

## Secrets in the Sediments: a History of Sediment and Pollution Loads in the Lower Torrens River, S.A.

*Peter Gell,<sup>1</sup> Peter Wallbrink,<sup>2</sup> Glenn Tassicker<sup>1</sup> & Marie Illman.<sup>1</sup>*

**SUMMARY:** Analyses of sediment sequences can improve stream management by placing present catchment conditions in a temporal context, by tracing the principle sources of sediments and nutrients and by identifying achievable levels of rehabilitation based on the past. Analysis of caesium-137 from sediment cores extracted from impoundments along the River Torrens, revealed that nearly all sediment post-dated 1958 and that deposition rates were potentially high. The low activity levels suggested that most (75-95%) of the sediment was derived from sub-surface material ie. not that transported from surface soil but from gullying and stream bank collapse. Modern diatom and water analyses revealed that the River is presently hypereutrophic, at times exceeding national guidelines for nitrate & phosphate. Analyses of fossil diatoms in a sediment core demonstrated that nutrient levels have been increasing towards the present but have been as high in the past. Phosphorous can attach to clay particles and so bank collapse and gully erosion constitutes major sources of phosphorous in some systems. As algae have the capacity to extract sediment-bound phosphorous it is conceivable that sediment input to the River Torrens is the main source of nutrients to stream water. The dual issues of high sedimentation rates and excessive nutrients in the River may be best addressed by focusing management effort on buffering the riparian zone from erosion. A practical way to achieve this would be to employ baffles or to retain a broader riparian strip than at present. Accumulated evidence suggests that this may be a prudent approach in most systems.

### THE MAIN POINTS OF THIS PAPER

- Analysis of sediments can reveal erosional, nutrient and pollutant histories of catchments
- Sediment accumulation rates in the Torrens are potentially high; material is derived from gully and channel erosion
- Torrens River becomes hypereutrophic at times, can exceed national guidelines
- It is likely that subsoil derived native phosphorus is the main contributor to river nutrient P status
- Management of this issue should focus on stabilising riparian buffers to reduce P and N.

### 1. INTRODUCTION

Sediments are generated within catchments as a function of their erosional history. It is also known that many nutrient, pollutant, inorganic and organic compounds are sorbed to sediments, and so they are important vectors for these compounds. Thus by analysing sediments that accumulate in reservoirs an attempt can be made to reconstruct a history of erosion, as well as nutrient and pollutant delivery, within catchments. If a chronology can also be constructed for the sediments, then contemporary catchment condition can be evaluated with respect to catchment behaviour in the past. This can aid catchment managers who aim to set remediation targets by providing them with an assessment of prior catchment condition, thus identifying those parts of the system that have changed. In this way it is then possible to outline the steps necessary to rehabilitate a catchment,

or at the least provide a framework to evaluate the benefits of management efforts.

The best environment in which to utilise these 'secrets in the sediments' is in situations where the sediment record is long. In this respect old reservoirs may provide a good record of catchment sedimentation. The Torrens River, S.A. (Figure 1) has three such reservoirs of considerable age. The purpose of our study is to attempt a reconstruction of pollutant and nutrient delivery in this catchment, utilising the sediments contained within these reservoirs. In this way some implications for future improvements in catchment condition can be made. The Torrens catchment itself is a good environment in which to attempt such a process, as it has been degraded for some time, and remains an important water supply source for the city of Adelaide.

<sup>1</sup> Department of Geographical & Environmental Studies, The University of Adelaide, SA, 5005. E-mail: pgell@arts.adelaide.edu.au.

<sup>2</sup> C.S.I.R.O. Division of Water Resources, Clunies Ross St., Acton, A.C.T., 2601.

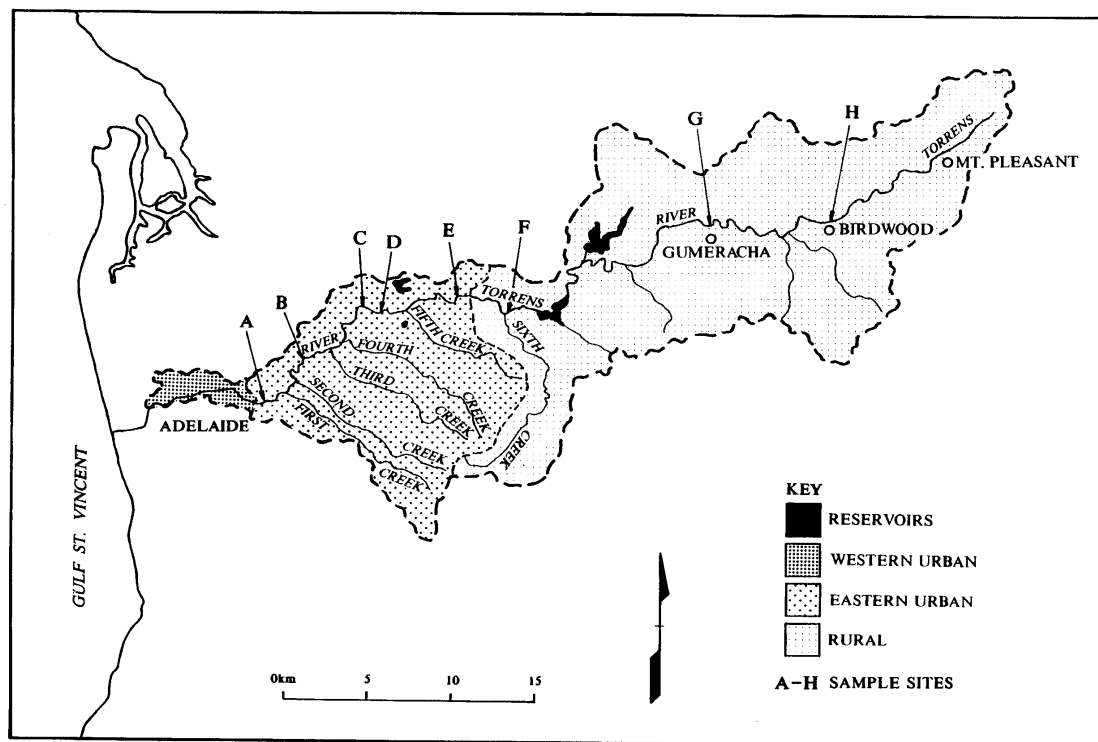


Figure 1. The Torrens River catchment and the location of modern sampling sites (based on E&WS, 1981).

## 2. THE RIVER TORRENS

The River Torrens catchment has a total area of 490 km<sup>2</sup>, of which 70% lies in the rural environment of the western slopes of the Mount Lofty Ranges, and the remaining area is urban (E&WS, 1981; Torrens Catchment Water Management Board, 1996). The climate is Mediterranean, with characteristically warm, dry summers and cool, wet winters. Precipitation is augmented by orographic uplift caused by the Ranges (see Fisher, this volume for a more detailed description).

## 3. SEDIMENT CORES

A series of sediment cores were collected from reservoirs within the catchment in February and March 1996 to document changes through time using radionuclide, sediment and/or fossil diatom analysis. The longest core (TL-3), was extracted from the centre of Torrens Lake. A core from Gorge Weir (GO-3), was taken from the surface of an exposed lateral bench, that ran for approximately 100m above the southern waterline. The core itself was located approximately 80 m from the dam wall within this deposit which appeared not to be disturbed by recent dredging (site I). At Gumeracha Weir (Site G), a core (GU-2) was taken from the middle of a submerged sediment deposit, ~35 m upstream of the dam wall, and about 15 m from the eastern edge. The depth of water overlaying the sediments was measured at about 40 cm.

## 4. METHODS & ANALYSES

### 4.1 Sediments

The three sediment cores were cut into one cm sections for the determination of bulk density, moisture content,

loss-on-ignition (organic content) and, in the case of cores GO3 and GU2, for radionuclide analysis. In the latter case, sections below 10 cm were bulked towards the base of each core. Increments are given as the actual core depths. ie. compaction has not been taken into account.

### 4.2 Fallout Caesium-137

Anthropogenic <sup>137</sup>Cs (half-life 30.2 yr) is the product of above-ground nuclear weapons testing during the 1950s-70s (Longmore *et al.*, 1983). It is deposited to earth primarily by rainfall, and thus labels exposed surface soils (Wallbrink and Murray, 1993). Studies in undisturbed Australian soils have found that the majority of this nuclide (> 90%) is retained within the top 100 mm of the soil (Wallbrink and Murray, 1993). The subsoil beneath them is unlabelled. In this way, it is an ideal tracer to quantify the contributions from surface and subsurface soils to suspended sediments. The retrospective contributions from both these sources can also be determined by analysing its concentration within sediment cores. The Caesium-137 (that is now detectable) in Australia was deposited since 1958. In this way, the first appearance of <sup>137</sup>Cs can also be used to date sediment horizons to this time (Olley *et al.*, 1990). An average accumulation rate can then be calculated from (i) the elapsed time in years from 1958 to the present day and (ii) the overlaying depth of deposits to the surface. This assumes that sediment accumulation has been progressive to the present day, and that no major scour or degradation of core material has occurred. Analyses of <sup>137</sup>Cs were undertaken by high resolution, low background gamma spectrometry using a germanium well detector following Murray *et al.* (1987).

### 4.3 Pollen

Pollen samples were prepared following Faegri and Iverson (1975) and a minimum of 100 grains were identified from each sample.

### 4.4 Fossil Diatoms

Diatoms<sup>3</sup> have an intricate, siliceous frustule or shell which preserves well in accumulated sediments. This allows for their use in reconstructing a record of change in water quality over time based on the known modern ecology of species in the fossil record. The Torrens Lake core (TL-3) was sub-sampled for diatoms and the proportions of each taxon determined from eleven levels. The was zoned on the basis of the CONISS dendrogram in the program TILIA (Grimm, 1992). The diatom-inferred conductivity and  $\text{NH}_4^+$  values were derived from the data set of modern samples using calibration and regression techniques (see ter Braak and Juggins, 1993). DAIPo<sup>4</sup> values were also computed from the fossil assemblages to provide a record of past inferred organic pollution.

### 4.5 Modern Water Quality and Diatom Biomonitoring

Water samples and modern diatoms were collected from eight sites along the River Torrens (Figure 1) during three visits (December 1995; April 1996; October 1996). Four water quality parameters were measured in the field (pH, conductivity, DO, temperature) and three ( $\text{PO}_4$ ,  $\text{NH}_4$  and  $\text{NO}_x$ ) were determined in the laboratory using a Jenway 6100 spectrophotometer. One epilithic (rock) and one epipellic (mud) diatom sample was taken from each site. One hundred and forty-three diatom taxa were recorded from the 47 samples (the December 1995 site C epilithic sample contained no cells). Weighted averaging of the Diatom Assemblage Index of Pollution (DAIPo) values of Watanabe *et al.* (1988) was undertaken to gain an indication of levels of organic pollution (*sensu* Reid *et al.*, 1995) between sites along the River Torrens and between seasons.

## 5. RESULTS AND DISCUSSION

### 5.1 Sources of Sediment

If it can be demonstrated that the total amount of  $^{137}\text{Cs}$  in the two dam cores is dominated by inputs from the catchment, as opposed to derived from direct fallout, then the concentrations of  $^{137}\text{Cs}$  on the sediments can be used as an indicator of their source in the catchment. The total inventory of  $^{137}\text{Cs}$  in core GO3 is  $3,383 \pm 215 \text{ Bq/m}^2$  and that from GU2 was  $4040 \pm 200 \text{ Bq/m}^2$ . These values are about an order of magnitude more than that measured from direct fallout alone at Meadows (near Adelaide) of  $360 \text{ Bq/m}^2$  (corrected to 1996) and confirms that the great majority of the  $^{137}\text{Cs}$  (and associated material) has been derived from the catchment. The high  $^{137}\text{Cs}$  concentrations observed at

the soil surface and the low concentration in the subsoil material, were used as end members in a two component mixing model, to determine their relative contributions over time to the sediment material found in the two cores.

For example it was found that the average contribution from subsoil material to Gorge Weir core (GO-3) sediments was 86% and that from topsoil is 14% with an estimated uncertainty on these values of ~11% (Figure 2). Such percentages are consistent with extensive bank collapse and gullying upstream of the Gorge Weir. It was determined that the average amount of subsoil contribution to the Gumeracha Weir core (GU-2) sediments was 82% and the topsoil component was 18%, with estimated uncertainty on these values of ~9% (Figure 3). The subsoil contribution is 4% lower than in the Gorge core, but this is still reflective of excessive bank erosion and/or collapse upstream of the Gumeracha Weir.

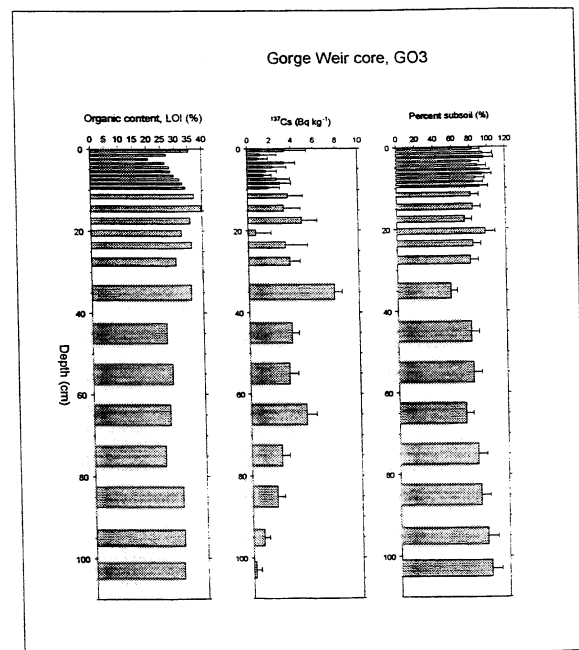


Figure 2. Radioisotope analysis of Gorge Weir core GO-3.

### 5.2 Core Chronologies

The Torrens Lake was formed in 1901 with the construction of the Torrens Weir. The core extracted from the lake is 156 cm. Therefore, the minimum rate of sedimentation would be approximately 1.6 cm/year (156 cm/90 or so years). The record for exotic *Pinus* pollen for Gorge Weir suggests that the basal sediments may just extend to *ca* 100 years at the base. However, the  $^{137}\text{Cs}$  analysis indicates that the material above 100 cm post-dates 1958. This suggests that all but the lower 7 cm of sediments in the GO-3 core are younger than 40 years old. The date of 1958 at 100 cm in the GO-3 core is equivalent to an average deposition rate of 2.6 cm/yr (Olley *et al.*, 1990). The Gumeracha Weir core (GU2)

<sup>3</sup> Diatoms are single-celled algae which are sensitive to fluctuations in water quality

<sup>4</sup> DAIPo is a scale from 0-100 where low values represent eutrophic conditions

reached a depth of 120 cm and  $^{137}\text{Cs}$  was found throughout the entire core, indicating that the sediments post-date 1958. Therefore a minimum accumulation rate of 3.15 cm/yr can be estimated (not accounting for compaction) for the Gumeracha Weir.

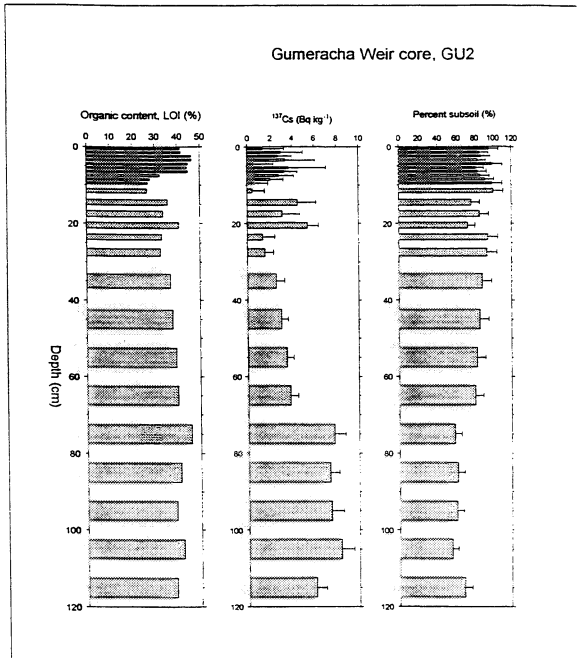


Figure 3. Radioisotope analysis of Gumeracha Weir core GU-2.

The proposed accumulation rates for the GO3 and GU2 cores must remain speculative however, until three issues are resolved. The first is that compaction in the cores has not been formally taken into account. The second is that material at the top of the cores may not have been deposited recently, due to the low trap efficiencies of these dams. In both these cases the 'true' accumulation rate would be underestimated, and the values given here would be minima. The third issue is that the presence of radioactive  $^{137}\text{Cs}$  and *Pinus* to these low core depths could be explained by within reservoir processes such as slumping and/or mixing of reservoir deposits. Further work aims to investigate the degree to which these issues influence the accumulation rates given here.

### 5.3 Water Analyses

Low water levels were noted in December 1995 and these had declined further by April 1996 resulting in a sequence of pools with high conductivity levels (Table 1). The October survey followed heavy rainfall and so the waters were diluted. Additionally, the flood flows produced a high degree of homogeneity between sites. The values of 1100  $\mu\text{g/L}$  of  $\text{PO}_4$  (site D, 12/95) and 17760  $\mu\text{g/L}$  (site A, 12/95) and 12560  $\mu\text{g/L}$  (site F, 12/95) of  $\text{NO}_x$  well exceeded national guidelines.

### 5.4 Modern Diatom Biomonitoring

Modern DAIPo analyses suggested that only minor differences in organic pollution levels existed between sites. Canonical Correspondence Analysis (ter Braak, 1988; 1990) revealed a shift in species assemblage from the upper to the lower sites (Tassicker, 1996) along a gradient best described by conductivity, and to a lesser extent N and P. Temporal variations in organic pollution were more pronounced, with significantly ( $P < 0.05$ ) lower DAIPo values recorded during periods of reduced flow and higher DAIPo values after heavy rains had diluted the concentrations of nutrients and salts. In April 1996, lower DAIPo values were recorded as compared with those of December 1995 and October 1996, suggesting maximum organic pollution concentrations. In the CCA ordination the October samples clustered to the dilute end of the conductivity gradient (Tassicker, 1996).

Date	Cond	pH	DO	Temp	$\text{PO}_4$	$\text{NH}_4$	$\text{NO}_x$
Site	( $\mu\text{S/cm}$ )		(%sat)	$^\circ\text{C}$	( $\mu\text{g/L}$ )	( $\mu\text{g/L}$ )	( $\mu\text{g/L}$ )
12/95A	2300	7.9	62.5	20.5	318	0	17760
12/95B	2700	7.7	80.3	22.2	279	0	6320
12/95C	2400	7.1	29.5	17.5	321	0	200
12/95D	2400	7.6	85.5	22.1	1100	62	218
12/95E	1500	8.4	63.2	21.0	460	53	108
12/95F	500	7.9	41.4	9.5	448	72	12560
12/95G	1800	7.9	65.1	17.3	463	41	241
12/95H	2600	8.1	87.5	20.2	490	62	142
4/96A	1005	7.1	69.5	17.7	44	333	350
4/96B	1783	7.3	73.5	18.6	14	121	709
4/96C	1366	7.4	66.4	16.8	18	99	22
4/96D	1065	7.3	64.4	16.6	13	109	11
4/96E	1684	7.4	65.9	17.2	289	140	21
4/96F	709	7.4	61.1	17.7	12	102	80
4/96G	713	7.6	84.0	16.5	28	84	18
4/96H	1729	7.5	73.9	16.0	19	93	12
10/96A	599	7.5	na	15.0	128	99	302
10/96B	516	7.4	na	13.3	134	82	284
10/96C	608	7.4	na	15.4	93	112	256
10/96D	504	7.3	na	14.7	118	83	268
10/96E	485	7.6	na	14.7	91	87	246
10/96F	485	7.6	na	15.0	91	70	232
10/96G	784	7.4	na	16.1	206	69	167
10/96H	889	7.2	na	15.7	146	93	91

Table 1. River Torrens water quality data.

### 5.5 Palaeodiatoms.

The proportions of the main diatom species recorded in the core TL-2 are presented in Figure 4. DAIPo values were reconstructed for each sedimentary level sampled based only on those taxa given indices by Watanabe *et al.* (1988) and these are presented with the diatom-inferred conductivity and  $\text{NH}_4$  in Table 2. The lowest DAIPo values in zone TL-2 supports evidence for the inferred reduced water quality within the Torrens Lake for the period covered by the record. The low DAIPo values in the upper sediments suggests that the water quality of the present period (TL-3ii) is poorer than in the past (zones TL-1 & TL-3i). This is somewhat contradicted by the high diatom-inferred  $\text{NH}_4$  values at 127 cm in zone TL-1.

**6. CONCLUSIONS AND RECOMMENDATIONS**

The monitoring regime of this project has highlighted the degraded water quality of the River Torrens. While the spatial variation of the pollution relates to the direct and indirect sources from different landuse types, the temporal variation best relates to the flow regime with poorest water quality prevalent during periods of reduced flow.

The water quality parameters most affected by the flow regime of the River Torrens are dissolved oxygen, conductivity, phosphate, nitrate and ammonium concentrations. Ponding and low flows contributed to consistently depressed dissolved oxygen levels which fell to below AWRC/ANZECC (1992) guidelines. Ammonium concentrations were highest in the April sampling period due to very low flows and the formation of stagnant pools where organic matter (leaf litter) was broken down, further increasing organic inputs into the system.

Depth (cm)	DAIpo	NH <sub>4</sub> (µg/L)	Cond (mS/cm)	Diatom Zone
0	50.94	75.4	1.74	TL-3ii
15	49.32	77.6	1.52	
31	53.88	50.7	1.55	
47	51.01	127.6	1.75	
63	54.00	56.4	1.83	TL-3i
79	54.22	72.2	1.47	
95	44.04	173.0	1.57	TL-2
111	39.05	278.6	1.94	
127	54.11	188.1	1.27	TL-1
143	52.81	50.4	1.35	
155	56.17	76.3	1.68	

Table 2. The conductivity, NH<sub>4</sub> and DAIpo reconstructions based on the fossil diatom record.

The nutrient load of a stream such as the River Torrens, has major implications for the management of the system. Phosphate and nitrate concentrations cause the most concern, particularly in terms of the prevention of eutrophication and the control of subsequent algal blooms. The concentration of phosphate (usually the limiting nutrient in a riverine environment) in the River Torrens, exceeded national guidelines for the protection of aquatic ecosystems in all sites during December, at site E in April and Sites A, B, D, G and H in October.

All sites in December registered a phosphorous concentration of over 250 µg/L with site D peaking at 1100 µg/L and nitrate values ranging up to 17 760 µg/L (over ten times the national guideline limits<sup>5</sup>). When these values are compared with the trophic status parameters of Forsberg and Ryding (1980) it can be seen that in certain months, the River Torrens can be classed as hypereutrophic (ie. [total nitrogen] > 1500 µg/L and [total phosphorous] > 100 µg/L).

<sup>5</sup> The national guidelines for [PO<sub>4</sub>] are 10 to 100 ug/L and for [NO<sub>x</sub>] are 100 to 750 µg/L (AWRC/ANZECC, 1992).

Increased streamflows during the October sampling period produced lower nitrate concentrations (50 times lower than December at site A - 302 µg/L and 17 760 µg/L respectively) and conductivity readings due to dilution by increased volumes of water. However, the higher flow volumes and low concentrations are not reflective of the total load of nutrients and salts in the system. Cullen *et al.* (1978) reiterates this finding by stating that although total nutrient loads are generally higher during floods, the increased volumes of water means that concentrations are lower. It is probable that high flows are a major source of sediment-bound nutrients which are deposited and periodically re-released to the water when flows decline.

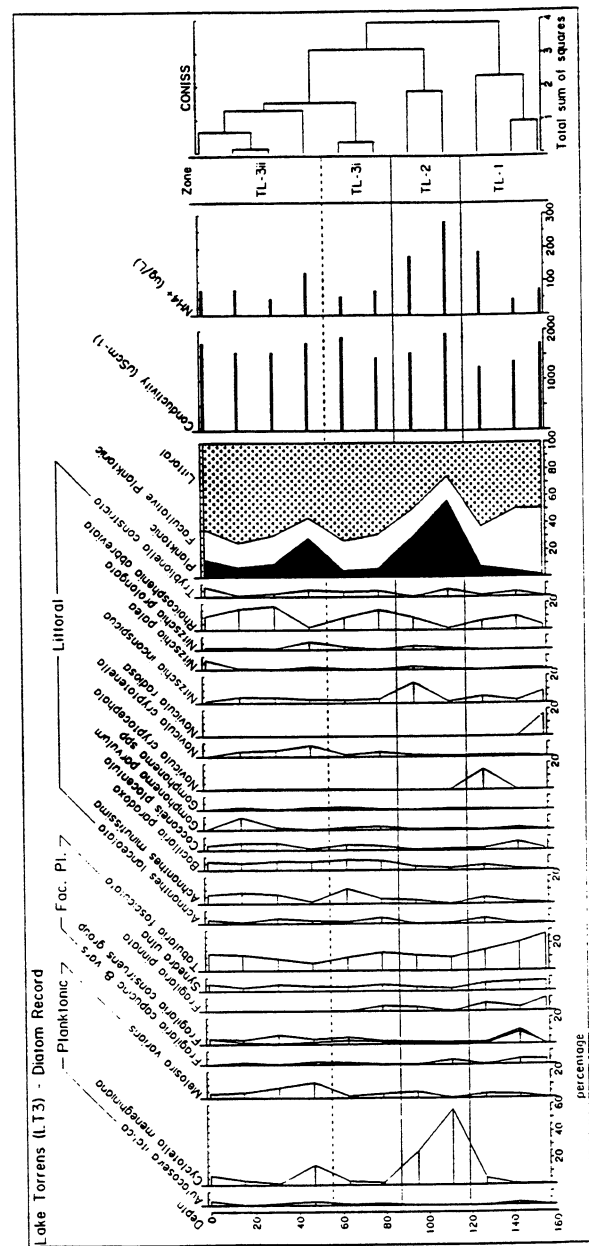


Figure 4. Fossil diatom and diatom-inferred NH<sub>4</sub> and conductivity record for Torrens Lake core TL-3.

The peaks in the eutraphentic diatom *Cyclotella meneghiniana* Kützing in the Torrens Lake fossil record (Figure 4) suggest that pollution levels have been high in the past. Increases in this species, and other pollution indicators such as *Gomphonema parvulum* Kützing and *Nitzschia palea* W. Smith in the uppermost sediments suggest that the recent trend is for declining water quality. Such a trend may have been a trigger for the cyanobacterial blooms of late last summer.

The <sup>137</sup>Cs analysis undertaken on cores GU-2 and GO-3 revealed that the Gumeracha and Gorge Weirs are located in catchments which have experienced potentially high rates of erosion since 1958. Accumulation rates for these two cores are estimated at 3.15 cm/yr and 2.6 cm/yr respectively in nearly 40 years. However, further work regarding compaction, and potential slumping and or mixing of sediments in the reservoirs themselves needs to be undertaken to confirm these rates. Nonetheless, these sediments are inevitably contributing to the overall phosphate load of the system and are likely to be a major factor driving the River's hypereutrophic status and perhaps also its recent cyanobacterial blooms. The sediment sourcing analyses demonstrate that this sediment is largely derived from subsoil rather than from surface erosion. Considerable improvement in the trophic status of the system could be achieved by targeting rehabilitation efforts at stabilising river banks and drainage lines to restrict the input of this sediment. This could be achieved by physical barriers such as baffles or more simply by retaining a broader riparian strip than at present. Given the high autumn NH<sub>4</sub> values recorded in autumn 1996 the riparian strip is best vegetated by indigenous species. These measures are likely to provide the additional benefits of extending the recurrence interval of expensive dredging episodes and to enhance rural and urban biodiversity values by providing crucial habitat for a variety of species.

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