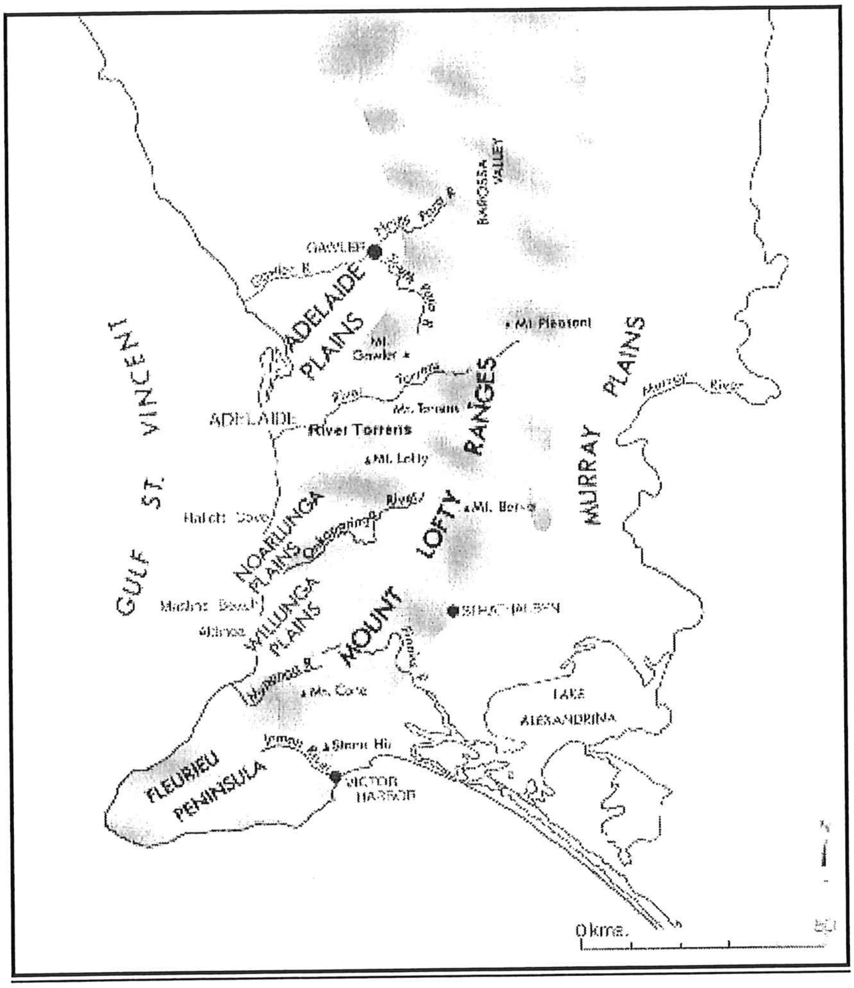


Figure 3.3 Locality of the River Torrens in the Mount Lofty Ranges. Adapted from Twidale (1976)

3.3 Hydrology

3.3.1 Climate and Hydrology

The River Torrens has a Mediterranean climate that is generally warm and dry during summer and wet and cool during winter. Around 70% of the total rainfall occurs within the six months of the cooler period (Schultz *et al.*, 2000). Over the last century of records, rainfall in the upper catchments has varied between 650mm and 900 mm, with a mean of 750 mm (Figure 3.4).

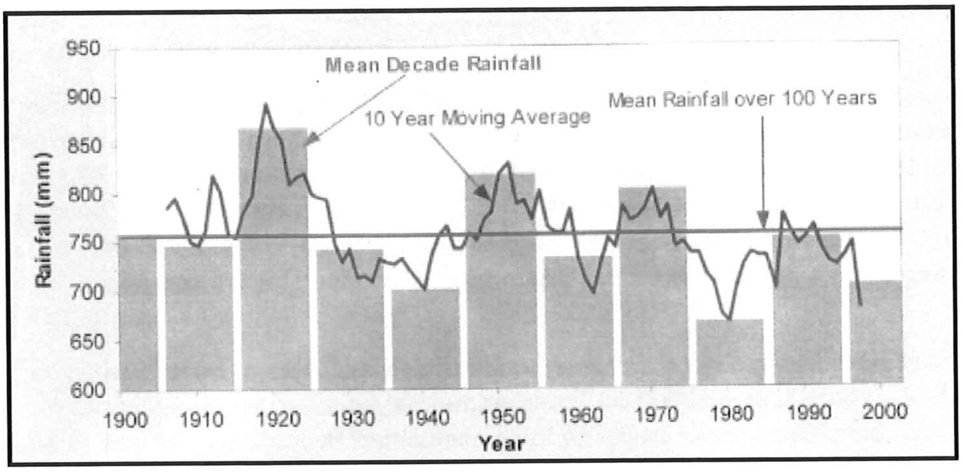


Figure 3.4 Decadal Rainfall Patterns for the Upper River Torrens Catchment. Adapted from Heneker (2003)

Rainfall patterns vary further when compiled for individual sub catchments of the upper River Torrens (Table 3.1). These sub-catchments contribute varying volumes of water into the River Torrens annually. The volume of average annual discharge that is drained from the sub-catchments into the River Torrens varies with the nature of the catchment. For example, larger sub-catchments generally discharge larger volumes of water as they cover more surface area (Table 3.1). The volume of discharge into the river from the sub-catchments can also, however, be influenced by the land use practices (Figure 3.5) in the catchment as there will be considerably less runoff in areas that are vegetated to those that have been cleared.

Sub-catchment	Area (km^2)	Mean annual Rainfall (mm)	Discharge (Lt/yr)
Birdwood	50.9	707	6308
Hannaford Creek	15.1	686	1968
McCormick Creek	9.3	772	1223
Angas Creek	27.2	727	2884
Footes Creek	9.5	809	1375
Kenton Valley	12.8	794	1938
Millers Creek	22.8	772	2958

Table 3.1 Mean Annual rainfall and discharge rates of seven sub-catchments in the Upper River Torrens Catchment

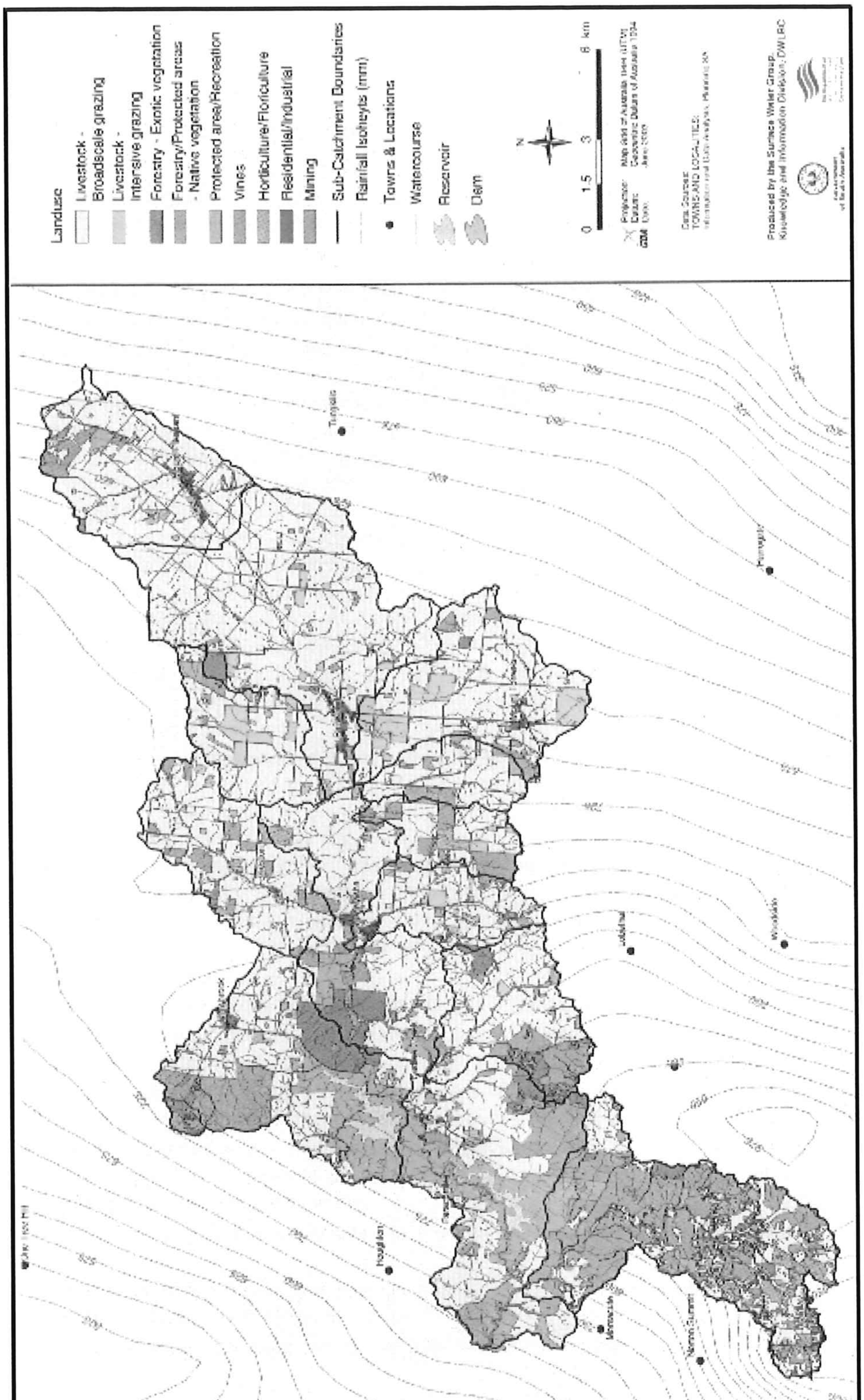


Figure 3.5 Types and Locations of different Land uses in the Upper River Torrens Catchment

3.3.2 European influences on the Hydrology

While, at present, there is a great deal of interest in restoring natural flows to the River Torrens, there was a time in our past when the public complained of its 'torrents' (Smith and Twidale, 1986). The nature of the hydrology of the River Torrens has been altered considerably by the hand of 'man', as, during early European settlement, there was considerable concern regarding the erratic characteristics and unpredictability of the River. One of the biggest concerns was that during periods of low flow, there was such a scarcity of water that it would often need to be transported from long distances to supply the town folk; this problem exacerbated social economic problems as the members of the public who could not afford to have their own well, or afford the services of water carters, would simply be left without water supplies (Smith and Twidale, 1986).

Another pressing concern was the dangers of people drowning during times of flooding. One member of the public was so concerned that he went so far as to write into the local Newspaper at the time (Register, January 20th 1844), declaring that the River Torrens was uncertain, dangerous and deceptive, and even went so far to suggest that a possible way to help people who might be swept away by the torrent, would be to strategically place long poles, each with some rope and a hook, along the river (Smith and Twidale, 1986). Due to the need for water supplies for the growing European population the river was transformed from an ephemeral water source to a permanent river (Fisher *et al.*, 1999). This was done through deliberately augmenting the catchment flows. The establishment of water flow controls such as reservoirs and weirs, along with the input and extraction of water to and from the River Torrens over the last century, has lead to a complete transformation of the hydrological nature of the River.

3.3.3 River Ecology

Changes in hydrology affects the physical characteristics of the River Torrens channel itself; it alters flow regimes and thus the main water quality parameters such as dissolved oxygen, conductivity, nitrate and ammonia concentrations (Illman and Gell, 1998). Turbidity, water levels, erosion and sediment accumulation rates are also affected by changes in hydrology. An increase in sedimentation rates through the importation of water and changes in land use practices has lead to an increase of nutrient loads. Significant changes in the chemical and biological characteristics of the river have been attributed to changes in phosphorus levels and these remain of high concern (Illman and Gell, 1998). Pollutant concentrations are generally higher during low flow in summer and autumn due to evapoconcentration. Such concentrations can impact heavily on native aquatic biota, such as native fish, macroinvertebrates and diatom assemblages, and increase threats such as algal blooms.

3.3.4 The Mannum-Adelaide Pipeline

A water diversion scheme was commissioned in 1954 to bring River Murray water into Adelaide water production catchments. The Mannum-Adelaide pipeline exports water from the River Murray into the upper River Torrens catchment via three separate scour outlet locations: Mount Pleasant, which only entered service in 1968 (Hammerton, 1986); Angas Creek, which is located 200 metres above the confluence with the River Torrens; and Millbrook Reservoir. Millbrook Reservoir is situated off the main river channel, however it can both receive river water from Gumeracha Weir and return it to the river at a point downstream of the weir (Illman and Gell, 1998). This is done to control mean monthly flow distributions of the River Torrens.

The only area of the river that is unregulated is at the headwaters in the Mount Lofty Ranges and down to the first input scour at Mount Pleasant. This area has the most natural hydrological flow regime, with low flows occurring during summer and early autumn and peak flows during winter and early spring (Illman and Gell, 1998). The input of River Murray water into the River Torrens increases monthly water flow during the summer and early spring months from October to April and decreases the extent of high flow events (Illman and Gell, 1998).

3.3.5 Weirs and infrastructures

Due to the alterations that have been made to the River Torrens, such as the development of weirs and reservoirs, along with the inputs and extractions of water to and from the river system, a reverse of the natural seasonal flow has occurred; therefore, summer flows now resemble Spring and Winter flows of the past (Illman and Gell, 1998). Along with the consequent modification of turbidity and water levels, weirs have also contributed to the geomorphological changes of the channel itself. Gumeracha Weir, for example, has increased the depth of the river between 2-4 m directly below the wall, since the 1st survey in 1973, most likely as a consequence of the high velocity of water flowing over the weir wall when it reaches capacity (Illman and Gell, 1998). Increases in erosion are also attributed to Gumeracha Weir as analysis of three bridges downstream from the Weir has shown decreasing localised erosion with increasing distance.

3.4 River Torrens, an important resource

It is imperative that the River Torrens be successfully managed to prevent degradation and improve the water quality of the river as extensive farms and rural towns depend on this resource (TCWMB, 2002). Approximately 30,000 ML/yr of water is extracted from the River Torrens for public supplies (Fisher *et al.*, 1999). The rural stretch of the River Torrens catchment supports around 1,350 properties, incorporates roughly 156,000 dwellings and their residents (Gell *et al.*, 1999). The people who are most dependent on this water resource may be contributing to the problems surrounding its quality through poor land use practices, exemplified in the increase of sedimentation due to erosion of banks where riparian vegetation has been removed (Illman and Gell, 1998). A number of costly proposals have been implemented in an endeavour to improve river health. These include the allocation of $22.4 million to be dispersed over the period between 2002 – 2007 to the Torrens Catchment Water Management Board, to the issues of the quality and supply of the River Torrens water (TCWMB, 2002).

CHAPTER 4 METHODOLOGY

In order to address the objectives of the study, a range of approaches were needed. Initially field and laboratory work was required to collect and prepare samples in order to generate data. The data was then objectively synthesized after statistical analysis.

4.1 Field Work

4.1.1 Site Selection

The intention of this study was to help establish the extent and reasons for changes in the sediment sources and water chemistry of the upper reaches of the River Torrens. Gumeracha Weir (GuW) was chosen as the site for intensive study for three reasons.

1. Location - its location down stream from the discharge outlets of the Mannum-Adelaide pipeline into the River Torrens. Gumeracha Weir's position within the hydrological cycle of the Upper Torrens makes it an ideal site to study as it receives the influx of Murray water from the Mannum to Adelaide pipeline after it has been discharged into Mount Pleasant and Angas Creek.

2. The weir has a long history - it was commissioned in the early 1900s so it is thought to contain over a century of sediment accumulation and, therefore, over a hundred years of data for analysis. Due to the time period that the sediment core was expected to cover, it was hoped that a strong differentiation between conditions of the River Torrens pre- and post-completion of the River Murray (Mannum to Adelaide) pipeline in 1954 would be revealed (Gell and Wallbrink, 2002).

3. Previous analysis – previously a smaller core sample (Gu2) was collected from Gumeracha Weir in the 1950s with a core length of 120 cm. Study of this core revealed that a comprehensive analysis could be undertaken of diatoms indicating that this site was suitable for a more detailed palaeolimnological study (Gell *et al.*, 1999).

4.1.2 Sample Collection

The core used for this project (GuW3) was attained in the year 2002 by employees of Diatoma in the Department of Geographical and Environmental Studies at Adelaide University using a 'D-section' or 'Russian' corer (Jowsey, 1966). This corer collects 50 centimetre sections of sediment at a time. The core extracts the sediment when the bit is pushed into the ground and twisted 180° before it is lifted back out. The sediment is then removed from the corer through a side opening chamber to prevent sediment compaction and placed immediately into labelled, split PVC pipe and wrapped in cling film to limit drying. Each 50 centimetre section gathered is collected in alternate, adjacent holes to prevent contamination. This processes is repeated until the desired depth of sediment is gathered or the corer hits bottom. At Gumeracha Weir this coring processes retrieved sediment to a depth of 371 centimetres, three attempts were made to push the corer further into the ground, however all attempts were unsuccessful and it was determined that they had hit rock, which was presumably the base of the sediment.

The end of the 'D' section corer that is pushed into the sediment is 15 cm long and does not collect sediment, therefore if a different corer had been used a sediment core of 386 cm would have been recovered. The GuW3 core was retrieved approximately 80 meters from the Gumeracha Weir wall. It is possible therefore that if the core had been taken closer to the wall a greater core depth would have been obtained as sediment would have accumulated there first.

4.1.3 Suspended Sediment Collection

Suspended sediment was collected from 7 sites upstream of Gumeracha Weir (See Table 4.1). The intention of gathering the suspended sediment from the upstream creeks was to obtain geochemical data, through XRF analysis (refer to section 4.2.4), which would help establish the source of excess sediment flowing into the river and help identify the key areas for erosion management. The sediment was retrieved from the river during a period of flooding when the water was most turbulent. The suspended sediment was extracted from the river in large 60 litre bins where it was then taken to the laboratory and allowed to settle. Once this was done the excess water was then siphoned out, until it was no longer possible to siphon water without disturbing the sediment. At this point the excess water was left to evaporate and then the remaining sediment was placed in an oven at 110° Celsius overnight to remove all moisture.

4.2 Laboratory Techniques

4.2.1 Sediment Stratigraphy

The four meters of sediment within the PVC pipe retrieved from GuW was laid out in the laboratory. The last 50 centimetre core section overlapped with the second last at depths 321-351 centimetres, therefore the total depth of sediment gathered was 371 centimetres. A description was taken of the entire core, including the overlapping sections, using both the modified Troels-Smith method after Kershaw (1997) and the 'Munsell Soil Color Charts'(Munsell Colour, undated).

Site	Collection date	Water volume L	Dry sediment weight g	Sediment mg/L
Kenton Creek	03-Aug-04	160	267.41	1671.30
Millers Creek	17-Jul-04	240	1.78	7.40
Footes Creek	17-Jul-04	300	8.90	29.66
Angas Creek	04-Aug-05	310	16.22	52.32
Williams Creek	03-Aug-04	290	9.65	33.27
Hannaford Creek	04-Aug-04	270	11.53	42.70
Stony Creek	17-Jul-04	280	17.51	62.54
Murray waters-Millbrook scour TR03001/1	12-Mar-03	672	14.94	22.23
Murray waters-Millbrook scour TR03001/2	12-Mar-03	990	22.44	22.67
Murray waters-Millbrook scour TR03001/3	12-Mar-03	990	23.29	23.53
Torrens with Murray water-d/s Millbrook TR03003/1	12-Mar-03	600	7.72	12.87
Torrens with Murray water-d/s Millbrook TR03003/2	12-Mar-03	900	11.39	12.66
Murray waters-at Mannum TR03004/1	13-Mar-03	990	23.82	24.06
Murray waters-at Mannum TR03004/2	13-Mar-03	990	25.3	25.56
Murray waters-at Mannum TR03004/3	13-Mar-03	660	14.19	21.50

Table 4.1 Figures for suspended sediment samples collected from seven sites upstream of Gumeracha Weir and eight suspended sediment samples collected of River Murray water; the volume of water collected at each site, the total dry weight of sediment in grams, retrieved from the water collected and the amount of dry sediment per milligrams per litre collected.

4.2.2 Moisture, Organic and Carbonate Content

Sediment was extracted in ten centimetre intervals from the GuW3 core and analysed for moisture[1], organic and carbonate content. In each case established relationships were used to calibrate the mass lost for each desired parameter (Heiri *et al.*, 2001, Dean, 1974). The sediment samples were placed in marked pre-weighed crucibles and then weighed again to establish wet sample weight. The samples were then dried in an oven at 105° Celsius for 24 hours and re-weighed to determine moisture content. Loss on ignition was calculated after the sediment was fired in a muffle furnace at 450° Celsius for four hours and then re-weighed. Carbonate content was established after the sample was fired at 900° Celsius for a further two hours, and reweighed.

4.2.3 Fossil Diatom Sampling and Preparation

Diatom samples of the GuW3 core were retrieved from the depths of. Approximately 1 cm^3 of sediment was taken at 10 centimetre intervals from the GuW3 core for diatom analysis. This is with the exception of the very top of the core where sediment was retrieved from the depth of 0 cm –5 cm to compensate for the sandy, loose nature of the section. The method used for diatom preparation and mounting onto slides followed Battarbee *et al* (1999) HCI and H_2O_2 digestion.

A minimum of 100 diatom valves was counted per slide using a Nikon Eclipse E600 light microscope at 1500x magnification, with Differential Interference Contrast. The diatoms were counted along vertical transects of known coordinates following Battarbee (1986). To

[1] Due to the possible drying out of the core during storage, the reliability of the results of % moisture cannot be assured.

identify the valves taxonomic texts Krammer and Lange-Bertalot (1986-91), Sonneman *et al* (2000) and Gell *et al* (1999) were used. Taxonomy was supported through image capturing and printing using a locally produced iconograph.

4.2.4 Geochemistry Sampling and Preparation

Geochemistry sediment samples for XRF analysis were extracted at levels from the core directly adjacent to those destined for diatom analysis, in order to maximise correlation between the two data sets. Such correlation facilitates the establishment of a relationship between the fossil diatom assemblages identified at each depth with the geophysical-chemical parameters. As XRF analysis requires 1 gram dry weight of sediment the majority of samples were approximately 1 cm^3 in size, with the exception of approximately 2.5 cm^3 of sediment being extracted from the depth between 3 cm - 5.5 cm, approximately 3 cm^3 being removed from depth 54 - 56 cm^3 and 2 cm^3 from both depths 42 cm - 44 cm and 103 cm - 105 cm. Extra sediment was gathered from these three depths to compensate for the loose and light nature of the sediment and for excess visible organic matter identified at these depths.

The samples were placed in pre-weighed crucibles and fired in an oven at 110° Celsius for two hours to remove moisture. The samples were then again fired in a muffle furnace at 960° Celsius for a further six hours to discharge any organic matter or carbonates from the sample. Once this was completed the samples were again weighed to calculate loss on ignition.

Following firing, the sediment was then ground, using a mortar and pestle, into powder form. From this 1 gram of fired sample was mixed with 4 grams of flux. The sample and flux[2], was precisely weighed. Fusion of the sample-flux mixture was conducted in a Pt-Au crucible using a propane-oxygen flame at an approximate temperature of 1150°; it was then poured into a preheated mould, producing a glass disc that was used for analysis. John Stanley, X-ray Analyst, Geology and Geophysics, School of Earth and Environmental Sciences then conducted analysis of the glass disc on a Philips PW 1480 X-ray Fluorescence Spectrometer.

4.2.5 Dating Techniques

The development of a chronology for the core, GuW3, was achieved using ^{210}Pb and ^{137}Cs analysis. Dating analysis was carried out on ten sections of the core. The interval between dating samples was between 33-41 centimetres, with the exception of the interval between the first and second samples taken which was 22 cm. Each sample taken for dating was taken adjacent to the diatom and geochemistry samples to tightly link measured changes with points in time past and the correlation of the end results.

To prepare the samples it was decided to sift the sediment through a 10 μm sieve using distilled water and a small brush. Although this was an unusual, and in fact unprecedented procedure, it was determined that this would help obtain the best results as ^{210}Pb has a strong affinity to fine particles. In this context, larger particles can be viewed as a dilutant, which decreases the reliability of the method.

The samples were then dried overnight in an oven at 105° Celsius before being weighed into aluminium containers and placed into a muffle furnace at 450° Celsius for a further 48

[2] Commercially available as type 12:22, comprising of 35.3% lithium tetraborate and 64.7% lithium metaborate.

hours. After ashing of the samples they were re-weighed to establish LOI. The samples were then finely ground and placed in sealed containers before being sent to CSIRO Land and Water, Canberra for dating. These samples were then analysed for their ^{210}Pb, ^{137}Cs, ^{226}Ra and ^{228}Th content using the method of Murray et al. (1987). Selected samples in the 0-100 cm interval were also analysed for ^{210}Pb by measurement of its short-lived daughter, ^{210}Po. This method, which provides improved sensitivity compared to gamma spectrometry, utilises a radioactive tracer (^{209}Po), radiochemical separation, and analysis by alpha particle spectrometry (Martin and Hancock, 1992).

4.3 Statistical Techniques

4.3.1 pH

Water column pH was estimated in C2 (Juggins, 2004) using the diatom-pH transfer function of Tibby *et al.* (2003). This transfer function has relatively strong predictive power, with a correlation between diatom inferred and measured pH of 0.77 and a root mean square error of prediction (a weighted standard deviation of the errors) of 0.35 pH units. All diatoms with relative abundance >1% were used in the reconstruction.

4.3.2 PCA

Principle Components Analysis (PCA) in Canoco 4.02 (Braak and Smilauer, 1999) was used to ordinate the modern and fossil (Gumeracha Weir) geochemistry data. Environmental variables were centred and standardised (to a mean of zero and a variance of 1) to account allow differences in their variability, rather than absolute value, to be compared (Braak and Prentice, 1988). In the PCA, fossil samples were made passive, so they could be located on the ordination, without influencing the relative position of the modern data set.

4.3.3 Diagram zonation

The GuW3 diatom diagram was zoned with the aid of CONISS (Grimm, 1987). Euclidean distance was used to determine the degree of similarity between samples, with the most similar samples (or groups) grouped first, subject to the constraint that they were adjacent to the sample (or group) to which they were being grouped. The zonation of the diatom diagram was also applied to the GuW3 geochemistry stratigraphy to enable an assessment of the degree of correspondence between the diatoms and geochemistry.

CHAPTER 5 RESULTS

The raw data collected from GuW3 consisting of fossil diatom analysis, geochemistry analysis and sediment analysis was compared with modern geochemistry data from the River Torrens catchment (Tibby, Gell, Nalbrink, Hancock, unpublished data)

5.1 Sediment Analysis and Stratigraphy

The 3.71 meter GuW3 core was laid out in the lab and described, with the assistance of Professor Martin Williams, Geographical and Environmental Studies, University of Adelaide and using the modified Troels-Smith method of Kershaw (1997) and the 'Munsell Soil Color Charts' (Munsell Colour, undated). The Stratigraphy (Figure 5.1) shows that sediment type B is most dominant throughout the core with bands of other sediment types ranging from 1 cm – 20 cm thick dispersed sporadically throughout. This includes Sediment type A, micaceous fine sand, which also frequently occurs throughout the core and may be representative of a slightly higher energy flow. Also identified throughout the core were mica traces. This, along with sedimentary analysis of percentage of moisture, organic matter and carbonate (Figures 5.2, 5.3 and 5.4 respectively), has lead to the identification of different units along the core.

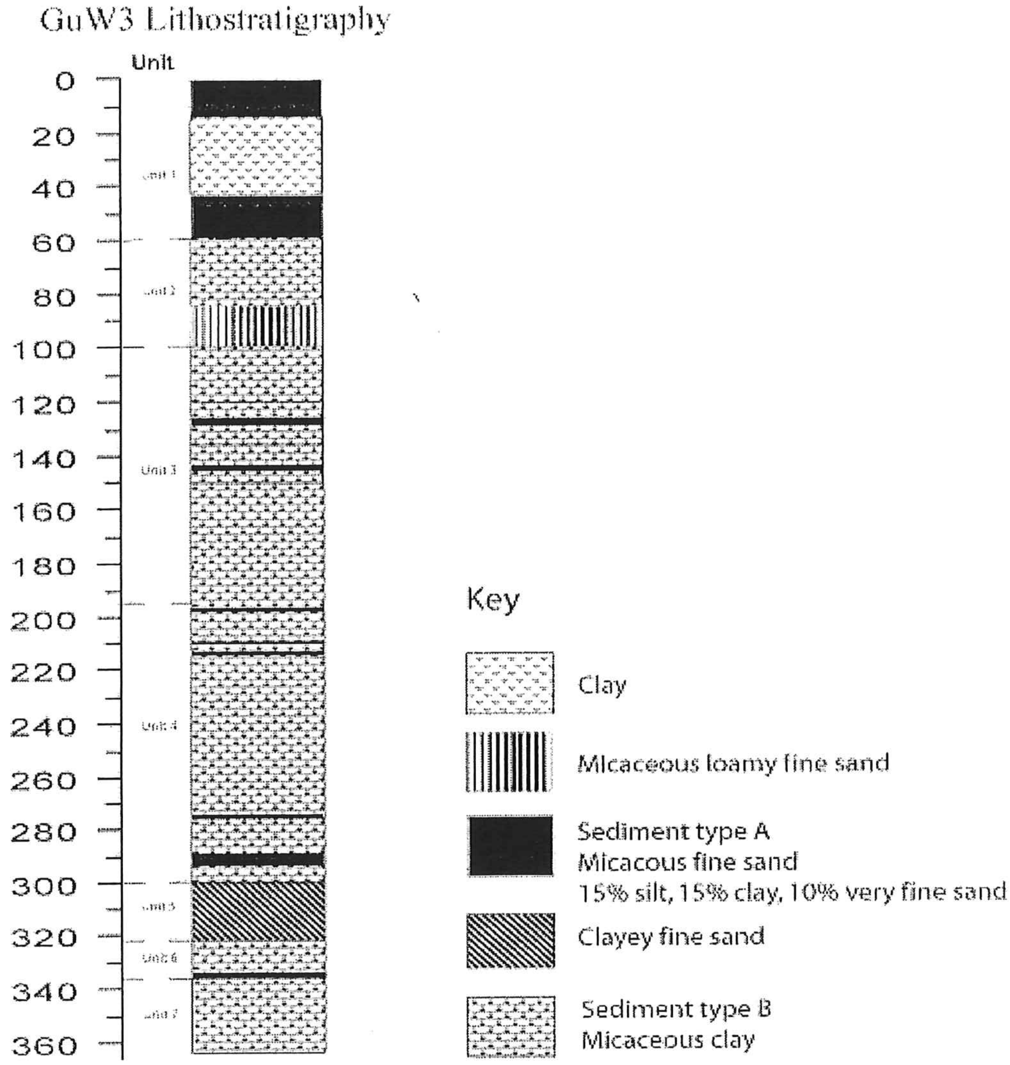


Figure 5.1 The stratigraphic units of Gumeracha Weir core, GuW3

5.1.1 Unit 7 (371 cm – 336 cm)

The bottom twenty-eight centimetres of the core was uniform sediment type B (described in Figure 5.1), with a grey-brown colour. In this unit, represented by three samples, the percentage of organic matter and carbonate content rose slightly. Carbonate content was

Figure 5.2 GuW3 Moisture content

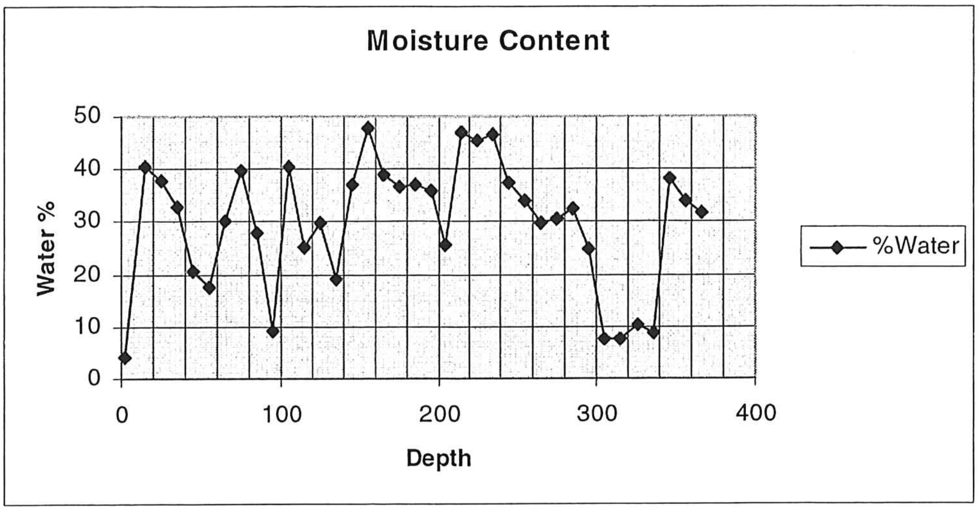


Figure 5.3 GuW3 Organic content

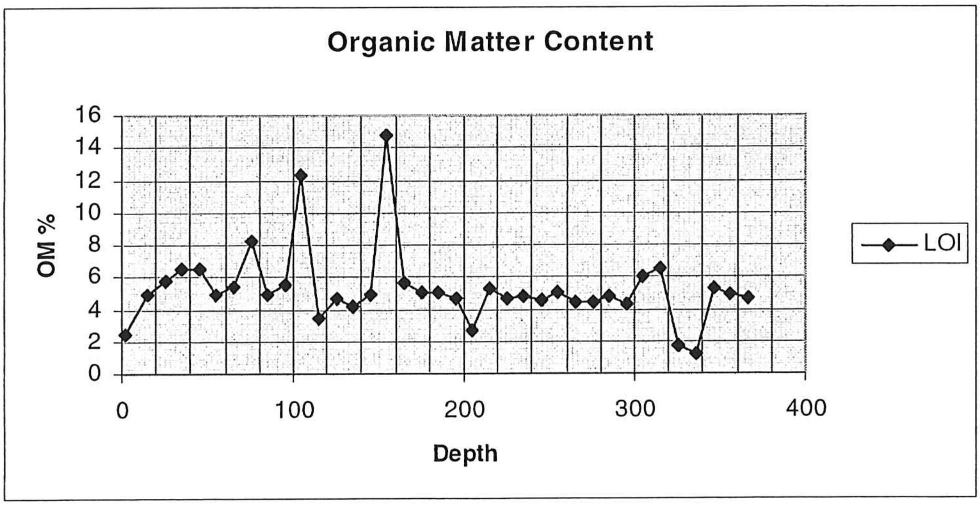
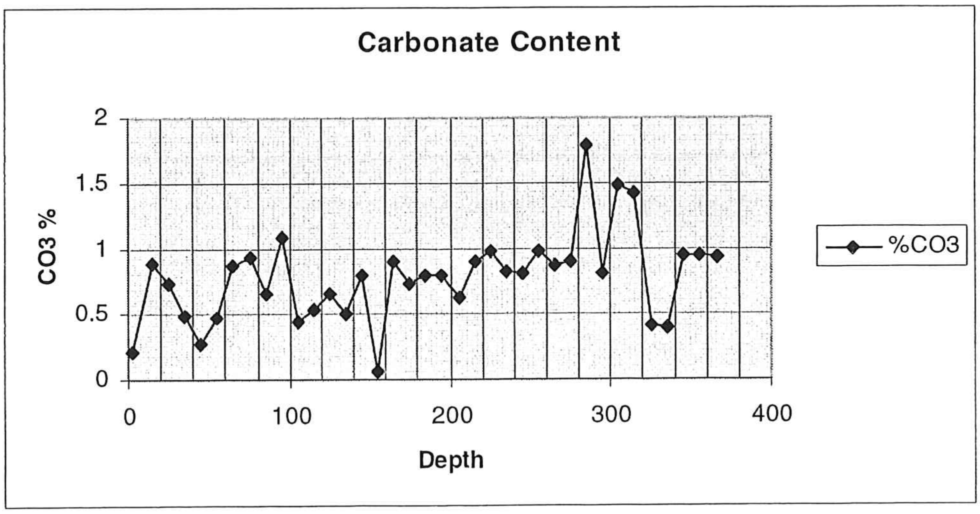


Figure 5.4 GuW3 Carbonate content



the most stable variable, staying just under 1%. Organic matter rose from 4.7% to 5.2% and moisture content had the largest change rising from 31.5% to 38%.

5.1.2 Unit 6 (336 cm - 321 cm)

This unit consisted predominantly of sediment type B, with 1-2 mm thick bands of yellow-brown, very fine sand between depth 336 cm – 333 cm, indicating signs of loading structures where sand is deposited on soft clay. All three variables dropped to their lowest points in the core at this level, the most notable was moisture content falling to 8.8% and then slightly rising back up to 10.5%. Carbonate content dropped from 0.9% in the previous unit to 0.4% and organic matter also fell to 1.3%, only slightly rising again to 1.7%.

5.1.3 Unit 5 (321 cm - 300 cm)

This unit consists of grey, clayey fine sand. The stratification of the soil indicates slightly reducing anaerobic conditions. Carbonate and organic matter again rose in this unit, carbonate increasing to around 1% and organic matter rising to around 6.5%. Moisture content continues to stay very low, falling to 7.7% and then down to 7.5%

5.1.4 Unit 4 (300 cm - 195 cm)

This unit was also dominated by sediment type B. It is relatively uniform right through this section, with the exception of a large band of sediment type A, micaceous fine sand, identified between depths 295 cm – 290 cm and smaller bands, around 1 cm – 2 cm thick, at depths 275 cm, 214 cm, 210 cm and 198 cm.

The percentage of organic matter varies between, 4.3 % and 5.3 %, between the depths 295 cm and 215 cm, before finally dropping down to 2.7% at depth 205 cm. Carbonate content fluctuates from 0.8 % to 1.8 % and back down to 0.9 % at depths 295 cm, 285 cm and 275 cm, respectively. It then stays relatively steady until 205 cm where it drops to 0.63 %. The percentage moisture varies the most in this unit. Beginning at 295 cm it starts off relatively low at 24.8% and then gradually rises to 46.7 % at 215 cm. At 205 cm there is again a sudden drop in moisture down to 25.6 %.

5.1.5 Unit 3 (195 cm - 100 cm)

This unit is dominated by sediment type B, micaceous clay, with lenses of pale yellow-brown, clayey white sand between the depths 144 cm – 143 cm and 128 cm – 126 cm. Additional, sporadic pockets of type B occurred between depths 150 cm and 100 cm. Fine rootlets and small woody detritus was also evident up to this depth, while large woody detritus was identified between the depths 162 cm and153 cm.

Organic matter content gradually rises at the beginning of this unit, peaking at 14.8 % at 155 cm, which concurs with the organic matter identified between depths 162 cm – 153 cm. From there it fluctuates between 3.4 % and 5 % before once again suddenly rising to 12.3% at 105 cm.

Moisture content gradually rises through the beginning of this unit and peaks to 47.6 % at 155 cm. From this depth to the end of unit 3 there is a considerable amount of fluctuation, from 36.8 % at 145 cm, down to 19.1 % at 135 cm, and then up again 10% to 29.9% at 125 cm and down again to 25 % at 115 cm, before rising back up to 40.4 % at 105 cm.

Carbonate content is relatively stable in comparison to the other variables, fluctuating between 0.8 % and 0.9 %. At 155 cm carbonate content was at its lowest value for the core, at 0.065 %. It then rises back up to 0.8% at 145 cm before gradually declining to 0.4 % at 105 cm.

5.1.6 Unit 2 (100 cm - 60 cm)

This unit consists of two sediment types. The first, between depth 100 cm to 84 cm, is a very pale grey-brown micaceous loamy fine sand, where a gradational change is evident. Between 84 cm and 60 cm sediment type B, a very dark grey-brown (colour 10Y 3/2) (Munsell Colour, undated), alluvial micaceous clay was evident.

Carbonate content rose sharply at the beginning of this unit to 1.6 % at 95 cm, however it fell abruptly again down to 0.65 % at depth 85 cm, before rising again to around 0.9% at depths 75 cm and 65 cm.

The percentage of organic matter dropped significantly at the beginning of this unit at 95 cm and then again down to 4.9 % at 85 cm, it rose once at 75 cm to 8.2 % and finally dropped again down to 5.4 % at the end of this unit at 65 cm.

Moisture content also fell considerably at the beginning of this unit dropping down to 8.9 % at 95 cm. It began to rise again to 28 % at depth 85 cm and again to 39.7 % at 75 cm, before once again falling to 30.2 % at 65 cm.

5.1.7 Unit 1 (60 cm – 0 cm)

Within this unit, there are two distinct sedimentary types. Firstly, sediment type A, a slightly micaceous fine sand, was identified at 60 cm – 43 cm and 14 cm – 0 cm. The lower band had woody detritus throughout. The upper band was yellow-brown in colour, correlating best to 2.5YR 5/2 from the 'Munsell Soil Chart' (Munsell Colour, undated). The second sediment type, lying between these two bands, was a slightly organic, slightly silty dark brown clay.

At 55 cm there was once again a significant fall in moisture content down to 17.5 %. It then gradually rose to 20.5 % at 45 cm, 32.9 % at 35 cm, 37.9 % at 25 cm and then again to 40.4 % at 15 cm, before dropping to 4.34 % at 0 cm.

The percentage organic matter also slightly decreased at 55 cm to 4.9 % before rising to 6.5 % at 45 cm and 35 cm. It decreases for the remainder of the core down to 5.7 % at 35 cm, 4.9 % at 15 cm and 2.5 % at 0 cm.

Carbonate content fell to 0.47 % at 55 cm, and to 0.28 % at 45 cm. It then rose slowly to 0.49 % at 35 cm, 0.7 % at 25 cm and 0.9% at 15 % before falling to 0.2 % at 0 cm.

5.2 Chronology and Sedimentation Rates

5.2.1 ^{137}Cs Dating

The ^{137}Cs dating that was conducted on the 10 samples collected from the GuW3 core, indicated that ^{137}Cs was present in the top 9 samples to a depth of 334 cm. The final sample dated from 365 cm – 371 cm had no traces of caesium. The ^{137}Cs dating was used to establish, down the core, the sediment deposited after 1958. It is unknown which level is precisely equivalent to 1958, therefore two separate points were proposed. The first is based on the lowest possible depth that ^{137}Cs may have occurred, just above the last sample at 367 cm. The second point was based on the lowest depth that ^{137}Cs was known to be present, 334 cm, from the section sent, however it may have only been present in the upper most cm of the section sent, between 326 cm – 334 cm.

5.2.2 ^{210}Pb Dating

Once the two possible 1958 depths were estimated from the ^{137}Cs dating, it was then possible to create a chronology of the core from the ^{210}Pb analysis using a CRS model. The results are shown in Figure 5.5. From the establishment of two possible depths representing the maximum and minimum point for 1958 from the ^{137}Cs dating, two alternate chronologies for the core were created. Two possible timelines for each depth given were suggested, as each depth ascends closer to the top of the core, the inferred dates for the depth converge.

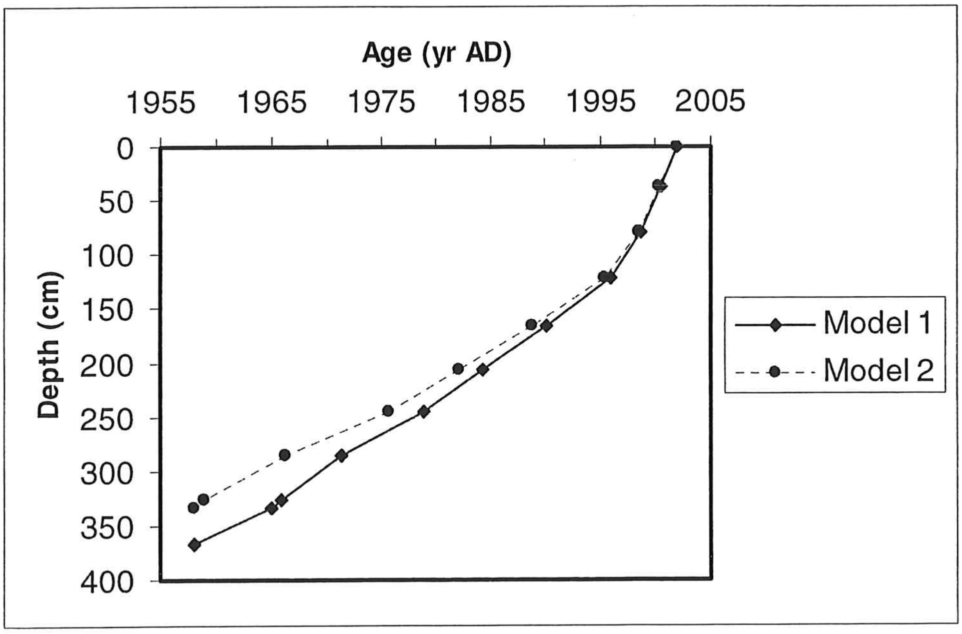


Figure 5.5 Two models for the chronology of GuW3 based on ^{210}Pb analysis.

5.3 Sediment Geochemistry

Energy dispersive X-ray fluorescence spectrometry (XRF) was used to analyse the geochemistry of sediment gathered from the GuW3 core and suspended sediment retrieved from seven tributaries upstream of Gumeracha Weir. The geochemistry procedure analysed eleven different types of elements, comprising, Silica (SiO_2), Aluminium (Al_2O_3), Iron (Fe_2O_3), Manganese (MnO), Magnesium (MgO), Calcium (CaO), Sodium (Na_2O), Potassium (K_2O), Titanium (TiO_2), Phosphorus (P_2O_5) and Sulphate (SO_3).

5.3.1 GuW3 Geochemistry Sediment Stratigraphy

The GuW3 geochemistry results were stratigraphicaly plotted (Figure 5.6). Figure 5.6 clearly indicates that silica is the most dominant ion throughout the core, fluctuating between 55% - 80%. Sodium tends to follow the same trends as silica, however on a smaller scale.

Aluminium is the second most dominant element, fluctuating between 5% - 20% and, for the most part, is a mirror image of the fluctuations of silica. It also generally represents the interchange-ability of the compounds, iron (Fe_2O_3), manganese (MnO), magnesium (MgO), potassium (K_2O), titanium (TiO_2), and phosphorus (P_2O_5), that tend to follow along similar trends to that of aluminium, on a smaller scale ranging from 0.002% - 6%.

Sulphate has the least association with the two chief elements, silica and aluminium, or any other compound, as does calcium to a lesser extent.

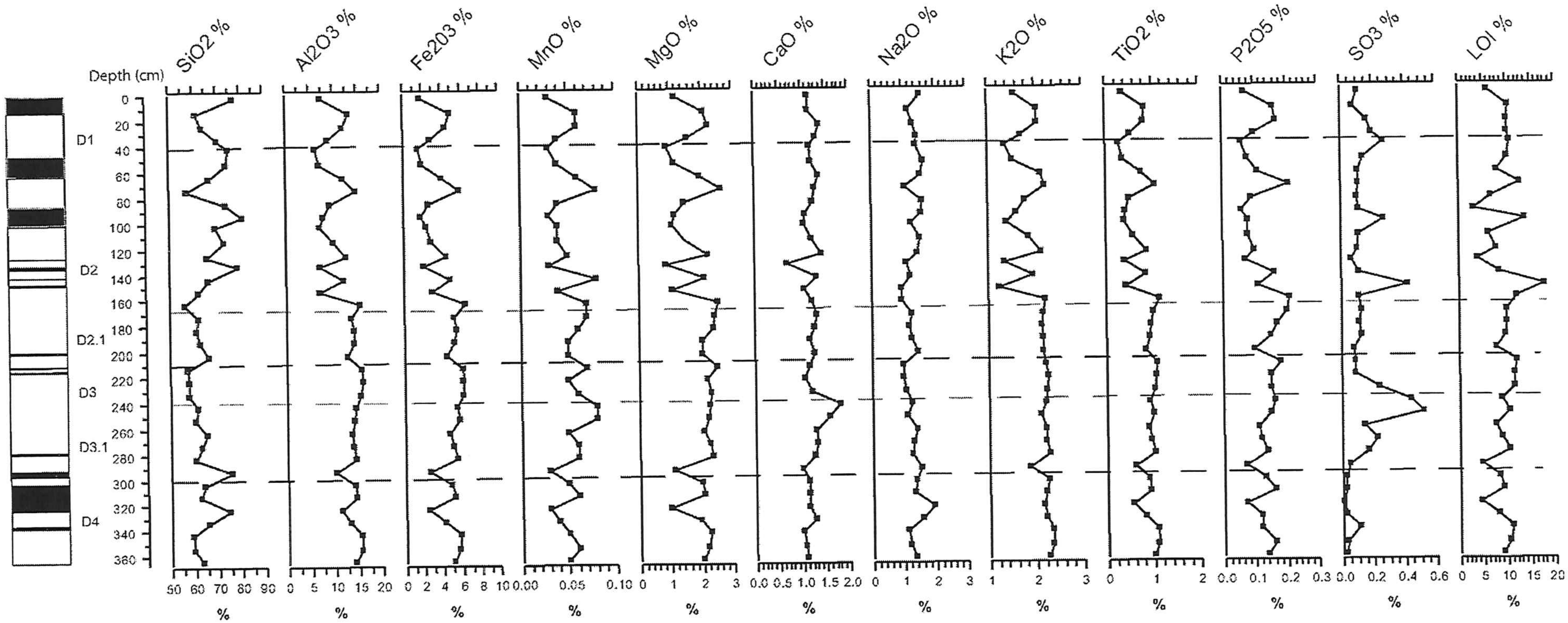


Figure 5.6 Gumeracha Weir (GuW3) geochemical stratigraphy representing the eleven ions analysed, with zonations established from diatom diagram. Each ion is scaled to emphasise its individual variances. On the left hand side of the Y axis is a modified scaled diagram of the lithostratigraphy of the core, the black represent sand bands.

5.3.1 Geochemistry Principle Components Analysis

Geochemistry results were placed in a principle components analysis (Figure 5.7), based on their geochemistry similarity (Figure 5.8). They are all indicative of high silica concentrations. There is a clear mixing line of the Gumeracha core samples, the River Murray samples and five of the Torrens (suspended sediment samples), Hannaford Creek, Angas Creek, Footes Creek, Kenton Creek and Williams Creek. The data displayed directly below the dotted line box (Figure 5.7), along the same mixing line, also have a high correlation to silica compared to the rest of the Torrens samples, however they have a slightly higher concentration of aluminium, titanium and potassium, and have a lower concentration of phosphorus and calcium. Stony Creek also appears to have a link with this mixing line, however has an even higher concentration of aluminium, manganese and iron compared to the other samples. Millers Creek is the only Torrens (suspended sediment) sample that does not appear to be linked with the established mixing line, but instead lies in between it and the other Torrens samples.

The dotted box outlined in Figure 5.7 was enlarged into a separate graph (Figure 5.9), defining the samples that are most evidently apart of the same mixing line. All the GuW3 core samples fall within this zone, representative of high silica concentrations. A clear mixing line can be seen of the GuW3 samples, one of the Torrens suspended sediment results, Hannaford and the eight River Murray samples, outlined by the dotted line box (this has been enlarged in Figure 5.9).

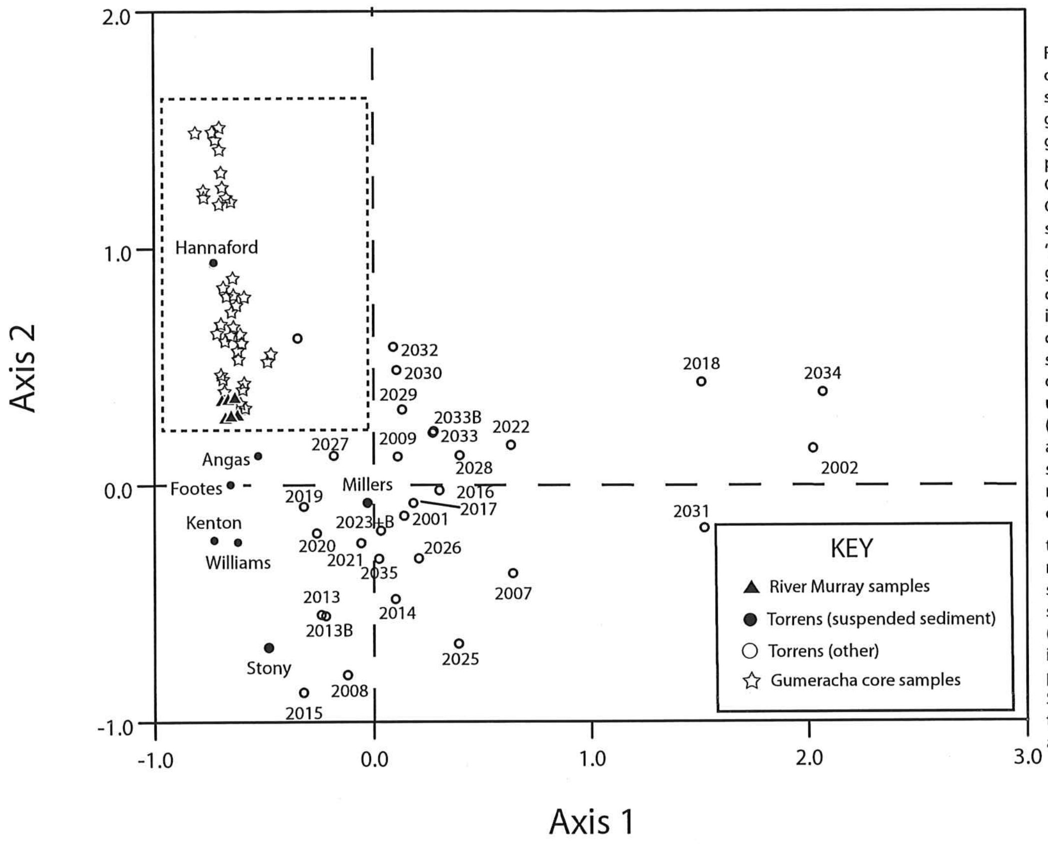


Figure 5.7 Principle components analysis sample biplot of geochemical results gathered from three potential sources and Gumeracha Weir. Gumeracha Weir samples were plotted 'passively' so their geochemical composition does not influence the location of the modern samples. Two sets of data from the sources used, Torrens (suspended sediment) and Gumeracha core samples, were retrieved during the course of this thesis by the author. The remaining two data sets used, River Murray samples and Torrens (other), have been integrated from previous research. Sample codes and types are listed in appendix 1.

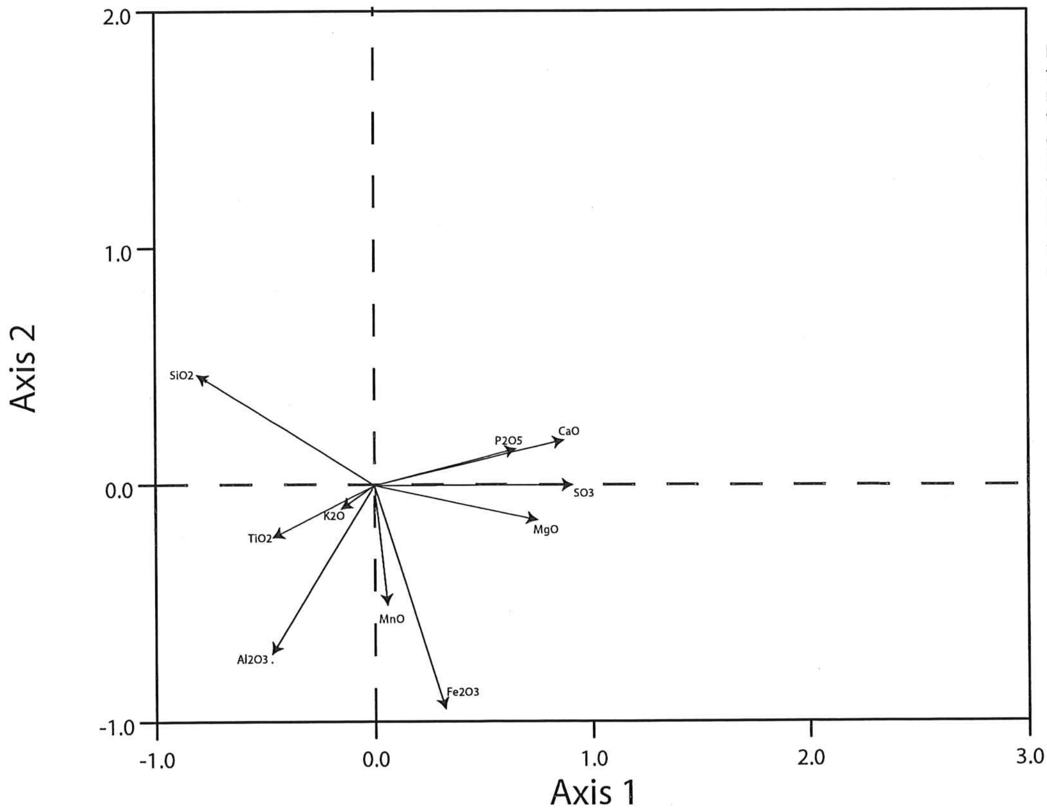


Figure 5.8 Vectors that summarise the main directions of variation in the geochemistry data. Length of the vector is proportional to the influence that variable has on the ordination

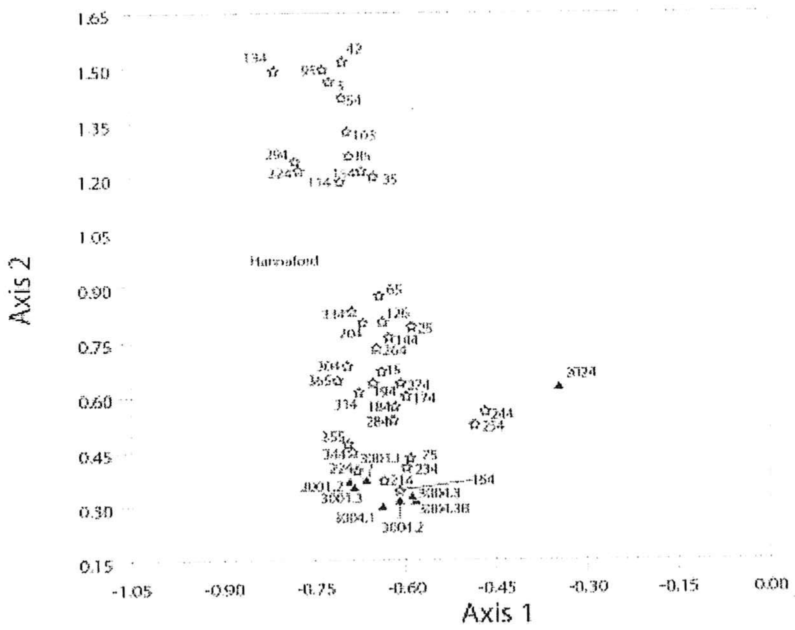


Figure 5.9 Enlargement of the data that is outlined by the doted line in Figure 5.7, these contain all GuW3 results, along with all eight River Murray samples and one Torrens (suspended sediment) result, Hannaford Creek.

5.3.1.2 Scatter Plots

A more defined analysis was conducted to gain a greater understanding of the patterns identified in the principle components analysis. Three ions were chosen for this analysis and plotted against each other into scatter plots (Figure 10, A sulphate against silica, B sulphate against calcium and C calcium against silica). Silica was chosen from the eleven ions because it was the most dominant and the principal variable. Sulphate and calcium, despite their low values, were used because they correlated least with silica or the other elements, therefore their fluctuations were less likely to be related to the trends of the more dominant elements. Manganese also showed considerable variation, however due to its extremely low percentage, was excluded from analysis.

From the three scatter plots represented in Figures 5.10, two GuW3 samples, depth 244 cm -245 cm and depth 254 cm- 255 cm, and the two Torrens with Murray water-d/s Millbrook samples (3003/1 and 3003/2) repeatedly shifted along a similar pathway from their respective assemblages. This indicates that these four data sets have similar geochemistry.

5.4 Fossil Diatom Analysis

There were thirty-seven diatom samples taken from the 3.71 meter GuW3 core at 10 cm intervals. A comparison of diatom species was conducted to establish the impact of River Murray water being diverted into River Torrens was having on both the algae community and the water chemistry of the river.

From Figure 5.11 it can be seen that *Actinocyclus normanii*, *Aulacoseira ambigua* and *Aulacoseira granulata* are the three dominant Murray River diatom species that have been identified. They are all planktonic taxa, that are found in the lower River Murray (Tibby and Reid, 2004) Both diatom species *Actinocyclus normanii* and *Aulacoseira granulata* first become present in the core at a depth of 336 cm. *Aulacoseira ambigua* does not present itself until depth 195 cm.

The diatom taxa were alphabetically ordered, with the exception of the three dominant River Murray species which are represented first. Four Zones and two sub-zones were identified from the diatom assemblages using a constrained incremented sum of squares technique throughout the core depth. Within these diatom zones shifts between the dominant diatom species are evident.

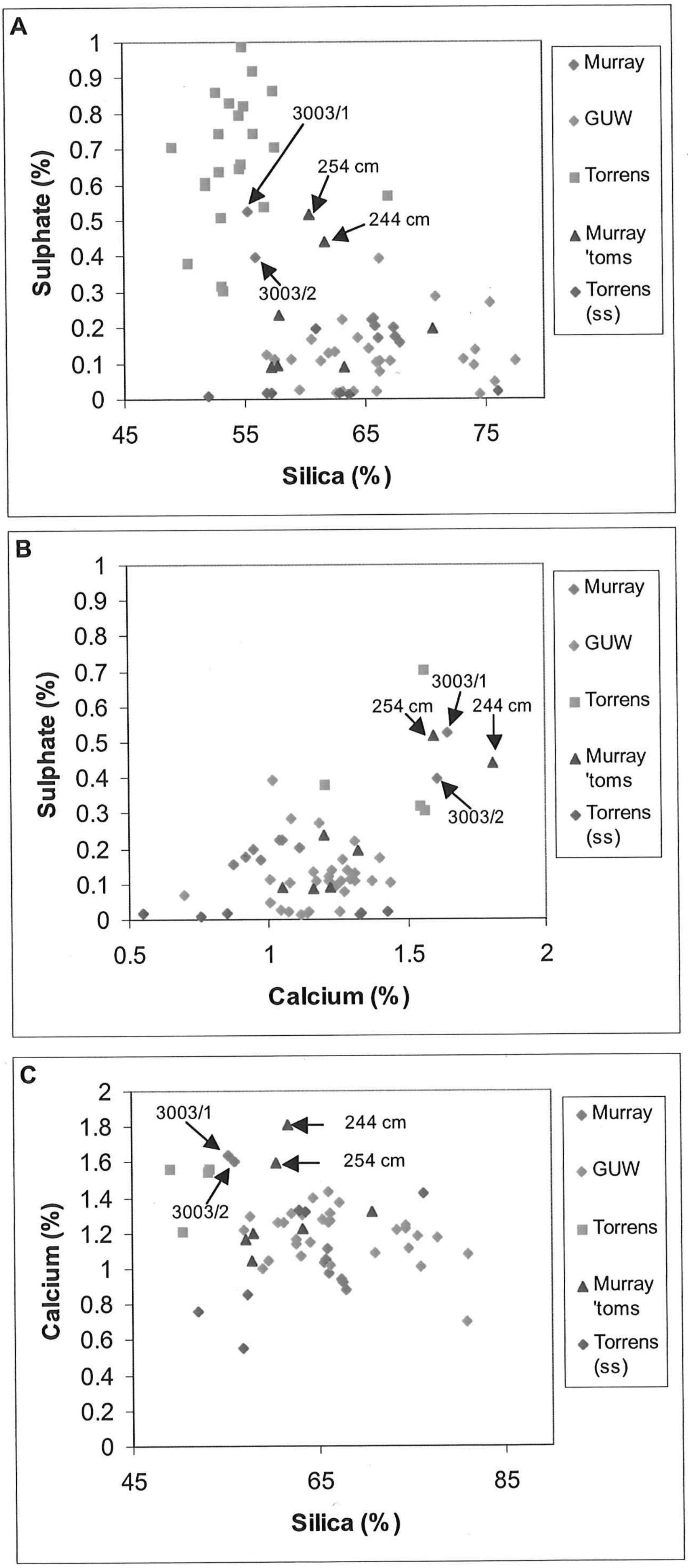


Figure 5.10
Bi-variate plots of selected elements in modern (River Torrens catchment and River Murray derived) and Gumeracha Weir sediments. Suspended sediment (ss) samples taken from River Torrens tributaries during a storm event are identified separately. Gumeracha Weir samples with a high proportion (>20%) of River Murray diatoms (Murray 'toms) are also separately identified. A Sulphate vs Silica. B Sulphate vs Calcium. C Calcium vs silica. Note samples 3003/1 were taken downstream of Millbrook Reservoir and potentially contain a mixture of Murray and Torrens sediment. Selected axes are truncated to focus on samples proximal to Gumerarka Weir.

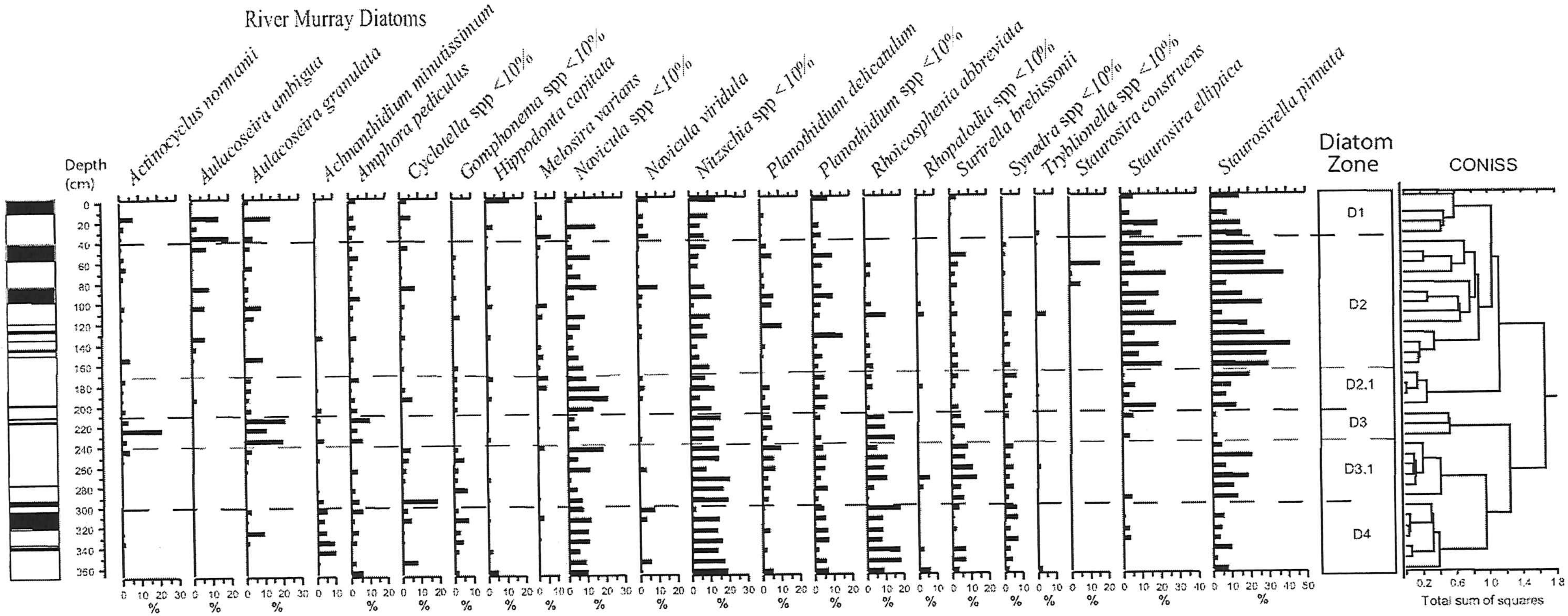


Figure 5.11 GuW3 Stratigraphy of diatom taxa that occured in abundances at, or greater than, 10%. The diatom taxa are alphabetically ordered with the exception of the three River Murray diatom taxa, which are displayed first. Diatom Zonations have been established from CONISS, total sum of squares.

5.4.1 Zone D4 (367 cm - 300 cm)

Rhoicosphenia abbreviata is the dominant diatom species in zone D4. There is also a large proportion of species within both the *Nitzschia* and *Navicula* genera. *Aulacoseira ambigua* and *Staurosira construens* are the only two species found elsewhere, that are not present at all in this zone, however *Staurosira elliptica*, and the two remaining River Murray diatom species, do not become present until 336 cm.

5.4.2 Zone D3.1 (300 cm - 240 cm)

At the bottom of sub zone D3.1 at a depth of 295 cm there is a significant peak of *Cyclotella* spp. There is also a considerable abundance of *Nitzshia* spp. and an increase of *Navicula* spp. towards the top of this zone. There is also a significant increase in the species *Planothidium delicatulum*, *Surirella brebissonii* and *Staurosirella pinnata,* making it the most abundant single species in this zone. *Actinocyclus normanii* and *Aulacoseira granulata* are absent for most of this section, only beginning to occur again at the very top at around depth 255 cm. *Rhoicosphenia abbreviata* declines slightly through this zone.

5.4.3 Zone D3 (240 cm – 210 cm)

Within this sub zone, *Staurosirella pinnata* falls to the lowest percentage (<3%) in the entire core. *Rhoicosphenia abbreviata* is again abundant, its presence increasing slightly from the previous zone. It is also at this point that *Actinocycus normanii* is in greatest abundance, >20% at depth 225 cm; however it peters off almost as abruptly as it begins. *Aulacoseira granulata* increases markedly, making it the most abundant single species in this zone, however the third River Murray species *Aulacoseira ambigua* is still absent from zone D3. There is also a noticeable decline of many other diatom genera, most noticeably those that have been present through the majority of the core up to this point, including *Synedra* spp., *Gomphonema* spp. and *Cyclotella* spp.

5.4.4 Zone D2.1 (210 cm – 170 cm)

Navicula spp. is the most dominant taxon of this zone, however *Staurosirella pinnata* increases considerably, making it again the most dominant single species in this section. *Staurosira ellipica* also becomes more abundant. *Synedra* spp., *Gomphonema* spp. and *Cyclotella* spp., return. One of the most noticeable changes in this zone is the massive decline in the abundance of *Rhoicosphenia abbreviata*, along with both River Murray genera *Actinocycus normanii* and *Aulacoseira granulata.* This is also the zone where the first occurrence, of the third River Murray species, *Aulacoseira ambigua*, which appears in abundance at 195 cm.

5.4.5 Zone D2 (170 cm – 40 cm)

Throughout this zone, the three River Murray species, *Aulacoseira ambigua, Aulacoseira granulata* and *Actinocycus normanii* are variably represented. *Staurosira ellipica* becomes one of the most abundant species within this zone, second only to *Staurosirella pinnata.* *Staurosira construens* occurs for the first and only time through the core and in considerable abundance. *Rhoicosphenia abbreviata* is in low abundance through this section, it increases sharply to 10% at 115 cm, however does not occur at all in others and is non-existent from 55 cm upwards. *Planothidium* spp. peaks at 135 cm and *Navicula viridula* peaks at 85 cm. *Achnanthidium minutissimum* only occurs once through this zone at depth 135 cm and then does not occur in the core again.

5.4.6 Zone D1 (40 cm- 0 cm)

Staurosira elliptica still has a strong presence in the 40 cm of the top of the core as does *Staurosirella pinnata* and *Nitzshia* spp. *Navicula viridula* and the River Murray species *Aulacoseira ambigua increases,* while *Actinocyclus normanii* and *Aulacoseira granulata* also maintain a notable presence. Along with *Rhoicosphenia abbreviata*, *Synedra* spp. and *Gomphonema* spp. are no longer present by the top section of the core.

5.5 pH Reconstruction from Fossil Diatom Analysis

The pH reconstruction based on the transfer function of Tibby (Tibby *et al.*, 2003) (Figure 5.12) shows that, while inferred pH levels have fluctuated throughout, there is a substantial increase in pH levels throughout the core. The pH reconstruction has been divided into the four diatom zones from which they were constructed.

5.5.1 Zone D4 (367 cm - 300 cm)

Between depths 366 cm and 315 cm pH levels fluctuate between 7.5 and 7.7 units, however it drops down to 7.37 units at 305 cm.

5.5.2 Zone D3.1 (300 cm - 240 cm)

The pH level sharply rises to 8.2 at 295 cm, before again dropping 0.3 units at the 285 cm. It rises up to 8.1 at 275 cm, before slowly decreasing to around 7.9 at 265 cm and 255 cm, and then down again to 7.7 at 245 cm.

5.5.3 Zone D3 (240 cm – 210 cm)

At depths 235 cm, 225 cm and 215 cm inferred pH levels fluctuate around 7.7 and 7.8.

5.5.4 Zone D2.1 (210 cm – 170 cm)

At depth 205 cm the inferred pH level again sharply rises to 8.2 units and falls back down to 7.9 units at 195 cm, and then to 7.8 units at 185 cm. The pH level then increases to 8.0 at 175 cm.

5.5.5 Zone D2 (170 cm – 40 cm)

The inferred pH level then sharply rises to 8.5 units at depth 165 cm. From depths 155 cm, 145 cm and 135 cm the levels fall to 8.3, back up to 8.6 and then back down to 8.3 respectively. At depth 125 cm there is again a sharp rise in pH levels to the second highest inferred value 8.8, recorded throughout the core. This is followed by a sharp drop to 8.4 units at the next depth. At 96 cm there is a 0.2 unit increase in inferred pH before the levels again fall to 7.8 units at 86 cm. At 76 cm the largest fluctuation of pH levels occurs in the core as they rise 0.9 units back up to 8.7. At 66 cm and 56 cm the pH level drops to 8.5 units and 8.4 units respectively, before peaking to 8.9 units at depth 46 cm.

5.5.6 Zone D1 (40 cm- 0 cm)

At depth 36 cm the greatest decline in pH levels occurs as it drops 0.9 units in 10 cm to 8.0. The inferred pH then fluctuates up to 8.5 units and back down to 8.0 units at depths 26 cm and 16 cm respectively, before remaining steady at 8.2 units at the final depth of 0 cm.

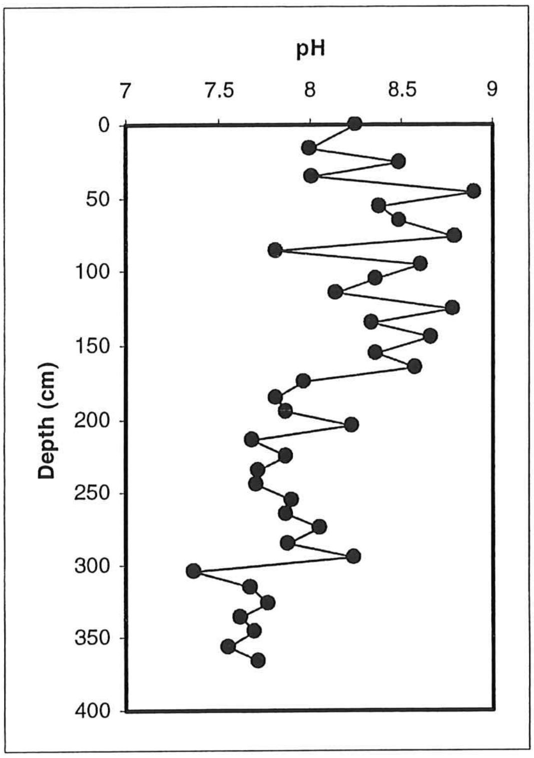


Figure 5.12 Diatom-based reconstruction of pH from Gumeracha Weir. pH was estimated using weighted-averaging calibration using the data set of Tibby *et al.* (2003). The model has a root mean square error of prediction of 0.35 pH units.

CHAPTER 6 DISCUSSION

6.1 Chronology and Sedimentation

From the two derived ^{210}Pb-based age-depth models, model two is used in this discussion, as the sequence of events outlined below supports the adoption of this model. From the ^{137}Cs dating (Figure 5.5), it can be established that, at a minimum, the top 334 cm of core, GuW3, has accumulated over 44 years, from 1958 to 2002 when the core was collected. The sedimentation rate at Gumeracha weir, post-1958, is therefore approximately 7 cm/yr.

Sediments between 334 cm and 371 cm pre date 1958. The remaining 37 cm of core, combined with the basal 15 cm beyond the reach of the D-section sampler (due to its elongated "nose"), total 52 cm. Hence, it could be suggested that since 1918 when Gumeracha Weir first became operational (Hammerton, 1986), a maximum of 1.3 cm/yr of sediment accumulated before 1958. However, GuW3 was extracted 80 meters upstream from the weir wall. This would have almost certainly limited the amount of sediment obtained as, sediment is likely to have begun accumulating at the base of the wall, accumulating vertically and longitudinally upstream to the point where GuW3 was obtained. The calculated sedimentation of 1.3 cm/yr before 1958 is therefore a minimum estimate. Sedimentation rates appear to be a great deal higher post Mannum-Adelaide pipeline (1954), which is not surprising as River Murray water has higher turbidity than those of the River Torrens and its tributaries (Davies *et al.*, 1992).

6.2 Sediment Sources in the Upper River Torrens Catchment

The main composition of GuW3 is a mixture of sand and clay-sized particles. The sand bands that are identified along the core lithostratigraphy (Figure 5.5) indicate periods where velocities are relatively high, as such velocities are required to carry heavier sand particles (Knighton, 1998). It is highly likely that the source of these deposits are high energy storm flows in the River Torrens. Even before regulation, the lower River Murray carried a predominantly fine suspended load, a condition accentuated following construction of regulation structures (Thoms *et al.*, 1999). Suspended sediment loads of the River Murray are therefore, unlikely to have contributed to the sand bands in the core.

Major sand bands do not appear to correlate with periods of high precipitation. Sand bands are evident at depths of 1 cm – 13 cm (2001), 43 cm – 60 cm (1999/2000), 84 cm and 100 cm (1996/97) and 300 cm – 321 cm (1960-63). There are a number of explanations for this including that the sand bands are a result of disturbance occurring upstream of the weir such as excessive erosion or riverbank collapse, that may be caused by activities such as land clearance or the land use practises outlined in Chapter 3. However, it is difficult to identify clear phases in the catchment history that can be related to the timing of sand deposition. It seems likely that the sand bands may represent small sand "slugs" which result from periods of erosion in the past and move slowly downstream during higher discharge events. Sand slugs are now recognised to be common phenomena in Australian rivers (Prosser *et al.*, 2001).

GuW3 samples with identified sand bands (including 3 cm, 42 cm, 54 cm, 85 cm, 95 cm, 294 cm and 324 cm) plot high on Principle Components Analysis (PCA) Axis 2 (Figure 5.7) and are, not surprisingly, characterised by high silica content (Figure 5.8). These, and the remaining GuW3 samples, are oriented largely in a line in the PCA Figures 5.7. Such a distribution suggests that there is a mixing of two (or more) distinct geochemical sources (Wallbrink *et al.*, 2003). Unfortunately, no potential source materials are identified at one end of the mixing line (high Axis 1). Samples with lower Axis 2 scores (i.e. those which plot lower than the Hannaford Creek suspended sediment samples) are, for the most part, located closest to samples from the modern River Murray. Sediment in these samples therefore appear to be largely derived from the River Murray. Indeed a number of these samples, including 164 cm, 214 cm, 224 cm and 344 cm, plot closer to some River Murray samples, than some River Murray sample plot to each other, indicating they have a very similar geochemistry. Importantly, whilst it could be argued that there is a substantial contribution to these sediments from the Angas, Footes, Kenton, Williams and Stony Creek catchments (which are located on the purported mixing line with low Axis 2 scores), no GuW3 samples plot below the modern Murray samples This is despite the fact that, at times, there is little River Murray inflow into the River Torrens for periods of more than a year (Heneker, 2003).

Further support for this interpretation comes from a combination of the diatom data and a more detailed examination of the geochemistry data. Figure 5.11, diatom stratigraphy, indicates the proportion of diatoms attributed to a River Murray source. Figure 6.1 illustrates these data in a different manner, with the proportion of River Murray diatoms expressed on a temporal axis. The first dated appearance of River Murray diatoms (1955) corresponds well with the commencement of the Mannum- Adelaide pipeline's operation (1954). Furthermore, there is a good correlation between the abundance of River Murray taxa and the volume of River Murray water pumped into the River Torrens channel in the period 1974 and 2002. The peak in Murray water input centred on 1978 is clearly registered in the relative abundances of Murray diatoms. Lower recorded values of River Murray diatoms in the GuW3 sediments correspond to reduced volumes of River Murray water pumped into the upper River Torrens catchment between 1986 and 1990. Lastly, the medium level pumping witnessed through the 1990s to present corresponds to elevated, albeit variable, relative abundances of River Murray diatoms in the sediments.

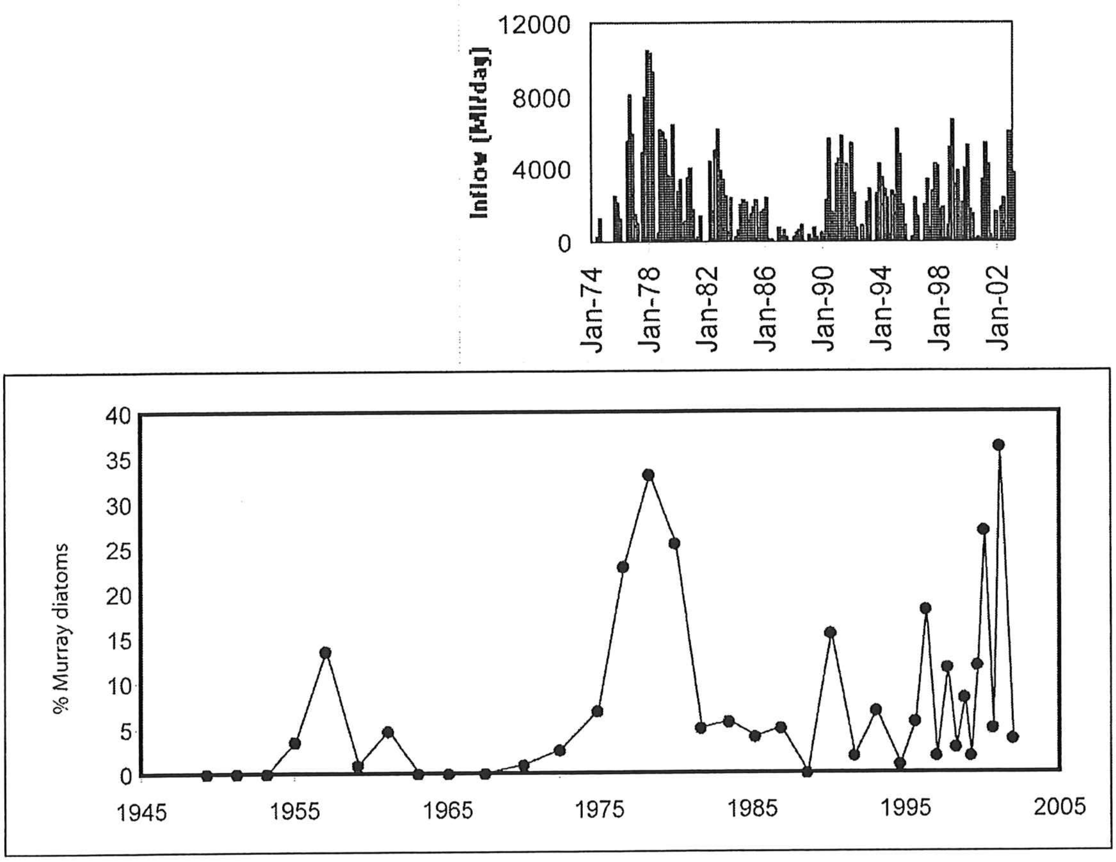


Figure 6.1: Inflows of River Murray water pumped into the River Torrens above Gumeracha Weir (i.e. from Mount Pleasant and Angas Creek scours) compared to the total relative abundance of River Murray diatoms (*Actinocylus normanii, Aulacoseira ambigua* and *Aulacoseira granulata*) in the GuW3 core. Volumes of River Murray water were estimated by Dr Teresa Heneker, Department of Water, Land and Biodiversity Conservation (Heneker, 2003).

Given the strong correspondence between River Murray diatoms and the volume of water pumped into the Torrens catchment, these data may be used to identify those samples most likely to be characterised by River Murray sediments. Through examination of selected elements which allow a separation of River Murray and River Torrens suspended sediment sources (Figure 5.10), it can be seen that the GuW3 samples that contain the highest proportions of River Murray diatom taxa often plot further from the River Murray samples than a number of other GuW3 samples, for example 334 cm, 314 cm, 304 cm, 274 cm, 265 cm, 204 cm, 144 cm, 65 cm and 25 cm. A number of these samples also fail to correlate with periods of River Murray water input. This observation suggests that, although the other GuW3 samples may not contain as high a percentage of River Murray diatom taxa, they do in fact have similar geochemistry to River Murray samples and that River Murray sediments are being deposited in the River Torrens system and then reworked during high natural (Torrens) flow events. A similar situation has been noted in Kangaroo Creek Reservoir, downstream of Gumeracha Weir, where periods where the most Murray sediment is deposited are those when the Torrens is flooding (Tibby and Gell unpublished data).

One possible contradiction to the above argument is that GuW3 samples, considered to have been deposited before commencement of pumping River Murray water (344 cm, 355 cm and 365 cm), also plot close to the modern Murray samples (Figure 5.7). It is possible that more precise results could have been obtained from the geochemistry if analysis conducted on GuW3 samples and River Torrens suspended sediment samples had been consistent with the River Murray samples. GuW3 samples and River Torrens samples were analysed using non-specific particle sizes, as there was not enough fine material on which to conduct the analysis. The River Murray samples analysed were, however, dominated by sediment particles <10 μm. The larger particle sizes originating from the catchment may be influencing, and possibly cloaking, some of the geochemistry elements from the smaller particle size, Murray sediment, giving only partial answers, especially considering that the bulk of Murray River sediment being transported into the River Torrens, consists of smaller particle sizes. Nonetheless, larger particle size analysis on the Guw3 and River Torrens samples is beneficial in the respect that it indicates that at least one source in the catchment, containing high proportions of silica that is greatly contributing to the sedimentation at Gumeracha Weir.

The provenance of that sediment derived from the River Torrens catchment, is, at present, uncertain. The data presented in Figure 5.9 indicate that Hannaford Creek is a possible source, due to its position on the mixing line and its high concentrations of silica. However, this catchment has relatively low rainfall (Heneker, 2003) and the suspended sediment concentrations in this stream during a substantial storm event (Table 4.1) suggest that it is unlikely to be a major source. As noted (above) From Figure 5.7 the mixing line also incorporates Angas, Footes, Kenton, Williams and, to some extent, Stony Creek, all of which are also possible sources. From the seven upstream creeks where suspended sediment samples were retrieved, Hannaford Creek contained the forth-smallest amount of sediment (42.7 mg/L), whereas Kenton Creek, the sub-catchment carrying the largest volume of suspended sediment (1671.3 mg/L), for instance was contributing almost forty times the sediment of Hannaford. Furthermore Kenton Creek is the closest, sampled creek to Gumeracha Weir and therefore should have the least amount of particle drop off to any other stream, as its distance from the weir is far less. Millers Creek, the seventh creek sampled, has been ruled out as a possible source as it does not sit along the mixing line. Furthermore there does not appear to be one or more specific type of land use in the Torrens catchment, e.g roads, generating the bulk of the Torrens' sediment contribution to Gumeracha Weir. As can be seen from an examination of Figure 5.7 PCA, a variety of land uses plot well away from the GuW3 samples and are not located on the hypothesised mixing line.

Weirs are sediment traps, the sediment that is washed down streams accumulate in them, rather than being deposited naturally downstream. In Gumeracha Weir the high sedimentation rates are causing the weir to fill at a rapid pace. This could firstly be a problem as it limits the weirs water holding capacity, possibly leading to more frequent overspills during large storm events. Secondly, at present the water at Gumeracha weir is 10 meters high, the sediment that has accumulated at the wall is 7 meters high, this is a concern because the sediment has accumulated to within 0.5 meters of the mouth of the off-take pipeline from Gumeracha Weir to Millbrook Reservoir (Brian Murray, Manager operations, Millbrook Reservoir). The transport of such a large amount of sediment is likely to have even greater affects upon the water chemistry being diverted to the reservoir, as well as filling up the reservoir and decreasing its storage capacity. Dredging is proposed for Gumeracha weir to rectify these problems (Brian Murray, Manager operations, Millbrook Reservoir), however it is a costly project that causes a great deal of disturbance to the river's ecology.

Between 1974 – 2002 the scours above Gumeracha weir, discharged 406, 000 ML of River Murray water into the River Torrens. This is only a slightly smaller percentage of the water flowing into the river from the catchment of 575, 000 ML (Heneker, 2003), reaffirming the probability of the River Murray being a major sediment source. So the sediment in Gumeracha Weir is originating from two or more sources, the first being the import of River Murray water.

6.3 Water Quality

The change in diatom taxa through the core provide substantial insight into changes in water quality of the River Torrens and the role of River Murray water in this change.

Murray diatoms are evident in sediments dated to the commencement of pumping (1954, 336 cm), but at relatively low values (Figure 5.11). The second major influx of River Murray diatoms begins at 265 cm (1968), and increases dramatically from 235 cm (1976), to 215 cm (1981). The first date coincides with the opening of the third scour importing River Murray water to the River Torrens and the second scour that affects the Gumeracha weir site. This third scour is situated at Mount Pleasant and has the capacity to release 492 ML/per-day, a large increase to the Angas Creek pipeline, which only has the capacity to release 168 ML/per-day. Therefore the Mount Pleasant scour drastically increased the amount of Murray input into the system, which would entirely explain the disproportionate increase of Murray diatoms at that time (Brian Murray, Manager operations, Millbrook Reservoir). The second dates correlate with the period when the largest volume of Murray water was being diverted into the Torrens (Heneker, 2003), accompanying the peak in River Murray taxa (Figure 6.1).

Between 205 cm (1982) – 165 cm (1990) there is an increase in *Staurosirella pinnata* and a decrease in *Rhicosphenia abbreviata.* This is attributed to the fact that *Staurosirella pinnata* is faculatative plankton, which means it can live within the water body and can also survives in epipelic (mud habitat) and epilithic (rock habitat). *Rhicosphenia abbreviata* on the other hand, can only live in epipelic and epilithic habitats. The change in taxon is most likely due to turbidity. Turbidity, among other things, decreases the ability for light to penetrate through the water column (Boulton and Brock, 1999) therefore limiting the ability for epipelic and epilithic diatoms to reproduce and photosynthesise. Planktonic taxa are more likely to thrive in such conditions as they have the ability to thrive in the water column where more light is available.

The euphotic zone is the depth at which 99% of light disappears in the water column and therefore, generally, the depth where the greatest reduction of photosynthesis occurs (Boulton and Brock, 1999). The depth at which the euphotic zone occurs varies greatly between water-bodies and is influenced by a number of different factors. In the River Torrens two such factors can be attributed to Murray water input, these are water depth and turbidity. Firstly, the influx of additional water from the Murray means that water levels are frequently higher than they would otherwise be. Higher water levels decrease the possibility of light penetrating down to epipelic and epilithic habitats as the further the light travels through the water column, the more likely it will be absorbed before it penetrates to the riverbed. The River Murray carries much greater loads of sediment than that of the River Torrens (Davies *et al.*, 1992), so input of River Murray water into the River Torrens there is a greater increase in turbulence.

Some indication of the possible impacts of turbidity on *Rhicosphenia abbreviata* are evident in Figure 6.2, as its presence decreases with an increase in turbidity in Mount Lofty Ranges streams (Gell, unpublished data). In general this taxon declines following the commencement of pumping to the Mount Pleasant scours. This taxon is eventually eliminated from the system and *Staurosirella pinnata* and *Staurosira elliptica* become the dominant taxa. These taxa are facultative planktonic (i.e. part of their life cycle is spent in the water column), with a chain-forming structure which enables them to be entrained into the water column. In comparison with an attached taxon *Rhicosphenia abbreviata* they are advantaged in turbid waters and are often associated with catchment clearance and soil erosion (Flower *et al.*, 1988). Their continued abundance in Gumeracha Weir presumably relates to continually elevated suspended solids concentrations in the water column resulting from River Murray pumping.

In addition to higher suspended solids, River Murray waters also have significantly higher total phosphorus concentrations. Indications that Gumeracha Weir has become more eutrophic over the past fifty years can be seen in changes in diatom assemblages. For example *Melosira varians*, a nutrient enrichment indicator (Sonneman *et al.*, 2000) increases in abundance at 185 cm (1985/86) just after the major influx of River Murray

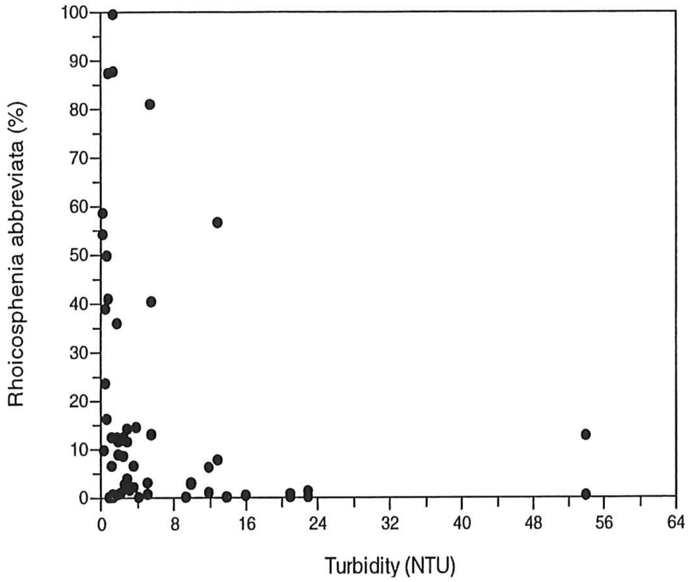


Figure 6.2 Relationship between *Rhoicosphenia abbreviata* and turbidity in a 61 sample Mt Lofty Ranges stream data set. NB: One sample with turbidity> 100 NTU (with no *R. abbreviata*) not illustrated. (Gell, unpublished data).

water entering the River Torrens system. It also increases in abundance at 35 cm (2000), where another large input of River Murray water comes into the river. This indicates that eutrophication of Gumeracha Weir is very likely to be a result of higher nutrient loads coming into the system from River Murray inputs, rather than from water quality changes brought about by ontogeny of the reservoir (described in detail in chapter 2) The most dominant species within the core *Staurosirella pinnata* and *Staurosira elliptica* give no great insight into changes of nutrients as they have a very broad ecological preference (Bennion *et al.*, 2001) and can therefore thrive in environments with very high and very low nutrient concentrations.

The pH reconstruction also indicates that shortly after the River Murray water was first being diverted into the Torrens, pH began to fluctuate to a much greater extent. Furthermore, over the past 50 years the pH levels have become significantly more alkaline. pH increases from an average of 7.6 units from the bottom of the core to 1964 (295 cm) up to an average of 7.9 units from 1964-1988 (295 cm – 165 cm) and then increases up to an average of 8.4 units from 1988 – 2002 (165 cm – 0 cm). This phenomenon was to be expected with the input of River Murray water into the River Torrens system as Murray water pH levels are considerably more alkaline with pH at Morgan (upstream of the Mannum off take) typically between 8.0 and 9.0 (Tibby and Reid, 2004). The change in species assemblage clearly outlines the increase in pH that has been occurring since 1954 when the pipeline was first established. Default trigger values have been estimated by Australian and New Zealand Environment and Conservation Council (ANZECC), and, Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ), at pH 8.0, at which point they suggest ecological health can be compromised (ANZECC, 2000).

CHAPTER 7 CONCLUSION

7.1 Sedimentation in River Torrens Catchment Reservoirs

By nature, reservoirs accumulate large volumes of sediment. The sedimentation rates in Gumeracha Weir are particularly high and potentially compromise its role in the Adelaide water supply system. Sediments in Gumeracha Weir originate from two sources. The first source is the River Murray, which has transported suspended sediment via the Mannum-Adelaide pipeline since it was established in 1954. Fine suspended sediments from the River Murray have impacted on the river health by increasing the turbidity in the Upper River Torrens System. This is exemplified by the elimination of the attached diatom *Rhoicosphenia abbreviata* and its replacement by turbidity tolerant taxa. Associated with this change is a substantial increase in inferred pH in Gumeracha Weir. The other sediment source originates within the Torrens catchment, the bulk of which is deposited as a result of high energy flow events and do not appear to be associated with any single land use practise in the River Torrens catchment.

7.2 Sources of Nutrients in River Torrens Catchment

The point sources of River Murray water entering the River Torrens system are a key source of nutrients in Gumeracha Weir. River Murray water contains higher concentrations of total phosphorus (Schultz *et al.*, 2000; Tibby and Reid, 2004), which is being transported into the River Torrens system attached to suspended sediment particles.

The diatom stratigraphy, particularly through the increased relative abundance of *Melosira varians*, indicates nutrient enrichment in Gumeracha Weir following the commencement of pumping of River Murray water into the River Torrens system.

7.3 Recommendations for Management

There are a number of options for better management of the River Torrens to improve the River's health. The quality of the water being transferred from the River Murray to the River Torrens could be improved by simply adjusting the timing of water pumping from the River Murray to a period of low turbidity in the source, for example during the months August and October. It may also be suggested that water from the River Murray be pumped straight to Millbrook Reservoir, where excess suspended sediment can settle out, thus limiting the impact of the River Murray water on the River Torrens. More fundamentally, a reduction in water use to the point where River Murray water input is no longer necessary would result in dramatic improvements in the ecological health of the Upper Torrens system. Such an initiative requires widespread community support, however such proposals are now in the public domain. Finally, it is recommended that dredging, though expensive, should be considered in areas along the river that have high sediment accumulation as this would reduce the impact of internal nutrient cycling which might otherwise be a substantial nutrient source for many years to come.

7.4 Suggestions for Further Research

This, and coincident studies within the River Torrens catchment, are likely to prompt a reassessment of the focus of sediment and nutrient research by the statutory authorities. As such, it opens up an array of future research opportunities. Further research possibilities include additional cores being retrieved from Gumeracha Weir as close as possible to the wall to assess the full volume of sediment trapped through the entire history of the weir. Such an initiative is necessary before proposed dredging of the weir takes place. By obtaining the entire depth of sediment, clearer insight could be gained into the pre Mannum-Adelaide pipeline conditions.

It would also be beneficial to conduct geochemistry analysis using <10 μm particle sizes on the core to obtain more comparable results between Gumeracha Weir sediment and River Murray samples that were analysed using <10 μm particle sizes.

The collection of a more extensive range of suspended sediment samples from tributaries sub catchments upstream would provide a more rigorous assessment of sediment sources. However to do this would be relatively difficult as it would require long-term access to a continuous flow centrifuge. Additionally, the major storm events that transport much of the sediment are sporadic (Schultz *et al.*, 2000) and the timing of sampling would need to catch the rise in these floods. Even in this event, at best only 1-2 samples would be obtained per flood.

Research could also extend to examine more widely the sources of sediment in other Mount Lofty Ranges impoundments, in particular Mt Bold and South Para Reservoirs. These sites, which also receive River Murray water flow diversions, would be a logical extension to the research. Mt Bold, in particular, is older than Gumeracha Weir and should contain sediment indicative of pre- and post Murray water divergence into the Mount Lofty catchments. It is anticipated that this research would bring about a clearer understanding of how River Murray water input has affected both the water chemistry and biota of the Mount Lofty water supply catchments and streams.

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Code	Location	Type
2001	Yacka ridge	Sediment grab
2002	Upstream of Mannum pipeline intake Griggs rd	Sediment grab
2013	Foresten Creek on northern side of Torrens	Deposited sediment
2014	Surrounds of Foreston Creek	Surface soil
2015	Within foreston Creek	Sub soil
2016	Torrens river @ Hynes bridge	Deposited sediment
2017	Kenton valley Creek	Deposited sediment
2018	Williams Creek	Deposited sediment
2019	Williams Creek	Surface soil
2020	Williams Creek	Subsoil erosion
2021	Torrens river	Deposited sediment
2022	Adjacent to Torrens river near Bulimberg hill	Surface soil
2023	Unknown Northern input stream NW of Birdwood	Deposited sediment
2024	Unknown Northern input stream NW of Birdwood	Surface soil
2025	Stony Creek	Sediment
2026	Torrens on black snake rd	Deposited sediment
2027	Black snake rd	Surface sediment from gravel rd
2028	Torrens river	Sediment
2029	Road leading to Cromer	Sediment from surface of road
2030	Near Cromer rd	Surface erosion from cultivated paddock
2031	Torrens u/s of input line next to Mt Pleasant	Deposited sediment
2032	Next to Mt Pleasant	Surface soil from cultivated land
2033	Adjacent to Mt Pleasant golf course	Sediment from road surface
2034	Upper Torrens river next to Mt Pleasant golf course	Deposited sediment
2035	u/s from Gumeracha Weir	Deposited sediment
3001/1	Murray waters-Millbrook scour	Continuous flow centrifuge
3001/2	Murray waters-Millbrook scour	Continuous flow centrifuge
3001/3	Murray waters-Millbrook scour	Continuous flow centrifuge
3004/1	Murray waters-at Mannum	Continuous flow centrifuge
3004/2	Murray waters-at Mannum	Continuous flow centrifuge
3004/3	Murray waters-at Mannum	Continuous flow centrifuge
3004/3B	Murray waters-at Mannum	Continuous flow centrifuge
3003/1	Torrens with Murray water-d/s Millbrook	Continuous flow centrifuge
3003/2	Torrens with Murray water-d/s Millbrook	Continuous flow centrifuge

Appendix 1: sample codes, sample location and type for modern geochemistry samples