Water Monitoring Report

Ambient Water Quality Monitoring of the River Murray

1990 - 1999

Report No 1

EPA
South Australia

Government of South Australia

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Environment Protection Agency
South Australia

DEPARTMENT FOR
environment
and heritage

Ambient Water Quality Monitoring of the River Murray 1990–1999
Report No. 1

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SUMMARY

The health of the River Murray is critical to the future well-being of South Australia. It is an important water source for public water supply and for irrigation. It is also used extensively for recreational activities and supports a diverse and significant aquatic ecosystem.

There is growing concern over water quality of the River Murray in South Australia. A recent report entitled *The audit report of the Murray-Darling Basin: A 100-year perspective* (Murray–Darling Basin Ministerial Council, 1999) raised concerns that salinity levels could rise substantially over the next 20–50 years. Other problems—such as turbidity, algal blooms, nutrients and faecal contamination—highlight the concerns about the state of health of the river.

This report assesses the water quality data from seven monitoring sites, ranging from Lock 9 upstream of South Australia on the Victoria–New South Wales border to Tailem Bend near Lake Alexandrina, over the period 1990–1999. The purpose of the report is to assess the ambient water quality at these sites over this period and to determine trends along the river for a number of important or key characteristics.

The important or key characteristics covered are:

- salinity (expressed as conductivity and total dissolved solids)
- water clarity or turbidity
- nutrients, including oxidised nitrogen, total and soluble phosphorus, and total Kjeldahl nitrogen
- heavy metals, including cadmium, copper, lead, mercury and zinc
- faecal coliforms as an indication of pathogens
- algae, particularly the cyanobacteria *Anabaena*.

Some important findings are listed below:

- Overall water quality at most sites could be described as moderate.
- Turbidity was high at all sites. Turbidity is caused by suspended matter in the water, particularly clay, giving it a cloudy or murky appearance. The high turbidity levels mean that the River Murray, like many other Australian inland rivers, has increased risks associated with swimming and related activities as the bottom is not visible to a depth of 1.2 metres.
- The cyanobacteria *Anabaena* were the most common algae found at all the sites monitored but numbers were generally low and not a cause for concern.
- Water quality deteriorated between Mannum and Tailem Bend. Nutrient concentrations (oxidised nitrogen and total phosphorus) and faecal coliform numbers rose over this stretch of the river. It is likely that this deterioration is due to irrigation return waters from dairy farms.
- Based on faecal coliform numbers, River Murray water in South Australia was unsuitable for drinking without treatment (e.g. boiling or disinfecting). It has, however, been recognised for some time that none of the rivers or streams in South Australia is suitable for drinking without such treatment, and the Department of Human Services has issued three warnings in the last three years to this effect. The River Murray is no exception.

- There was a notable deterioration in microbiological quality in the lower River Murray between Mannum and Tailem Bend. Both Murray Bridge and Tailem Bend failed to meet the *Australian Guidelines for Recreational Use of Water* (NHMRC, 1990) for primary contact (e.g. swimming) at times during the period. The Department of Human Services has advised that, although the risk to human health from exposure to microbial hazards in the river is increased from Mannum to Tailem Bend, the risk of illness remains low.
- Salinity substantially increased down the river, with large increases between Lock 9 and Lock 3, and between Lock 3 and Morgan. It is likely that irrigation practices, coupled with saline groundwater intrusion, evaporation and mallee clearance, all contribute to these increases.
- There was no indication of a substantial rise in salinity at Mannum or other sites over the last 10 years. This indicates that the salt interception schemes have been effective to date.

A number of measures have already been taken to address many of these water quality issues:

- Water taken from the River Murray and supplied to Adelaide and major towns is treated to a high level, and regularly monitored, to ensure that it meets the *Australian Drinking Water Guidelines* (NHMRC & ARMCANZ, 1996).
- Several water safety campaigns and initiatives focusing on education and safety awareness specific to the river environment are delivered to the Riverland Region every year. In addition, forums such as tourism expos and promotional literature are used to ensure the safety awareness message specific to the Murray also reaches recreational users of the river.
- There are six State Emergency Service Units located on the River Murray which provide an emergency rescue component and risk management focus to river safety.
- During 2001 a draft State Water Safety Plan has been proposed to ensure a coordinated strategy to water safety across the State.
- A number of irrigation districts have been rehabilitated, with replacement of old and inefficient infrastructure leading to salinity reductions.
- On-farm irrigation practices have been improved through government support and funding for irrigated crop management services resulting in salinity benefits.
- Better dairy shed waste management practices in the Lower Murray have been implemented with nutrient reductions.
- Irrigation management practices have been improved in the Lower Murray, resulting in reductions in nutrients and bacteria in drainage water.
- A number of other initiatives have been taken in the Lower Murray such as metering, water allocation, trials of improved irrigation practices and rehabilitation planning.
- Salt interception schemes have been installed at Woolpunda and Waikerie, together with other salinity reduction actions under the Murray Darling Basin Commission.

Additional new initiatives are being implemented to improve water quality in the River Murray:

- In collaboration with dairy farmers and the local community, the State Government has committed $40 million to rehabilitate the Lower Murray Swamps. The five-year plan will see major infrastructure changes designed to dramatically improve irrigation efficiency and convert some of the irrigated land to wetlands. These initiatives are expected to reduce 80% of polluted water from dairy pastures running back into the River Murray.

- New salt interception schemes are being developed to stop highly saline groundwater from entering the river.
- An action plan is being developed, with the support of dairy farmers, to deal with problems caused by irrigation return water from the lower Murray swamps.
- A Water Quality Policy is being developed with provisions against the discharge of a waste that causes pollution of a waterway.
- Industries such as dairies are required to comply with waste management requirements aimed at reducing or eliminating runoff into waterways and urban source pollution from streets.
- The Murray–Darling Basin Commission plans to reduce nutrient and salt inputs throughout the catchment.
- The River Murray Catchment Water Management Board is preparing a Catchment Water Management Plan and a Water Allocation Plan.
- Community-based programs such as Landcare have been implemented to assist revegetation and other works to improve water quality.
- Communities are being better educated and their awareness raised about the issues facing the River Murray. These include the dangers associated with swimming and related activities.

The quality of water in the River Murray has a substantial impact on South Australia, and the availability of good quality water is closely linked to the prosperity of the State. The River Murray is a major water source, and improving the quality of its water would result in environmental, economic and social benefits for South Australia.

1. INTRODUCTION

The health of the River Murray is critical to the future well-being of South Australia. It is an important water source for public water supply and for irrigation. It is also used extensively for recreational activities and supports a diverse and significant aquatic ecosystem.

There is growing concern over water quality of the River Murray in South Australia. A recent report entitled *The audit report of the Murray-Darling Basin: A 100-year perspective* (Murray–Darling Basin Ministerial Council, 1999) raised concerns that salinity levels could rise substantially over the next 20–50 years. These findings were based on modelling predictions of the impact on the river of saline groundwater. Salt levels in groundwater have risen because of land clearance and irrigation practices over the last 100 years or more.

The Salinity Audit report found that the average salinity of the lower River Murray will exceed the 800 EC unit threshold for desirable water quality in the next 50–100 years. The report estimated that by 2020 the 800 EC unit threshold will be exceeded about 50% of the time. (The 800 EC unit threshold is a target set by the Murray–Darling Basin Commission for water quality at Morgan to protect irrigation and drinking water quality.)

Other problems—such as turbidity, algal blooms, nutrients and faecal contamination—highlight the concerns about the state of health of the river. In 1991 the world's biggest algal bloom occurred for a number of months on the Darling River, a major tributary of the Murray. A State emergency was declared in New South Wales during that period. The bloom stretched for over 1000 km and had a severe impact on public water supplies and the aquatic ecosystem. Stock deaths were also ascribed to the bloom.

Water quality in the River Murray had been previously comprehensively assessed by the (then) River Murray Commission (Mackay et al 1988). That report used data collected from 1978, the start of the monitoring program, to 1986 and found that the substantial variations in river flow significantly influenced water quality. The report stated:

> *. . . water quality does not simply deteriorate with increasing distance downstream; rather there are distinct spatial and temporal patterns in the concentrations of different water quality parameters which result from the complex interactions between river flow, sedimentation, water chemistry and photosynthesis as well as the impact of tributary streams.*

This new report draws on the findings of earlier studies and assesses the water quality data from seven monitoring sites, ranging from Lock 9 on the Victoria–New South Wales border to Tailem Bend near Lake Alexandrina, over the period 1990–1999. The purpose of the report is to assess the ambient water quality at these sites and to determine trends along the river for a number of important or key characteristics.

The important or key characteristics covered are:

- salinity (expressed as conductivity or total dissolved solids)
- water clarity or turbidity
- nutrients, including oxidised nitrogen, total and soluble phosphorus, and total Kjeldahl nitrogen (organic nitrogen plus ammonia)
- heavy metals, including cadmium, copper, lead, mercury and zinc
- faecal coliforms as indicators of pathogens

- algae, particularly the cyanobacterium *Anabaena.*

The report also assesses trends along the river for important or key characteristics to determine the changes occurring down the river.

1.1 Ambient water quality

Ambient water quality refers to the quality of water when all the effects that can impact upon a waterbody are considered, rather than just the effects of particular discharges. The objectives of the ambient monitoring program are to:

- provide a qualitative and quantitative assessment of South Australia's surface water
- determine statistically significant changes or trends in the key characteristics of water quality
- provide data to assess the long term ecologically sustainable development of surface waters.

Data held in the Environment Data Management System (EDMS) were used to assess water quality. Data over the last 10 years (January 1990 to August 1999) were assessed to determine the condition of the River Murray in those years and to determine whether there have been any significant changes along the river during this period.

1.2 Importance of the River Murray

The River Murray supports a wide variety of activities: industry, irrigation, urban and rural development, recreation and landscape amenity. Recent statistics have shown that the River Murray provides nearly 30% of South Australia's harvestable water resources. Adelaide draws 40% of its public water supply from the River Murray; during drought years this figure rises to 90% (RMCWMB 1999).

Despite these uses, most water loss from the River Murray is through evaporation and seepage—approximately 800,000 ML of water per year.

Water is an indispensable natural resource, vital to numerous ecological processes and an essential part of the environment, and requires appropriate attention and maintenance. The recognised environmental values of River Murray water are:

- protection and maintenance of the integrity of aquatic ecosystems
- recreational and aesthetic purposes
- potable and agricultural uses.

1.3 Description of the program

Good data records are available from the seven sites shown in Figure 1.1. Two of these sites, at Lock 9 and downstream of Rufus River, are in New South Wales upstream of South Australia, but are included in this report as indicators of water quality entering South Australia. A description of these sites and the distances from the mouth are shown in Table 1.1.

The characteristics included in this report are shown in Table 1.2. Not all characteristics were measured at each site. The frequency of monitoring is only indicative and sometimes varied over the period of record. The significance of each characteristic in assessing water quality is discussed in Section 2.

Table 1.1 Descriptions of sampling sites along River Murray

Gauging station no.	Description	Distance from river mouth (km)
GS426501	Lock 9	765
GS426200	Downstream Rufus River	696
GS426517	Lock 3	431
GS426901	Morgan	320
	Mannum (No.1 pump station)	150
GS426522	Murray Bridge (No.1 pump station)	115
GS426551	Tailem Bend	89

Table 1.2 Characteristics analysed for River Murray ambient water quality monitoring program

Characteristic	Units	Frequency of sampling
Algal counts	cells/mL	weekly/monthly
Faecal coliforms	cells/100 mL	weekly
Metals (lead, copper, cadmium, mercury, zinc)	mg/L	monthly
Oxidised nitrogen	mg/L	weekly
Total Kjeldahl nitrogen (TKN)	mg/L	weekly
Salinity as conductivity	µS/cm	weekly
Salinity as Total dissolved salts (TDS)	mg/L	weekly
Flow	ML	daily
Total phosphorus	mg/L	weekly
Soluble phosphorus (filtered reactive as PO_4)	mg/L	weekly
Water clarity: turbidity	NTU	weekly

1.4 Water quality classification

Characteristics assessed in this report are based on the water quality requirements to support the designated environmental values as contained in the *Australian Guidelines for Fresh and Marine Waters* (ANZECC 1992) and the *Australian Drinking Water Guidelines* (NHMRC & ARMCANZ 1996).

Water quality data were assessed using a 'good, moderate, poor' classification scheme (Figure 1.1). While the determination of these classifications was somewhat arbitrary, they were based on national water quality criteria and reviewed by a number of experts in the field to ensure that they were reasonable.

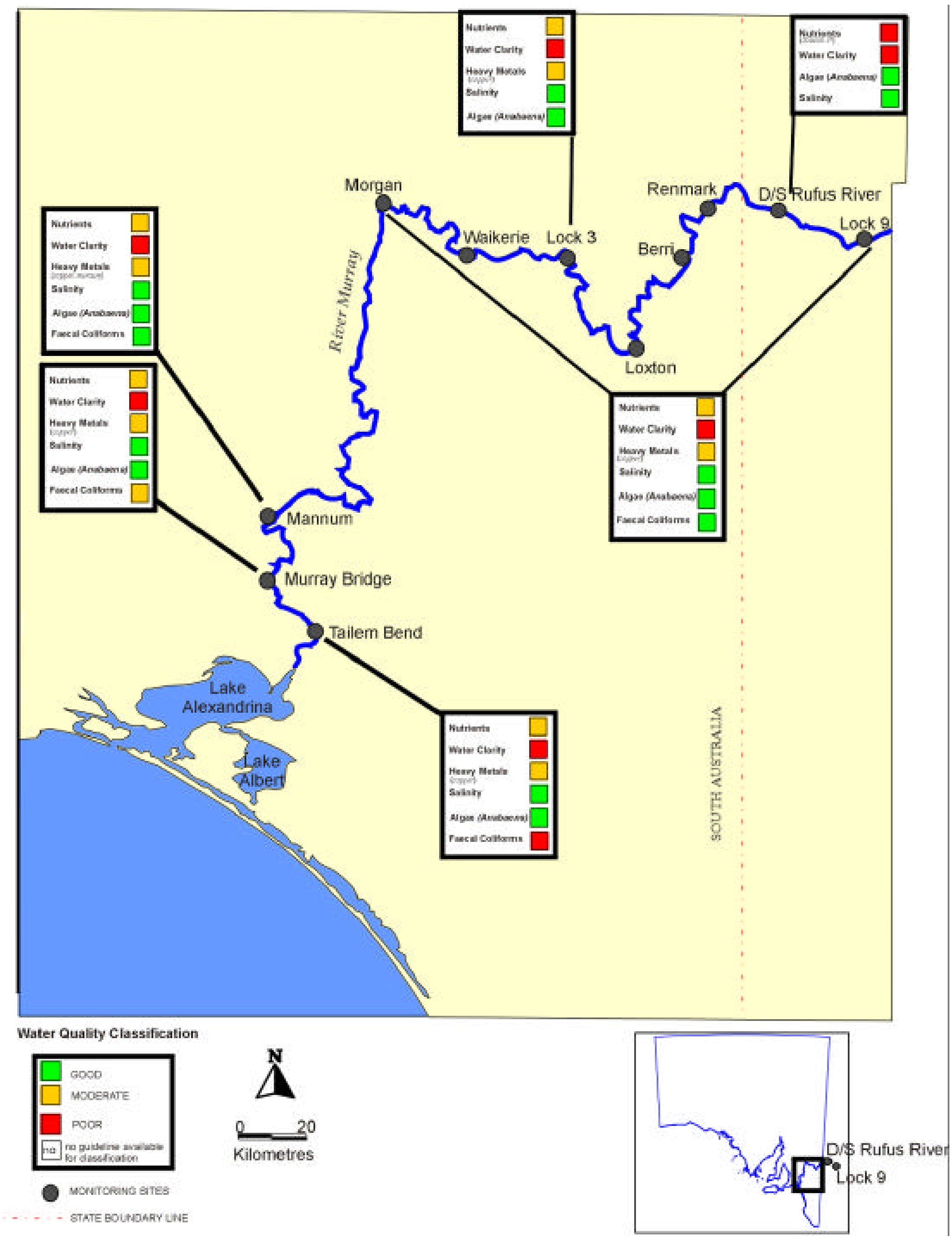


Figure 1.1 Classification of water quality at sites along the River Murray

2. KEY WATER QUALITY CHARACTERISTICS

2.1 Heavy metals

Heavy metals, such as cadmium, copper, lead, mercury and zinc, occur naturally in the environment from the weathering of rocks, but can also materialise from sewage discharges, road runoff, industrial discharges, and runoff from agricultural activities.

Although heavy metals are toxic to some aquatic organisms, some metals such as zinc and copper are important trace elements for biological processes and only become toxic at higher concentrations. The toxicity of heavy metals has been extensively studied and national guidelines are available that can be used to determine whether the concentrations found are likely to be a problem (ANZECC 1992).

Heavy metals readily accumulate in sediment due to adsorption on particulate clay surfaces. Some heavy metals (e.g. lead, mercury and cadmium) can bioaccumulate, moving up the food chain into human food sources.

Criteria used to classify water quality for heavy metals are based on the use of the 90^{th} percentile and the median as follows:

- GOOD: 90^{th} percentile is less than or equal to the criteria specified in Table 2.1. Using this criterion water quality is classified as good if it meets these criteria most of the time.
- MODERATE: 90^{th} percentile is greater than a criterion given in Table 2.1 but the median is less.
- POOR: Median is greater than or equal to the criteria given in Table 2.1 ***or*** any single measurement is more than 10 times the criteria. Using this standard, water quality is classified as poor when concentrations exceed the criteria most of the time or when a single measurement is at acute toxic concentration levels.

The water quality criteria specified in Table 2.1 are based on national guidelines (ANZECC 1992, NHMRC & ARMCANZ 1996, NHMRC 1990) but adapted to suit South Australian conditions, taking into consideration analytical detection limits where appropriate.

Table 2.1 Water quality classification for heavy metals

Characteristic	Criterion	Comment
Cadmium (total)	0.002 mg/L	National guidelines for protection of aquatic ecosystems (ANZECC 1992).
Copper (total)	0.01 mg/L	National guideline for protection of aquatic ecosystems is 0.005 mg/L (ANZECC 1992). A higher criterion is used to overcome difficulties associated with measurements at the limit of detection.
Lead (total)	0.005 mg/L	National guidelines for protection of aquatic ecosystems (ANZECC 1992).
Mercury (total)	0.0002 mg/L	National guideline for protection of aquatic ecosystems is 0.0001 mg/L (ANZECC 1992). A higher criterion is used to overcome difficulties associated with measurements at the limit of detection.
Zinc (total)	0.05 mg/L	National guidelines for protection of aquatic ecosystems (ANZECC 1992).

2.2 Nutrients, salinity and water clarity

Nutrients

Waters enriched with nutrients, in particular phosphorus and to a lesser extent nitrogen (Banens 1996), can cause *eutrophication*, and algal blooms that can be toxic to humans, livestock and aquatic animals.

Nutrients adsorb onto silt and clay particles, a factor that is of concern in areas where soil erosion is prevalent or is known to occur. Thus turbid streams often have high total phosphorus and nitrogen levels (MDBC 1988, 1994). Major contributors of these nutrients are:

- rocks and soils of the river's natural environment
- remobilisation of nutrients due to resuspension of sediment under turbulent conditions, and changes in the physico-chemical state due to anoxic conditions
- discharges from diffuse or non-point sources such as runoff from agricultural land or roads
- discharges from point sources such as sewage treatment works, industrial activities, feedlots, intensive agricultural operations and stormwater runoff from urban areas.

Nitrogen is naturally abundant and may be present in many forms in water. Those of interest include ammonia, organic nitrogen, nitrites and nitrates. Oxidised nitrogen (NO_x) describes the combined [soluble] concentration of nitrate (NO_3) and nitrite (NO_2). Nitrite concentrations tend to be low in well-oxygenated surface waters. Total Kjeldahl nitrogen (TKN) is a measure of organic nitrogen plus ammonia. Total nitrogen is usually expressed as the sum of oxidised nitrogen and TKN.

Phosphorus (P) is an important nutrient for plants. Total phosphorus measures all forms of phosphorus, including dissolved, inorganic and organic components. Some forms of total phosphorus are not immediately biologically available and may be bound up in organic matter. Filtered reactive phosphorus on the other hand measures the concentration of phosphorus in water that has been filtered through a fine sub-micron filter, and is usually regarded as biologically available.

Criteria used to classify water quality for nutrients are based on the use of the 90^{th} percentile against the criteria shown in Table 2.2. These criteria were set using:

- published criteria used in ambient water quality monitoring of other rivers and streams in South Australia (EPA 1998)
- range criteria for freshwaters (ANZECC 1992).

Salinity

Salinity is of major concern for the River Murray. The river is a naturally saline environment due to salty ground water incursion from extensive salt deposits. However, the salinity problem has intensified due to human activities such as land clearing and irrigation (MDBC 1988, Crabb 1997).

Electrical conductivity (EC) is a simple and common measure of salinity. It measures the conductance of electrical charge due to presence of dissolved ions.

Total dissolved solids (TDS) measures concentrations of inorganic salts (major ions) and organic matter dissolved in water, hence the name. For the River Murray, TDS can be calculated from conductivity using the approximate relationship (valid for conductivity of less than about 1500 EC units):

TDS (mg/L) = EC (µS/cm) × 0.548

Criteria used to classify water quality for salinity are based on the use of the 90th percentile against the criteria shown in Table 2.2. Broad water quality classifications for salinity are based on criteria to protect the aquatic ecosystem and recreational use (ANZEC 1992, NHMRC 1990). Criteria for total dissolved solids were derived from the *Australian Drinking Water Guidelines* (NHMRC & ARMCANZ 1996).

Water clarity: turbidity

Turbidity is a measure of the light-scattering property of water (Gippel 1989). Light is scattered from suspended material such as silt and clay, and to a lesser extent phytoplankton and zooplankton. Turbidity is visible as a cloudy or milky appearance. The hydrologic regime (e.g. flow, rainfall) and geomorphology (e.g. the weathering aspects of slopes) can influence turbidity levels.

Turbidity is measured in nephelometric turbidity units (NTU). Turbidity can be approximately related to water clarity as follows:

	Visibility depth (metres)
2 NTU	10.0
5 NTU	4.0
10 NTU	2.0
25 NTU	0.9
100 NTU	0.2

A turbidity of 20 NTU would correspond to a visible depth of approximately 1.2 metres, which is required for the NHMRC guidelines for primary contact recreation (NHMRC 1990).

Criteria used to classify water quality for salinity are based on the use of the 90th percentile against the criteria shown in Table 2.2. Criteria for turbidity are based on water clarity requirements for swimming (NHMRC 1990).

Table 2.2 Water quality classification criteria for nutrients and turbidity

	TKN-N (mg/L)	Oxidised nitrogen (mg/L)	Total phosphorus (mg/L)	Soluble phosphorus (mg/L)	Salinity as TDS (mg/L)	Salinity as conductivity (µS/cm)	Turbidity (NTU)
GOOD:	<1.0	<0.1	<0.1	<0.025	<500	<1000	<20
MODERATE:	1.0–10.0	0.1–1.0	0.1–1.0	0.025–0.25	500–1000	1000–2000	20–50
POOR:	>10.0	>1.0	>1.0	>0.25	>1000	>2000	>50

2.3 Microbiological pathogens

Faecal coliforms (or alternatively *Escherichia coli*) are indicators of recent faecal contamination by warm-blooded animals such as birds, cattle, horses, cats, dogs and humans.

The *Australian Drinking Water Guidelines* (NHMRC & ARMCANZ 1996) specify that good quality drinking water should be free of faecal coliforms. The *Australian Guidelines for Recreational use of Water* (NHMRC 1990) specify a median value not exceeding 150 faecal coliforms per 100 mL for recreational waters during bathing seasons (primary contact e.g.

swimming). Guidelines for secondary contact (e.g. boating) state that the median should not exceed 1000 faecal coliforms per 100 mL.

Criteria used to classify water quality for faecal coliforms are based on the use of the 90th percentile and the median as detailed below:

- GOOD: 90th percentile is less than or equal to the NHMRC *Guidelines for Recreational use of Water* (primary contact). Water quality is deemed good if it meets primary contact criteria for faecal coliforms except, possibly, on the rare occasion (90th percentile less than or equal to 150 faecal coliforms per 100 mL).
- MODERATE: 90th percentile is greater than NHMRC guideline but the median is less than this criterion (90th percentile >150 faecal coliforms per 100 ml but median ≤ 150 faecal coliforms per 100 mL).
- POOR: Median is greater than NHMRC guidelines. Water quality is classified as poor if it exceeds primary contact criteria for faecal coliforms most of the time (median greater than 150 faecal coliforms per 100 mL).

2.4 Algae

Algae, or phytoplankton, are naturally occurring aquatic organisms and are important components of a healthy ecosystem. Their presence in large numbers, however, can cause problems. These can include taste and odour, oxygen depletion and the presence of algal toxins.

Algal toxins are known to have caused death to cattle, horses, and other animals. They have also caused illness in humans.

Many different algae occur on the River Murray. The algae of particular concern are cyanobacteria (the so-called blue-green algae). Cyanobacteria found in the River Murray include *Anabaena, Microcystis and Oscillatoria*.

Algal ‘blooms’ occur when conditions are suitable for rapid multiplication of the algae. Factors contributing to blooms of cyanobacteria are:

- eutrophication—particularly elevated concentrations of phosphorus and nitrogen
- reduced water flows, calm conditions
- sunlight—high light availability
- warm water temperatures.

Cell counts for *Anabaena* were used to assess water quality because cyanobacteria are potentially of concern and *Anabaena* are the most common cyanobacteria found along the River Murray. Criteria used to classify water quality for algae were therefore based on the use of the 90th percentile and the median of *Anabaena* numbers as detailed below:

- GOOD: 90th percentile of *Anabaena* counts is less than or equal to 2000 cells / mL. Using this criterion water quality was classified as good if the algal numbers were less than 2000 cells / mL nearly all the time.
- MODERATE: 90th percentile of *Anabaena* counts was greater than 2000 cells / mL but the median was less than or equal to this criterion.
- POOR: Median of *Anabaena* counts was greater than 2000 cells / mL. Using this criterion water quality was poor if the algal count exceeds 2000 cells / mL most of the time.

The criterion used for cyanobacteria was based on the trigger value of 2000 cells / mL given in the *Australian Drinking Water Guidelines* (NHMRC & ARMCANZ 1996).

3. WATER QUALITY AT SITES ALONG THE RIVER MURRAY

This section summarises water quality data at the main monitoring sites along the river. The tables summarise the main characteristics and the graphs show some of the more significant variations in key characteristics over time.

Changes between sites are discussed in more detail in Section 4.

3.1 Lock 9

Lock 9 is located approximately 116 km upstream of South Australia on the Victoria–New South Wales border. It is downstream of the confluence of the Murray and Darling rivers but upstream of Lake Victoria, which provides an important source of water for the River Murray during times of low flow. Lock 9 is used to control water intake into Lake Victoria and thereby augment supply into South Australia.

Results are summarised in Table 3.1 below. Water quality was generally moderate based on the following:

- Turbidity levels were high. High turbidity means that the River Murray, like many other Australian inland rivers, has increased risks associated with swimming and related activities as the bottom is not visible to a depth of 1.2 metres. Details of initiatives and water safety campaigns focusing on the river have been included as part of the concluding remarks of the report (see section 5).
- Levels of salinity and most heavy metals were classified as good.
- Nutrient (nitrogen and phosphorus) and total copper levels were classified as moderate.

Table 3.1 Lock 9: Water quality results

	Characteristics ((mg/L) unless specified)	Mean ± confidence interval	Median	N	Std dev	P (10)	P (90)	Water quality classification
Nutrients	Oxidised nitrogen	0.072 ± 0.011	0.02	478	0.119	0.005	0.212	moderate
	TKN	0.689 ± 0.019	0.65	473	0.257	0.4	1.02	moderate
	Total phosphorus	0.125 ± 0.008	0.102	474	0.09	0.047	0.244	moderate
	Soluble phosphorus	0.081 ± 0.022	0.029	92	0.104	0.015	0.233	moderate
Clarity	Turbidity (NTU)	58 ± 5	39	466	55	16.2	120	poor
Heavy metals	Total cadmium	0.0003 ± 0.0001	0.0002	98	0.0007	0.0002	0.0002	good
	Total copper	0.0081 ± 0.001	0.005	98	0.0047	0.005	0.016	moderate
	Total lead	0.0033 ± 0.0015	0.002	98	0.0077	0.001	0.004	good
	Total mercury	0.0001 ± 0.00001	0.0001	88	0.0001	0.0001	0.0002	good
	Total zinc	0.0134 ± 0.0035	0.0075	89	0.0168	0.005	0.027	good
Pathogens	Faecal coliforms per 100mL	12.9 ± 4	6.5	116	20	1	30	good
Salinity	Conductivity (µS/cm)	337 ± 8	336	469	86	222	447	good
	Total dissolved solids	185 ± 4	184	480	49	121	245	good

Time series plots for all characteristics listed in the table over the period 1990–1999 are shown in Appendix 1.

In view of the concerns raised over salinity levels in the Salinity Audit report (MDBMC 1999), it is interesting to look at the salinity data from Lock 9 in more detail to determine trends over time. These data over the last 10 years (Figure 3.1) show substantial variations that make trend analysis difficult.

Salinity is inversely related very strongly to flow, with lower flows resulting in higher salinity. The impact of flow on salinity should therefore be taken into account before trying to assess trends over time, otherwise the effect of a period of wet or dry years could be misguidedly perceived as a trend in salinity.

For the purpose of exploratory data analysis, the salinity data can be flow-corrected by using a simple regression model with flow as the explanatory variable. This is not intended to be a rigorous modelling exercise. The results of such modelling (using the log of the flow regressed against the log of the conductivity and then back transformed to give the estimated salinity) can be compared against the measured data (Figure 3.1). The agreement is quite reasonable.

The time series plot in Figure 3.2 shows the difference between the modelled salinity and the measured data. The difference between the two represents the flow-corrected salinity and ought to show, more clearly than the uncorrected data, any underlying trend over time. As can be seen, there was clearly no upward trend and, if anything, the salinity level appeared to decrease over the period, although the trend may not be statistically significant (this would need to be determined through a more rigorous modelling study that is beyond the scope of this report).

This apparent decrease could be the result of salt interception and reduction schemes put in place by the Murray–Darling Basin Commission in the last 10–15 years.

The Salinity Audit report (MDBC 1999) raised concerns that by 2020 the salinity of the lower Murray will exceed 800 EC units 50% of the time and exceed this threshold nearly all the time by 2050.

Figure 3.3 shows the percentage of samples in each year since 1968 that exceeded 800 EC units at Lock 9. As can be seen, conductivity did not exceed 800 EC units at any time. The significance of this result will be more apparent when compared with results from downstream sites.

The turbidity (or cloudiness) of the River Murray is also an important issue as it impacts on recreational use of the river, drinking water quality, and the aquatic ecosystem.

The time series plot in Figure 3.4 shows turbidity at Lock 9 over the period 1990–1999, and Figure 3.5 shows the median turbidity values on a yearly basis. It is evident from these figures that there were times when the turbidity was very high (particularly mid-1990 and late 1998). These periods corresponded to high flow in the Darling River.

Unlike salinity, the relationship between river flow and turbidity (and other water quality characteristics) is confounded by other factors (for example, Darling River water has a high turbidity due to the suspension of very fine clay particles, algal numbers and rainfall intensity). It is therefore much more difficult to assess any underlying trend over the natural variability.

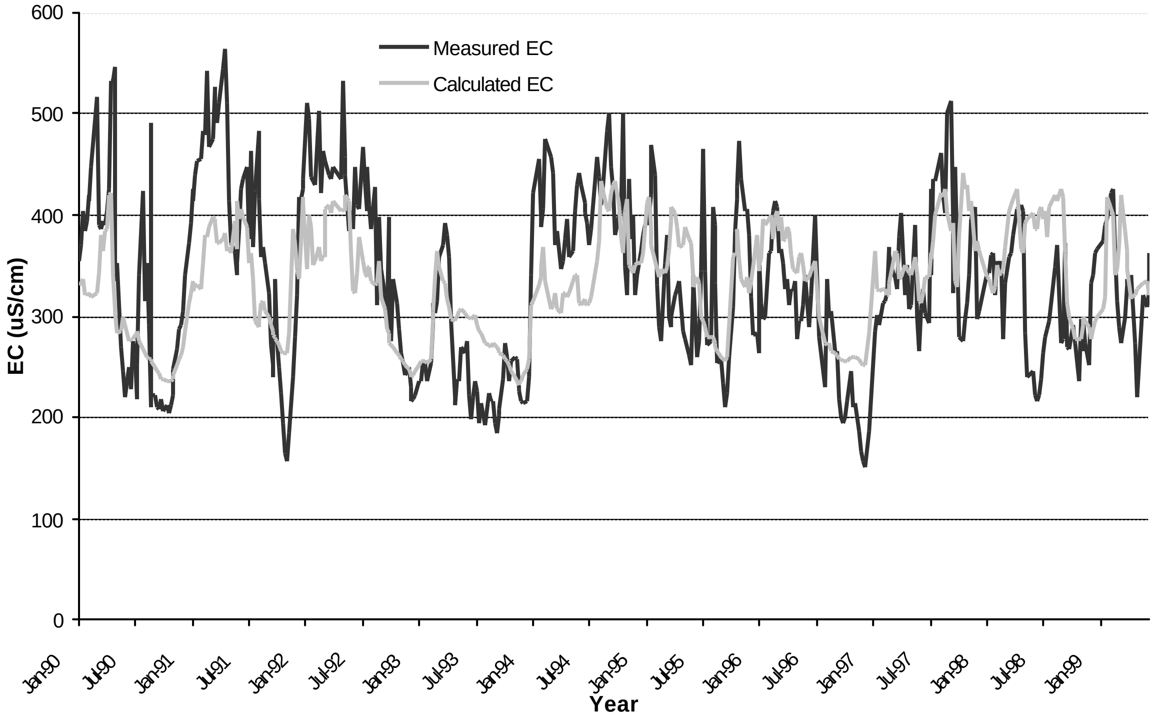


Figure 3.1 Lock 9: Measured and calculated salinity (as conductivity), 1990–1999

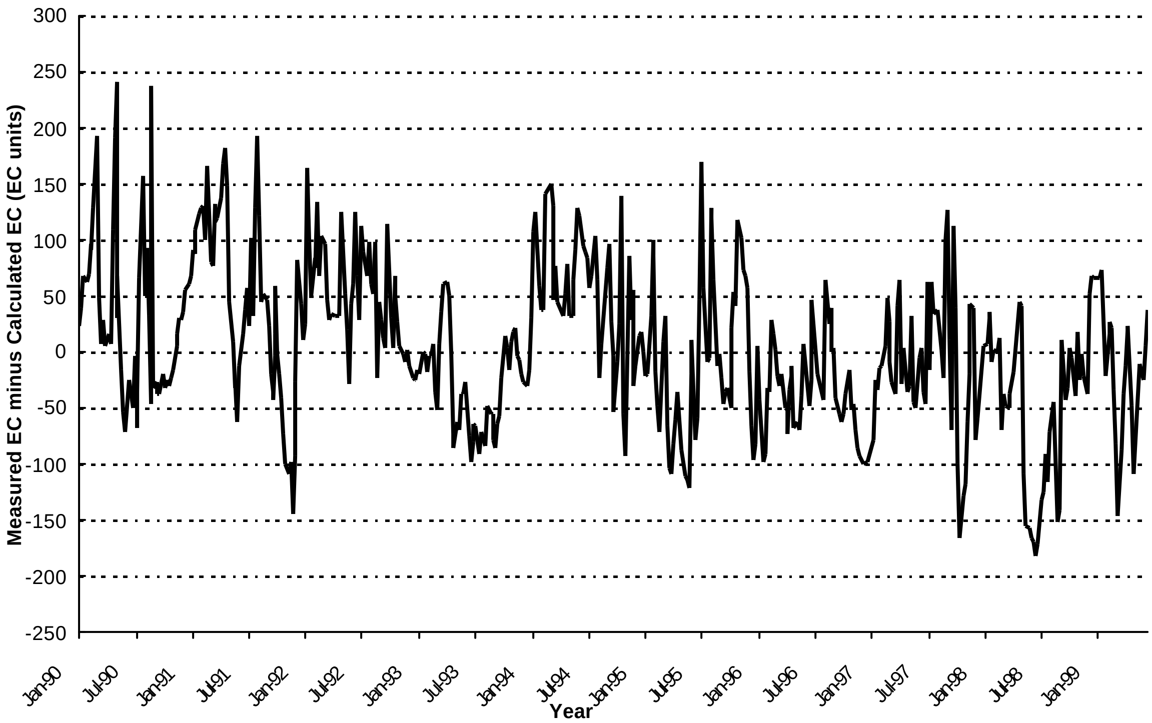


Figure 3.2 Lock 9: Measured minus calculated salinity (as conductivity), 1990–1999

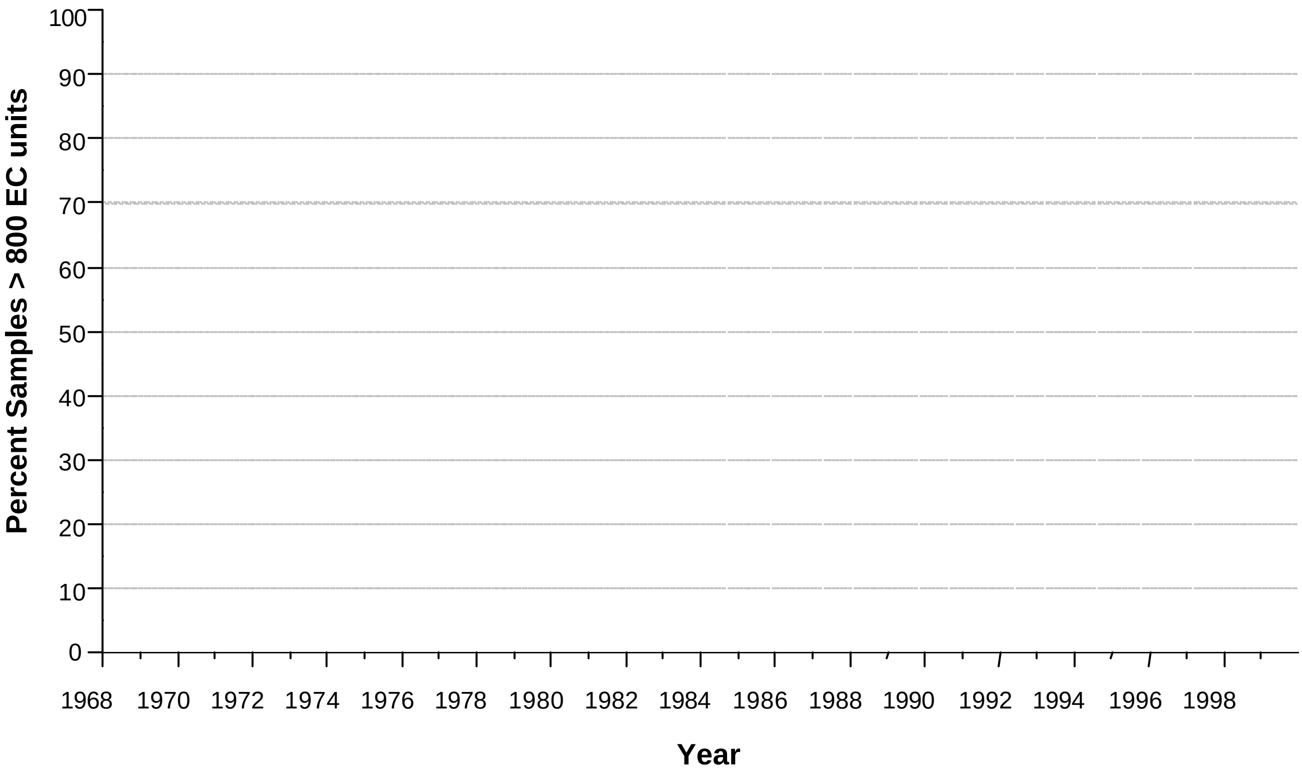


Figure 3.3 Lock 9: Percentage of samples exceeding a salinity of 800 EC units in each year, 1968–1999

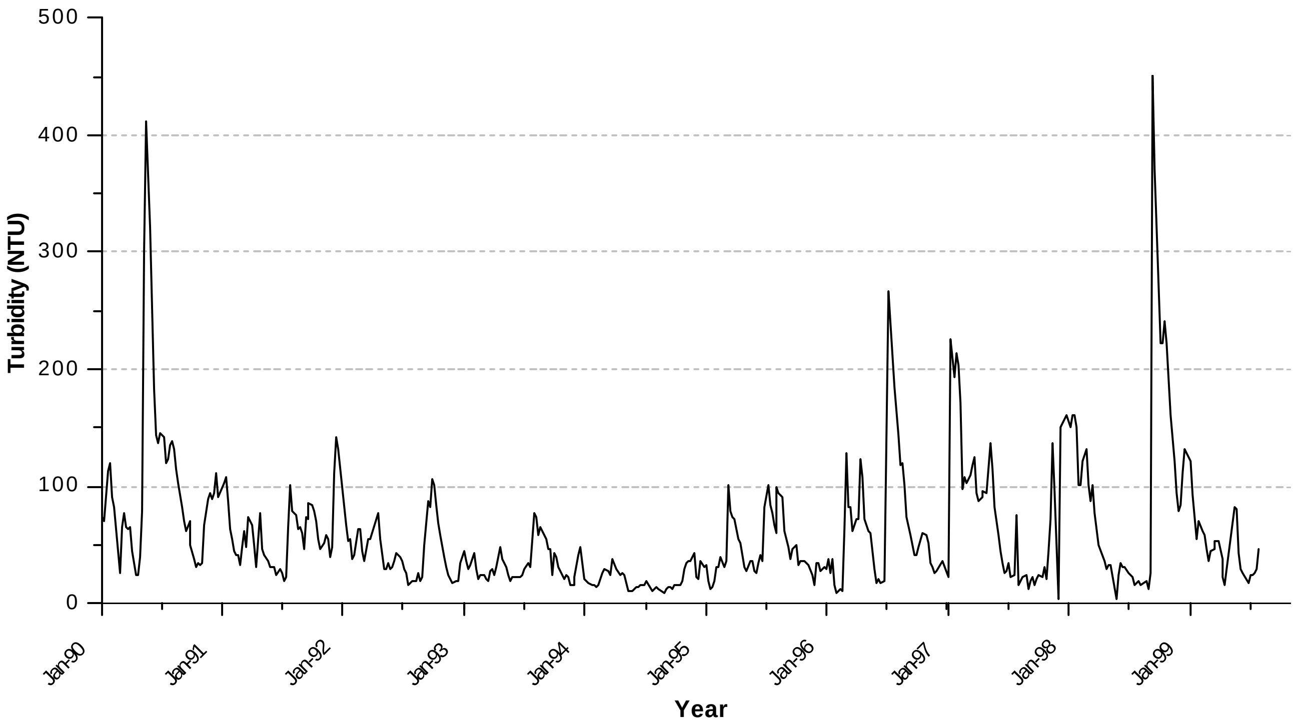


Figure 3.4 Lock 9: Turbidity, 1990–1999

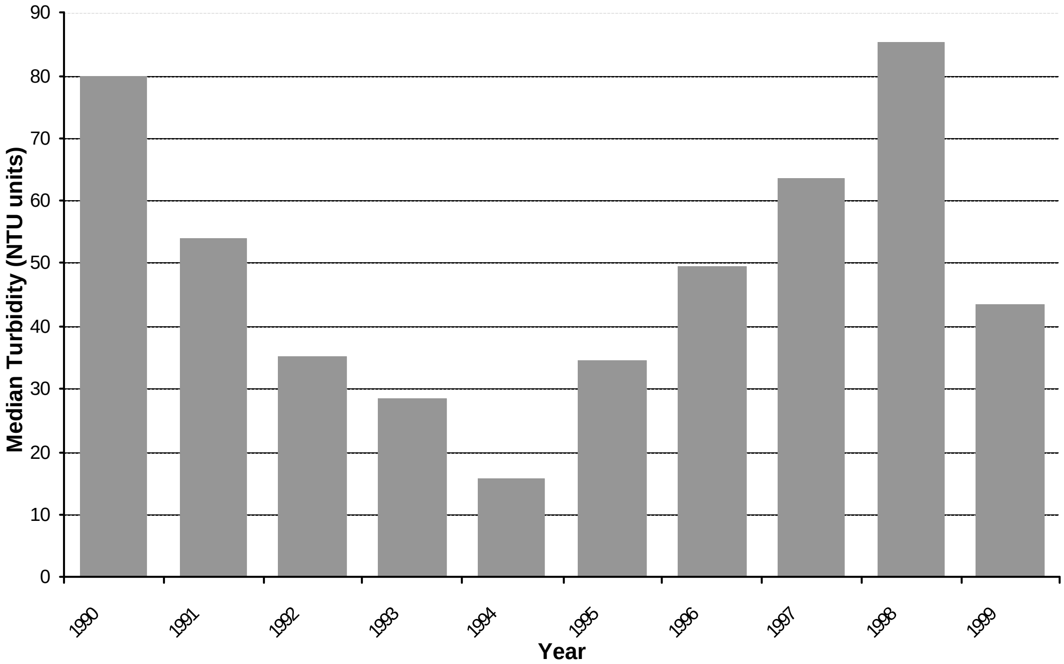


Figure 3.5 Lock 9: Median turbidity for each year, 1990–1999

3.2 Downstream Rufus River

This site is approximately 46 km upstream of South Australia on the Victoria—New South Wales border. It is downstream of Lake Victoria and therefore broadly indicative of the water quality coming into South Australia.

Lake Victoria is used to augment flow in the River Murray in dry years. Water quality in the lake can, however, be affected by evaporation.

Results are summarised in Table 3.2 below. Water quality was generally moderate based on the following:

- Turbidity levels were high (see comments in section 3.1).
- Salinity was classified as good.
- Nutrient levels (oxidised nitrogen and phosphorus) were classified as moderate although TKN levels were good.

Table 3.2 Downstream Rufus River: Water quality results

	Characteristics (mg/L unless specified)	Mean ± confidence interval	Median	N	Std Dev	P (10)	P (90)	Water quality classification
Nutrients	Oxidised nitrogen	0.078 ± 0.012	0.03	384	0.117	0.01	0.208	moderate
	TKN	0.694 ± 0.022	0.66	381	0.222	0.45	0.97	good
	Total phosphorus	0.119 ± 0.006	0.108	382	0.064	0.056	0.208	moderate
	Soluble phosphorus	0.089 ± 0.022	0.049	88	0.103	0.015	0.276	poor
Clarity	Turbidity (NTU)	65 ± 5	56	441	48	21	121	poor
Salinity	Conductivity (µS/cm)	359 ± 8	371	455	85	227	458	good
	Total dissolved solids	197 ± 5	201	444	50	124	254	good

Time series plots for all characteristics listed in the table over the period 1990–1999 are shown in Appendix 2.

The time series plot in Figure 3.6 shows conductivity at Rufus River over the period 1990–1999. The results of modelling salinity using flow as the explanatory variable (see Section 3.1) are also shown in Figure 3.6 where modelled salinity can be compared against the measured data.

The time series plot in Figure 3.7 shows the difference between modelled or estimated salinity and the measured data. The difference between the two should show any trend over time. As can be seen, no significant trend was evident.

Figure 3.8 shows the percentage of samples in each year since 1968 that exceeded 800 EC units—clearly greater for this site than for Lock 9.

The time series plot in Figure 3.9 shows turbidity at downstream Rufus River over the period 1990–1999 and Figure 3.10 shows a histogram plot of median turbidity values on a yearly basis. There was little change from the results at Lock 9.

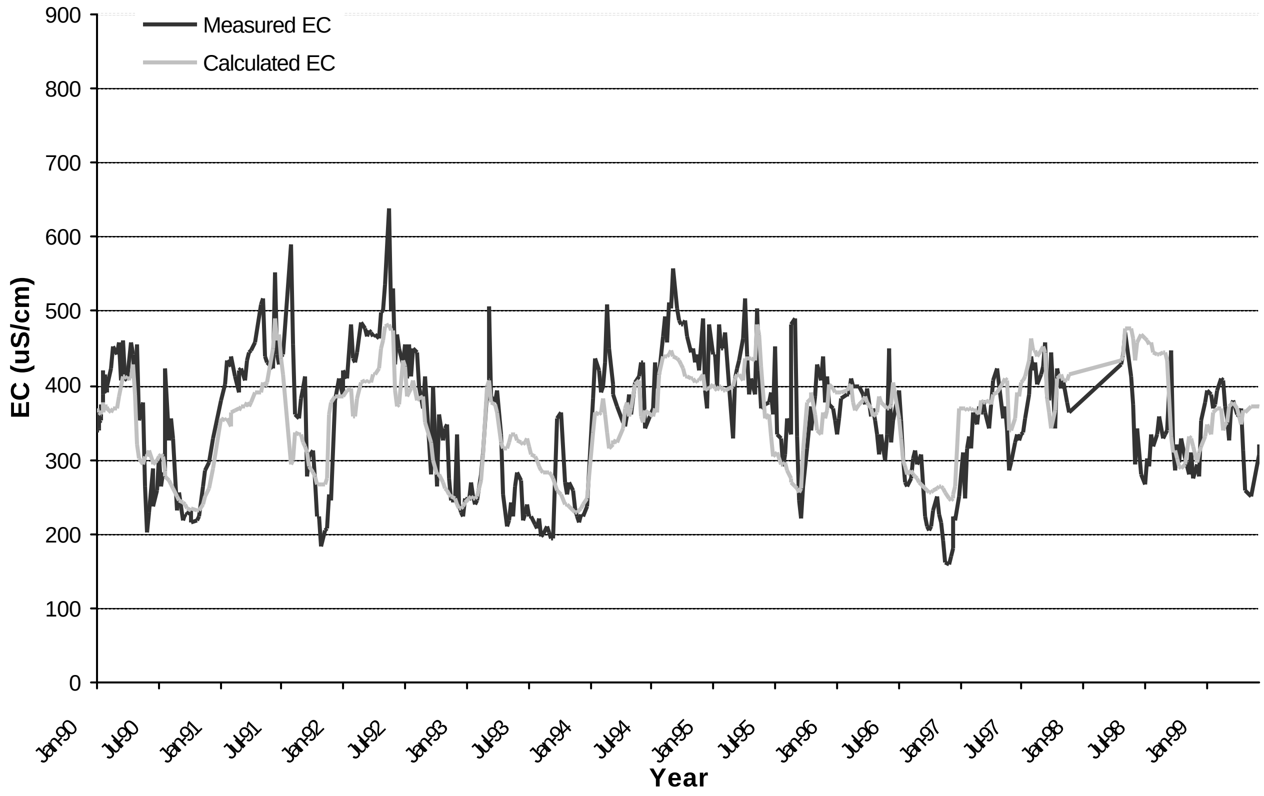


Figure 3.6 Downstream Rufus River: Measured and calculated salinity (as conductivity), 1990–1999

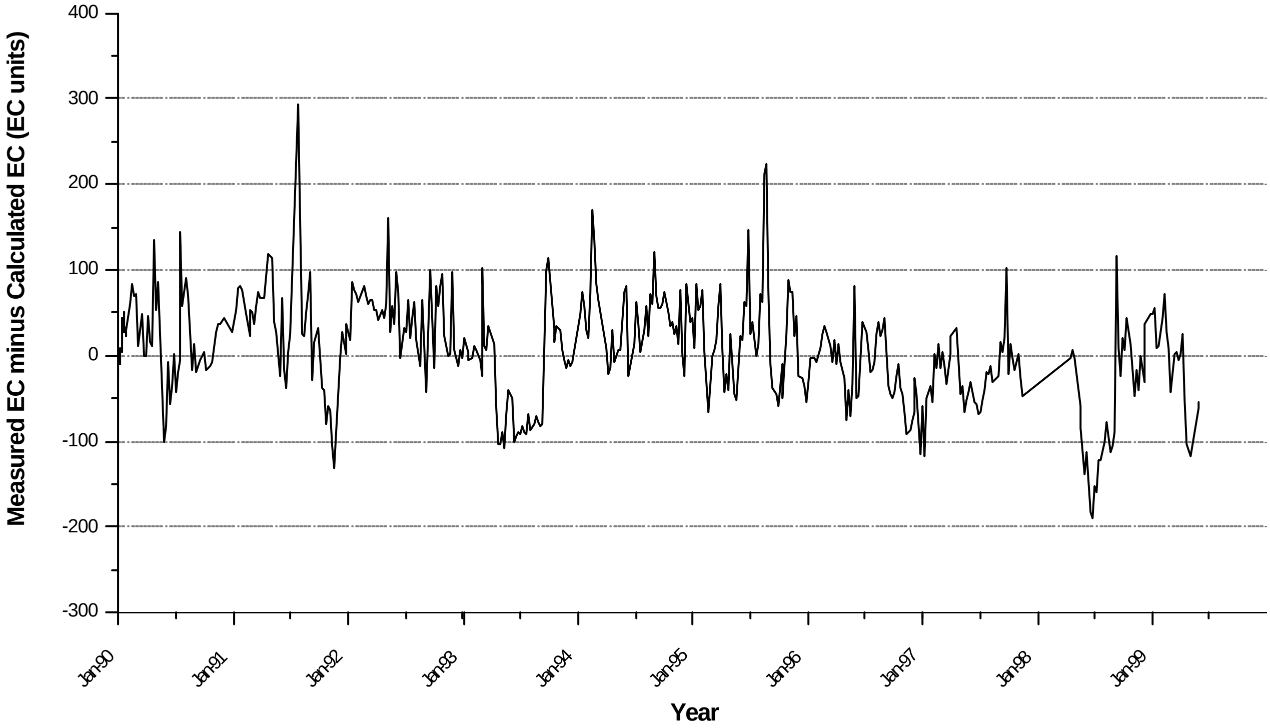


Figure 3.7 Downstream Rufus River: Measured minus calculated salinity (as conductivity), 1990–1999

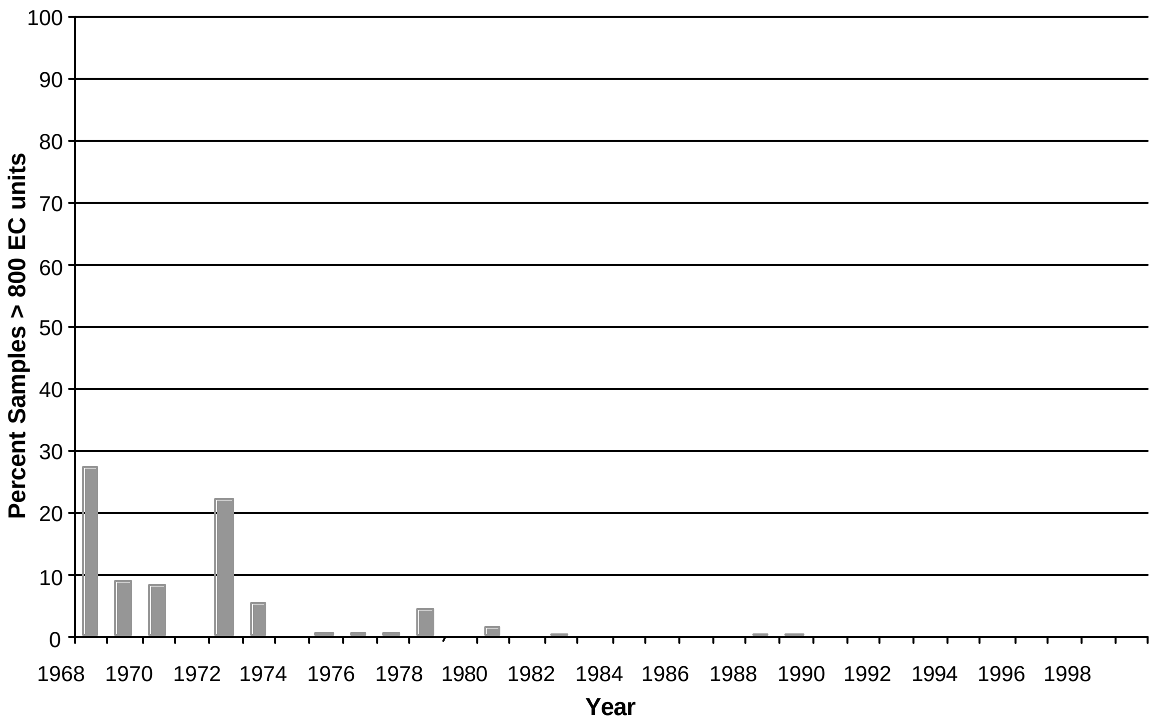


Figure 3.8 Downstream Rufus River: Percentage of samples exceeding a salinity of 800 EC units each year, 1968–1999

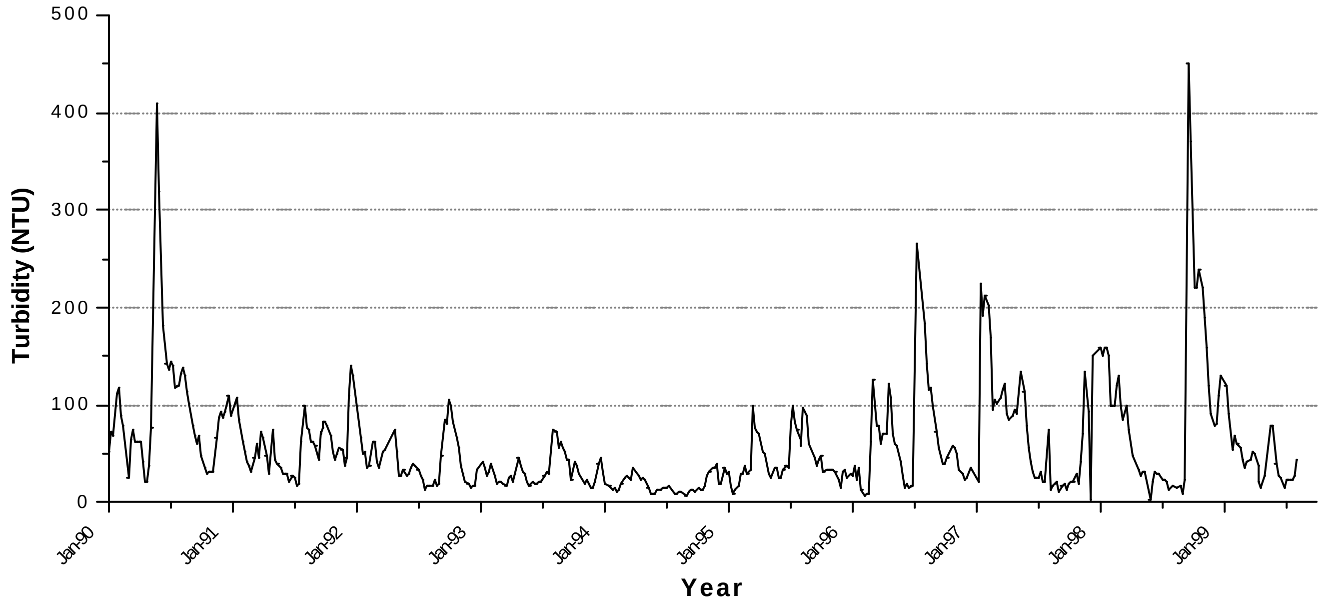


Figure 3.9 Downstream Rufus River: Turbidity, 1990–1999

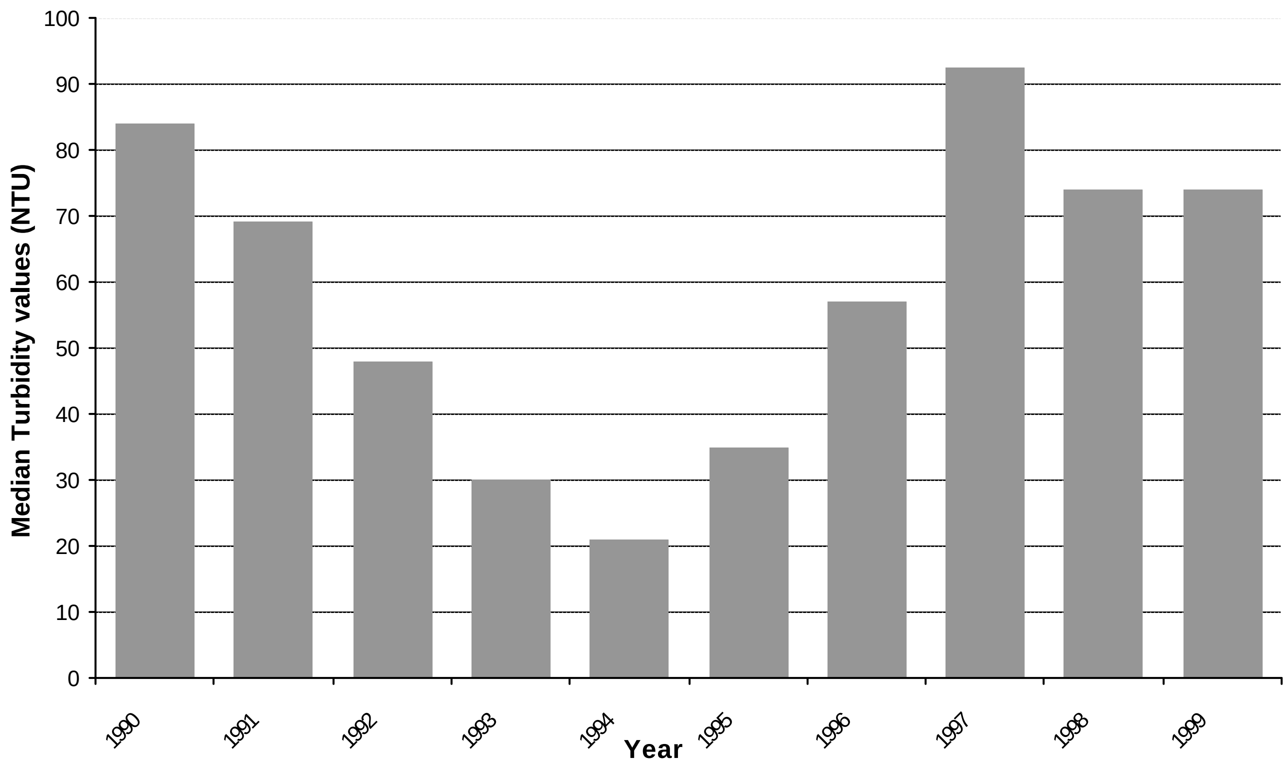


Figure 3.10 Downstream Rufus River: Median turbidity for each year, 1990–1999

3.3 Lock 3

Lock 3 is in South Australia, downstream of Loxton, Berri and Renmark. There is an extensive set of data for all the key characteristics spanning the period 1990–1999.

Results are summarised in Table 3.3 below. Water quality was generally moderate based on the following:

- Nutrient levels (nitrogen and phosphorus) were moderate.
- Salinity was classified as good.
- Total copper was classified as moderate.
- Turbidity levels were high (see comments in section 3.1).

Table 3.3 Lock 3: Water quality results

	Characteristics ((mg/L) unless specified)	Mean± confidence interval	Median	N	Std Dev	P (10)	P (90)	Water quality classification
Nutrients	Oxidised nitrogen	0.042 ± 0.011	0.01	191	0.076	0.01	0.12	moderate
	TKN	0.796 ± 0.038	0.79	188	0.262	0.47	1.11	moderate
	Total phosphorus	0.118 ± 0.009	0.111	189	0.06	0.05	0.199	moderate
	Soluble phosphorus	0.065 ± 0.017	0.032	94	0.084	0.015	0.147	moderate
Clarity	Turbidity (NTU)	65 ± 4	58	470	45	20	117	poor
Heavy metals	Total cadmium	0.0002 ± 0.00002	0.0002	86	0.0001	0.0002	0.0003	good
	Total copper	0.0104 ± 0.002	0.007	67	0.0081	0.005	0.021	moderate
	Total lead	0.0024 ± 0.0003	0.002	85	0.0015	0.001	0.004	good
	Total mercury	0.0001 ± 0.00002	0.0001	85	0.0001	0.0001	0.0002	good
	Total zinc	0.0161 ± 0.0031	0.011	89	0.0147	0.005	0.035	good
Salinity	Conductivity (µS/cm)	521 ± 14	526	477	155	313	713	good
	Total dissolved solids	286 ± 8	289	477	85	176	392	good

Time series plots for all characteristics listed in the table over the period 1990–1999 are shown in Appendix 3.

The histogram plot (Figure 3.11) shows the percentage of samples in each year since 1983 that exceeded 800 EC units. There has been a substantial increase in the frequency of occurrence relative to upstream sites. There are extensive irrigation areas between the site downstream of Rufus River and Lock 3. The increase is likely to be partly due to these activities and partly to saline groundwater intrusion. More monitoring in the stretch of the river between Lock 3 and downstream of Rufus River is required to identify problem areas.

The time series plot in Figure 3.12 shows turbidity at Lock 3 over the period 1990–1999. The median turbidity for each year over the same period is shown in Figure 3.13. There was a slight reduction in turbidity compared with the upstream sites over the same period.

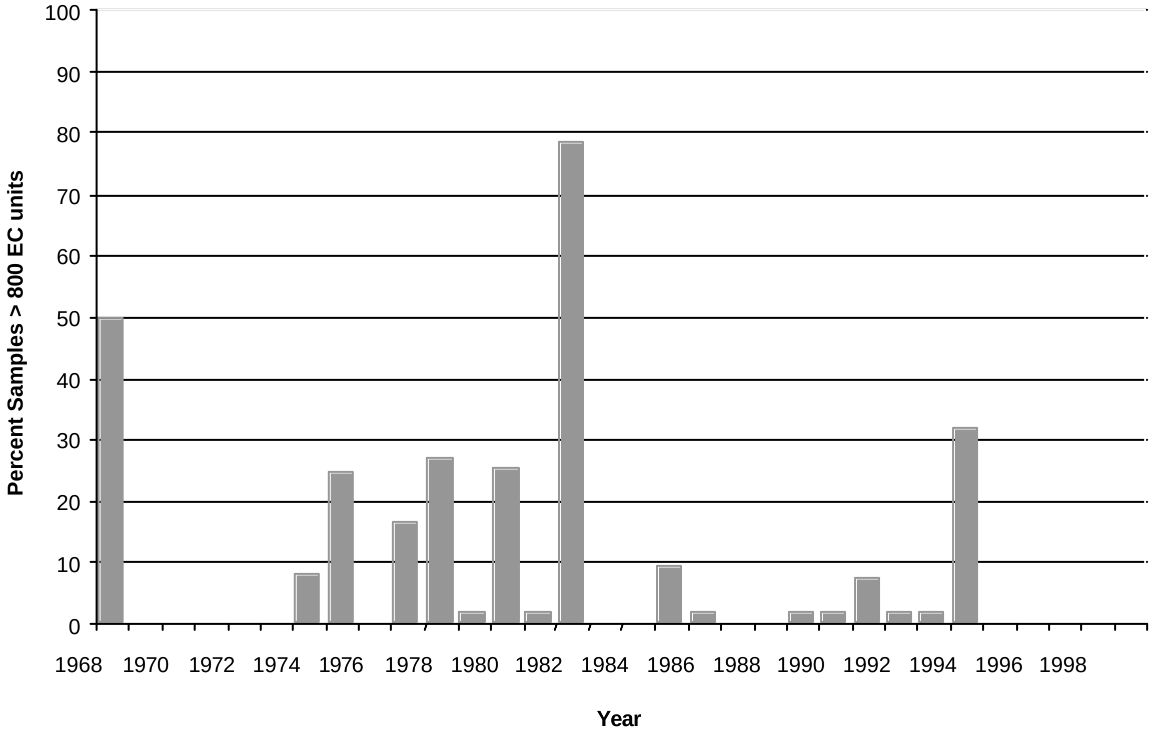


Figure 3.11 Lock 3: Percentage of samples exceeding a salinity of 800 EC units in each year, 1968–1999

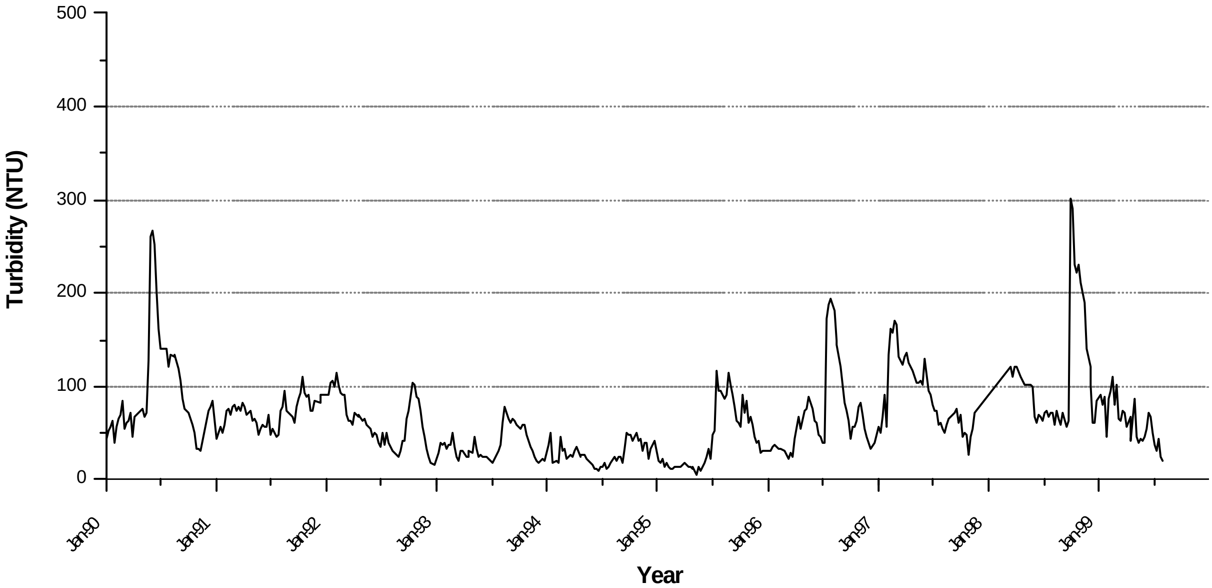


Figure 3.12 Lock 3: Turbidity, 1990–1999

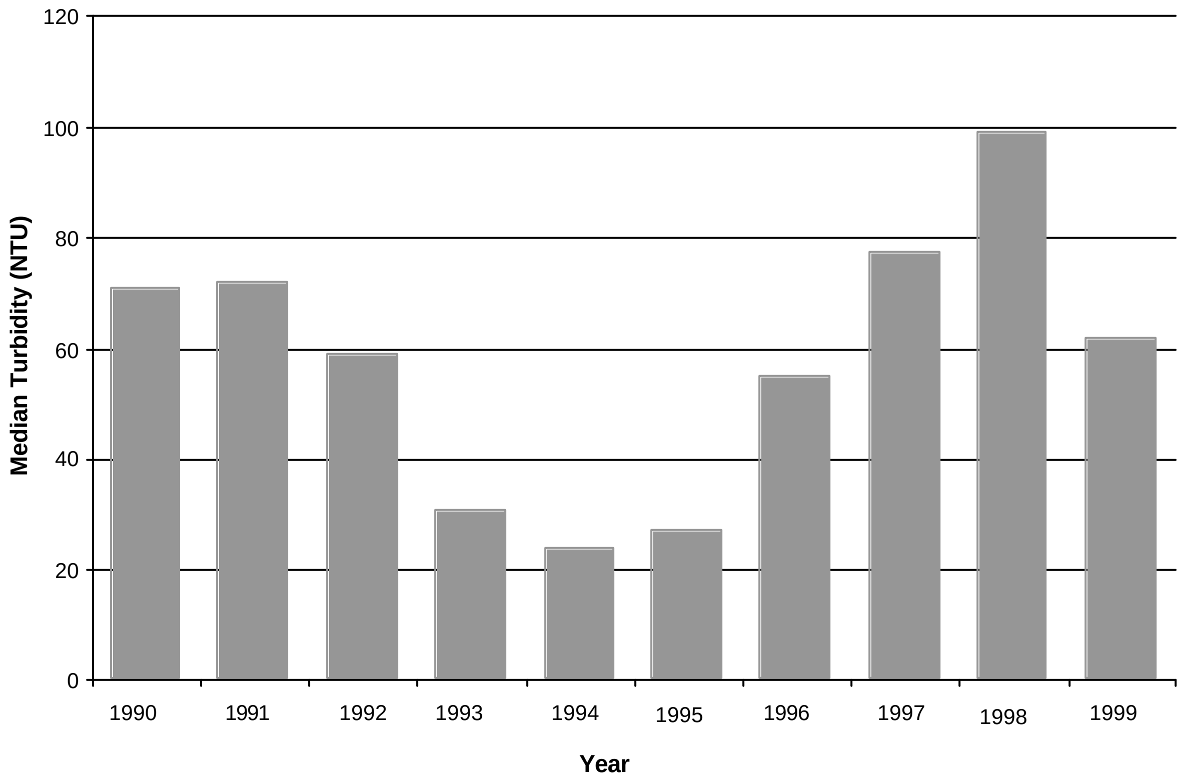


Figure 3.13 Lock 3: Median turbidity for each year, 1990–1999

3.4 Morgan

Morgan is an important water quality monitoring site used by the Murray–Darling Basin Commission and is located downstream from major irrigation developments. Apart from supplying the town itself, water extracted from the River Murray is treated and piped from there to Port Pirie, Port Augusta and Whyalla.

Results are summarised in Table 3.4 below. Water quality was generally moderate based on the following:

- Nutrient levels (nitrogen and phosphorus) were moderate.
- Salinity was classified as good.
- Total copper was classified as moderate.
- Turbidity levels were high (see comments in section 3.1).
- Faecal coliform quality was good.

Time series plots for all characteristics listed in the table over the period 1990–1999 are shown in Appendix 4.

Salinity data for Morgan for the period 1990–1999 are shown in Figure 3.14, along with the results of the exploratory modelling undertaken to remove the effects of flow on changes in salinity (see Section 3.1).

The time series plot in Figure 3.15 shows the difference between the modelled or estimated salinity and the measured data. The difference between the two should show any trend over time. As can be seen, no significant trend is evident. It is likely that the salt interception and reduction schemes put in place by the Murray–Darling Basin Commission have had the effect of negating the expected rise in salinity due to highly saline groundwater intrusion into the river over this period.

Table 3.4 Morgan: Water quality results

	Characteristics ((mg/L) unless specified)	Mean± Confidence interval	Median	N	Std Dev	P (10)	P (90)	Water quality classification
Nutrients	Oxidised nitrogen	0.048 ± 0.008	0.01	495	0.088	0.005	0.145	moderate
	TKN	0.839 ± 0.029	0.8	448	0.315	0.47	1.2	moderate
	Total phosphorus	0.128 ± 0.006	0.12	495	0.071	0.053	0.222	moderate
	Soluble phosphorus	0.062 ± 0.017	0.024	92	0.082	0.015	0.166	moderate
Clarity	Turbidity (NTU)	64 ± 4	54	489	48	19	121	poor
Heavy metals	Total cadmium	0.0003 ± 0.00004	0.0002	102	0.0002	0.0002	0.0004	good
	Total copper	0.0101 ± 0.0016	0.006	106	0.008	0.005	0.022	moderate
	Total lead	0.0024 ± 0.0003	0.002	102	0.0016	0.001	0.005	good
	Total mercury	0.0001 ± 0.00002	0.0001	102	0.0001	0.0001	0.0002	good
	Total zinc	0.02 ± 0.0037	0.015	106	0.019	0.005	0.042	good
Pathogens	Faecal coliforms per 100mL	11.7 ± 2	8	261	18	2	22	good
Salinity	Conductivity (µS/cm)	567 ± 17	550	498	198	318	815	good
	Total dissolved solids	317 ± 10	320	451	113	168	462	good

The histogram plot (Figure 3.16) shows the percentage of samples in each year since 1968 that exceeded 800 EC units. There was a substantial increase in the frequency compared with sites upstream. At Morgan, salinity exceeded the 800 EC unit threshold in 23 years out of 30 with one year, 1982, exceeding this value 100% of the time (1982 was a particularly dry year with low river flows). At Lock 9, by comparison, salinity did not exceed the 800 EC unit threshold in any year. This increase is probably due to the combined result of irrigation practices and saline groundwater intrusion.

With the exception of 1994, when there was low flow in the river and consequently higher salinity (see Appendix 4 for graphs showing flow), the percentage of samples exceeding 800 EC units in each year was generally less than for earlier years. This may be due to the introduction of salt interception and reduction programs.

The time series plot in Figure 3.17 shows turbidity at Morgan over 1990–1999. The median turbidity for each year over the same period is shown in Figure 3.18. Comparing these plots with similar plots for other sites, it can be seen that there was a slight reduction in turbidity (particularly the very high values) down the river. This is probably due to some settling out of the suspended material over time.

Figure 3.19 shows the strong linear correlation (R^2 = 0.71) of turbidity with total phosphorus. The clay particles that cause turbidity also adsorb phosphorus-containing compounds. Bioavailable phosphorus can be released through chemical and microbiological action, providing a food source for algae.

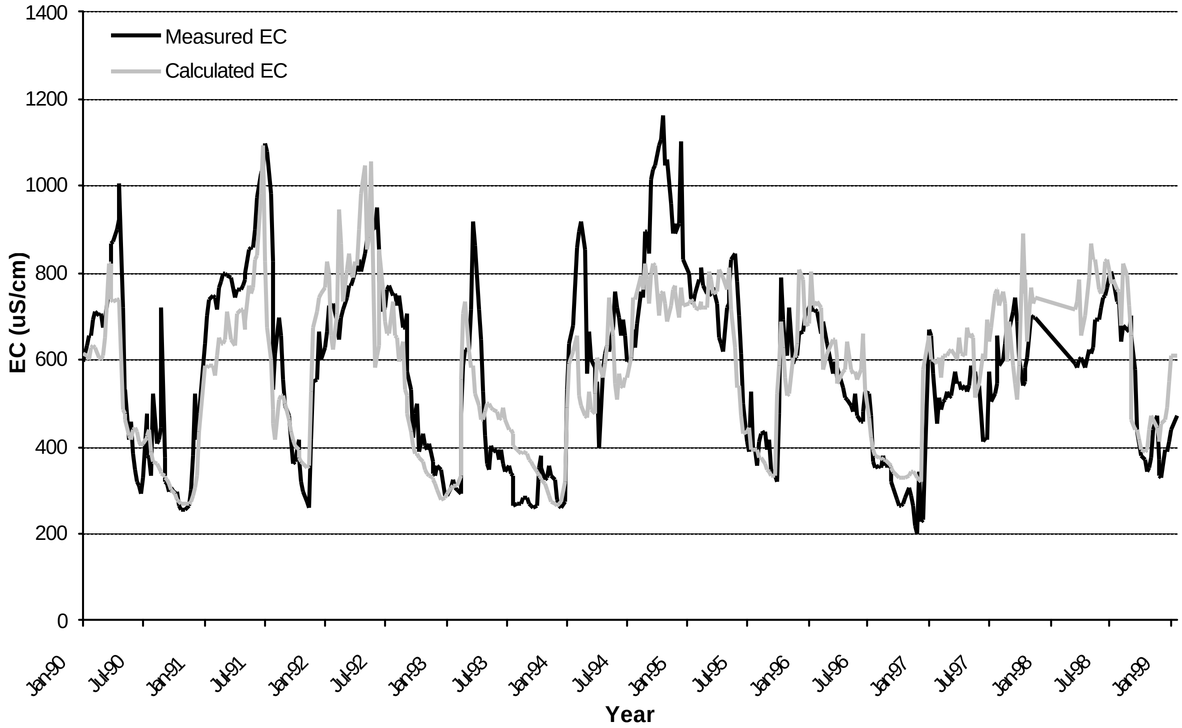


Figure 3.14 Morgan: Measured and calculated salinity (as conductivity), 1990–1999

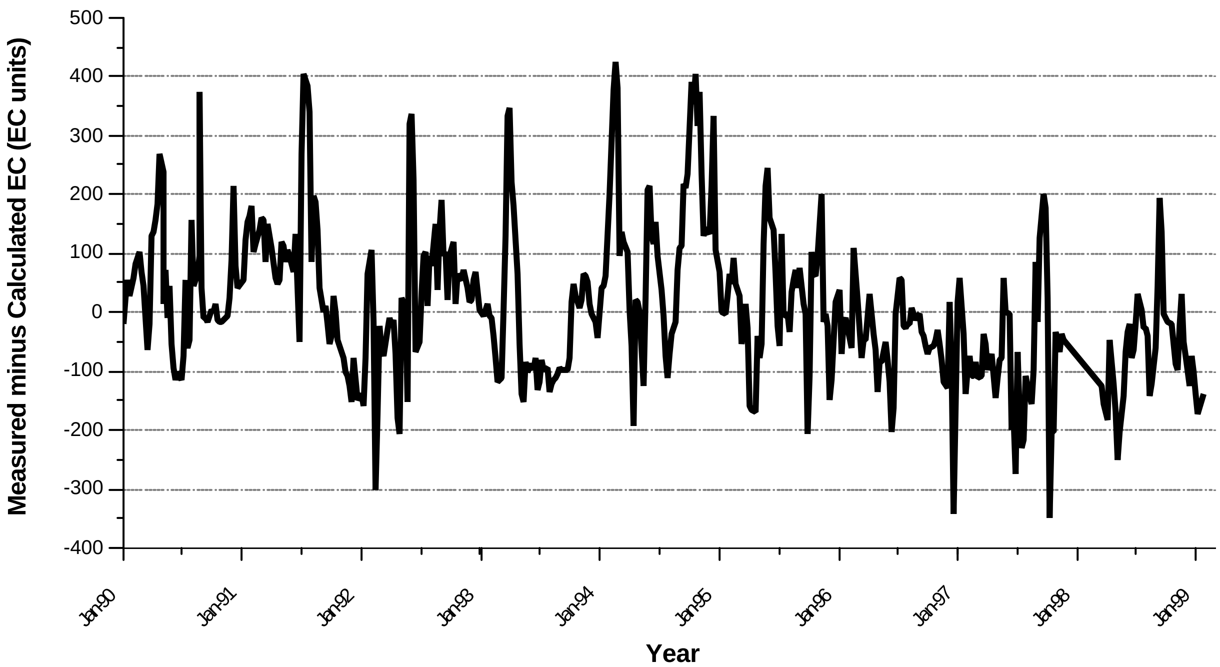


Figure 3.15 Morgan: Measured minus calculated salinity (as conductivity), 1990–1999

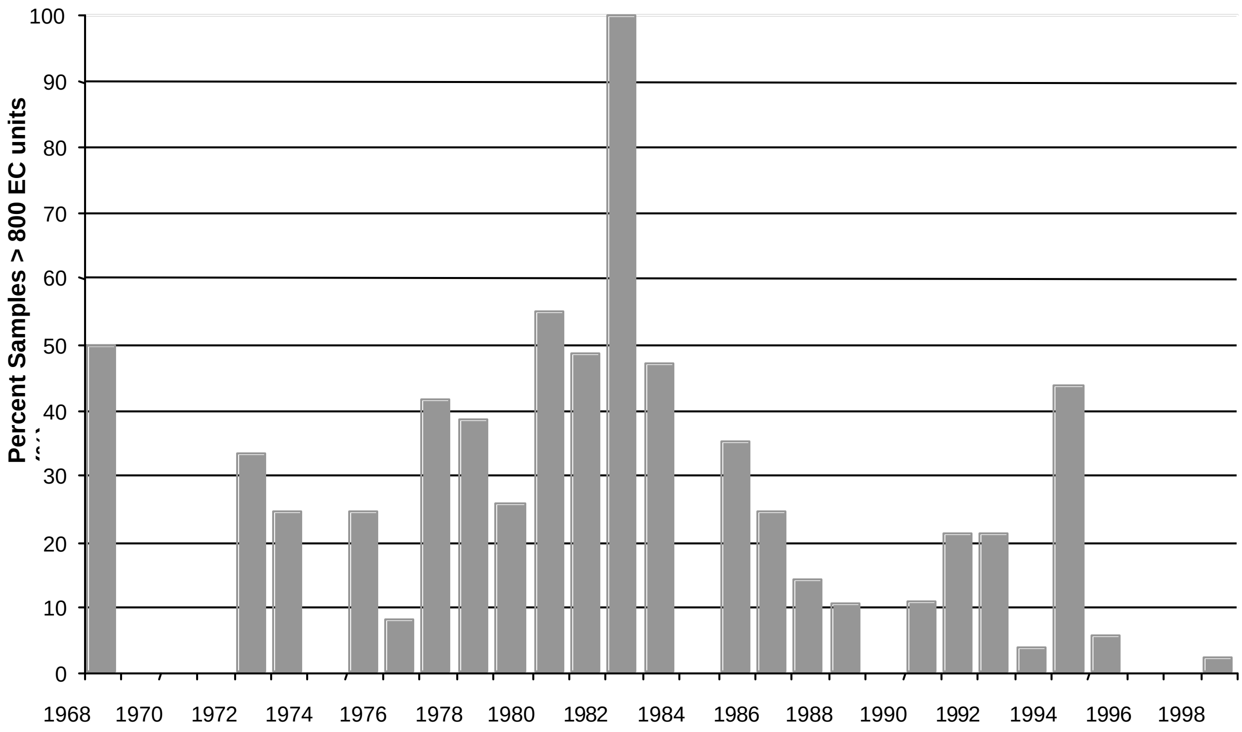


Figure 3.16 Morgan: Percentage of samples exceeding a salinity of 800 EC units in each year, 1968–1999

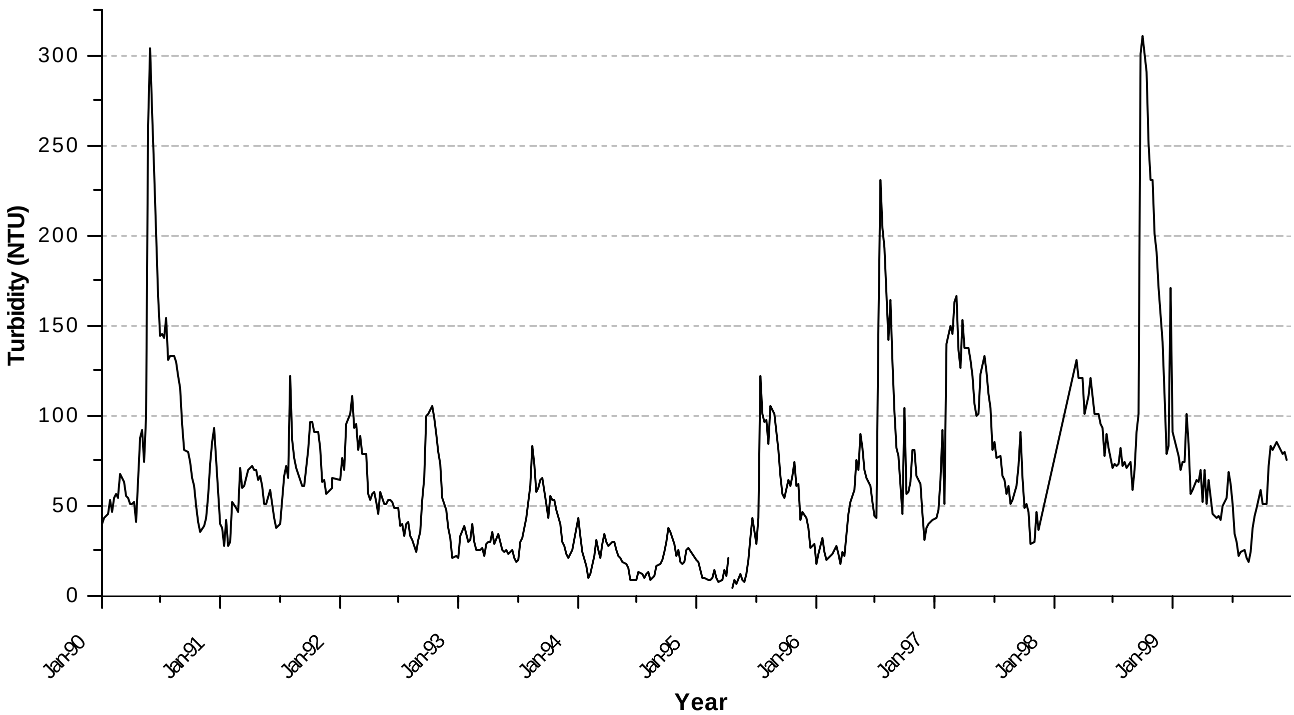


Figure 3.17 Morgan: Turbidity, 1990–1999

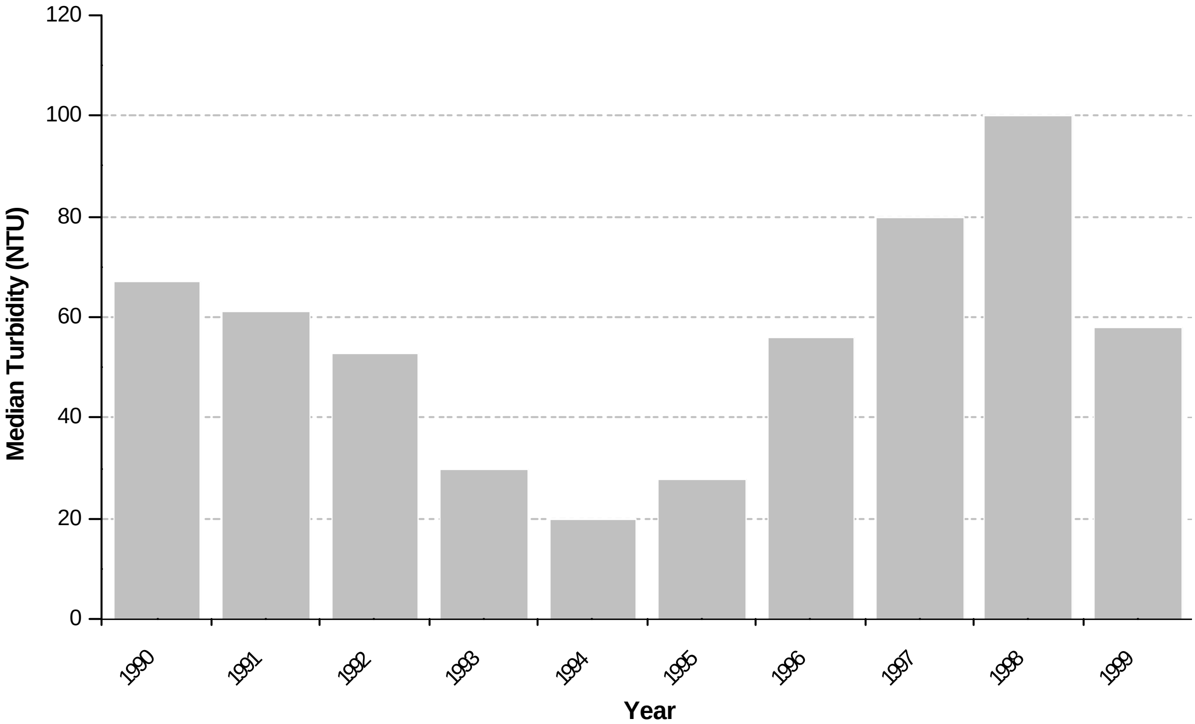


Figure 3.18 Morgan: Median turbidity for each year, 1990–1999

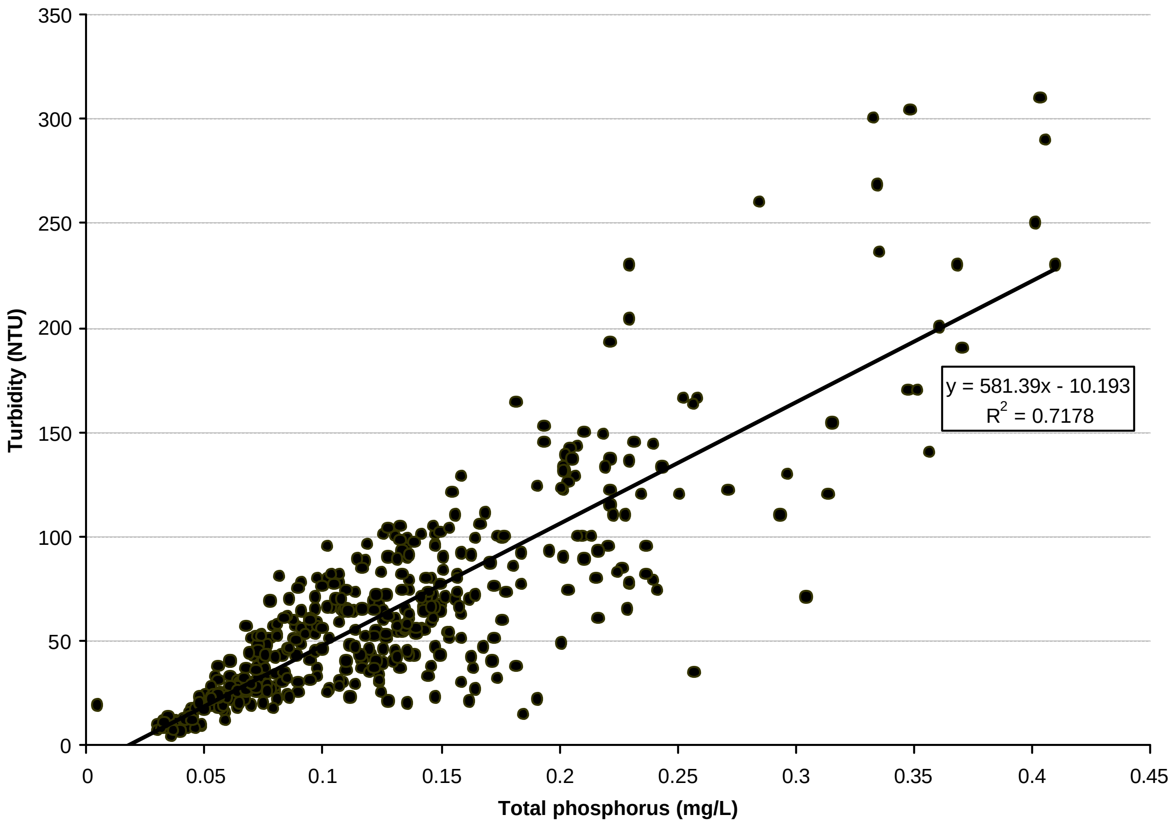


Figure 3.19 Morgan: Correlation plot of turbidity versus total phosphorus

3.5 Mannum

Mannum has one of the main pumping stations supplying water to Adelaide. It is therefore an important water quality monitoring site and there is an extensive data set for this site.

Results are summarised in Table 3.5 below. Water quality was generally moderate based on the following:

- Nutrient levels (nitrogen and phosphorus) were moderate.
- Salinity was classified as good.
- Total copper and total mercury were classified as moderate.
- Turbidity levels were high (see comments in section 3.1).
- Faecal coliform quality was good.

Table 3.5 Mannum: Water quality results

	Characteristics ((mg/L) unless specified)	Mean± Confidence interval	Median	N	Std Dev	P (10)	P (90)	Water quality classification
Nutrients	Oxidised nitrogen	0.097 ± 0.019	0.05	101	0.10	0.01	0.22	moderate
	TKN	0.855 ± 0.05	0.77	117	0.28	0.57	1.19	moderate
	Total phosphorus	0.136 ± 0.013	0.12	117	0.074	0.06	0.22	moderate
	Soluble phosphorus	0.110 ± 0.026	0.055	109	0.137	0.0153	0.292	moderate
Clarity	Turbidity (NTU)	61. ± 4	51	482	44	18	110	poor
Heavy metals	Total cadmium	0.0003 ± 0.00005	0.0002	93	0.0003	0.0002	0.0004	good
	Total copper	0.0125 ± 0.0020	0.007	117	0.011	0.005	0.028	moderate
	Total lead	0.0028 ± 0.0004	0.002	92	0.0021	0.001	0.005	good
	Total mercury	0.0001 ± 0.00002	0.0001	86	0.0001	0.0001	0.0003	moderate
	Total zinc	0.021 ± 0.0038	0.017	92	0.018	0.017	0.035	good
Pathogens	Faecal coliforms per 100mL	53 ± 5	41	402	49	16	96	good
Salinity	Conductivity (µS/cm)	582 ± 20	570	420	210	313	847	good
	Total dissolved solids	321 ± 12	317	395	118	170	467	good

Time series plots for all characteristics listed in the table over the period 1990–1999 are shown in Appendix 5.

The time series plot in Figure 3.20 shows conductivity at Mannum over the period 1990–1999, along with the results of modelling salinity using flow as the explanatory variable (see Section 3.1).

The time series plot in Figure 3.21 shows the difference between the modelled salinity and the measured data. The difference between the two should show any trend over time, but no significant trend is evident.

Figure 3.22 shows the percentage of samples in each year since 1968 that exceed 800 EC units. For five out of the six years, 1978–1983, conductivity was over 800 EC units for more than 50% of the time. The plots for Morgan and Mannum show a similar pattern.

The time series plot (Figure 3.23) of turbidity at Mannum, and the histogram plot (Figure 3.24) of yearly median turbidity levels, show little change between Morgan and Mannum.

The median and 90th percentile faecal coliforms numbers at Mannum for each year are shown in Figure 3.25. The water quality at Mannum meets the *Australian Guidelines for Recreational Use of Water* (NHMRC,1990) for primary contact (e.g. swimming).

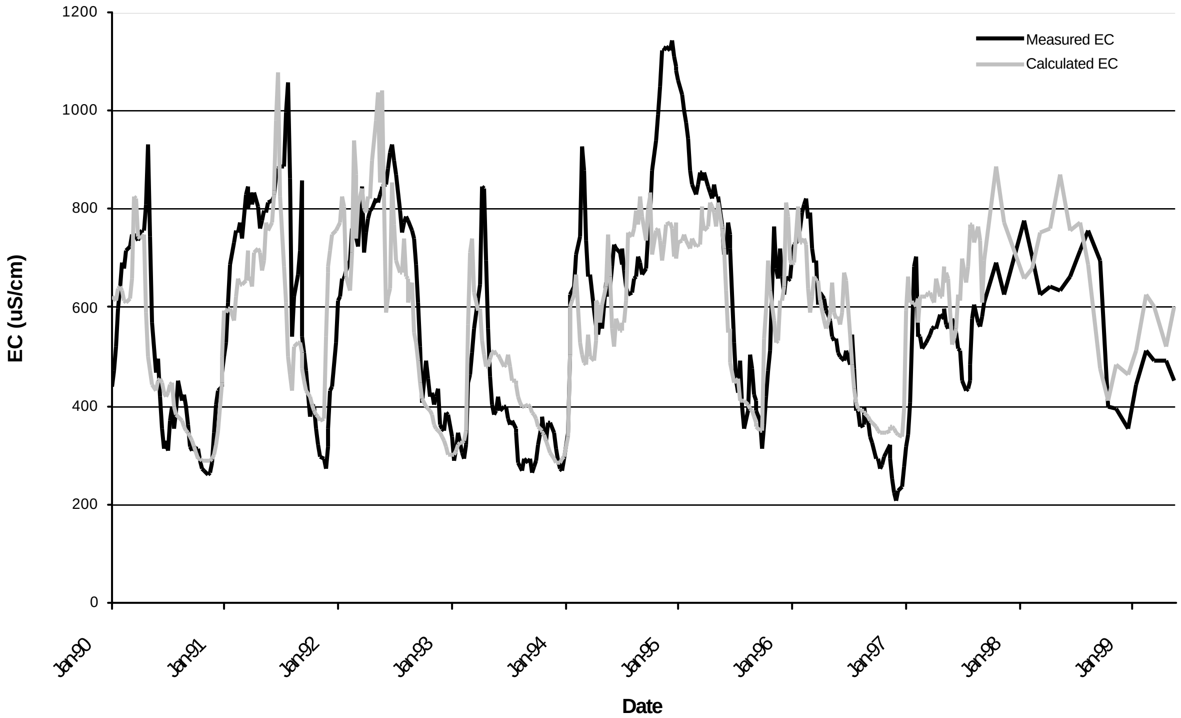


Fig 3.20 Mannum: Measured and calculated salinity (as conductivity), 1990–1999

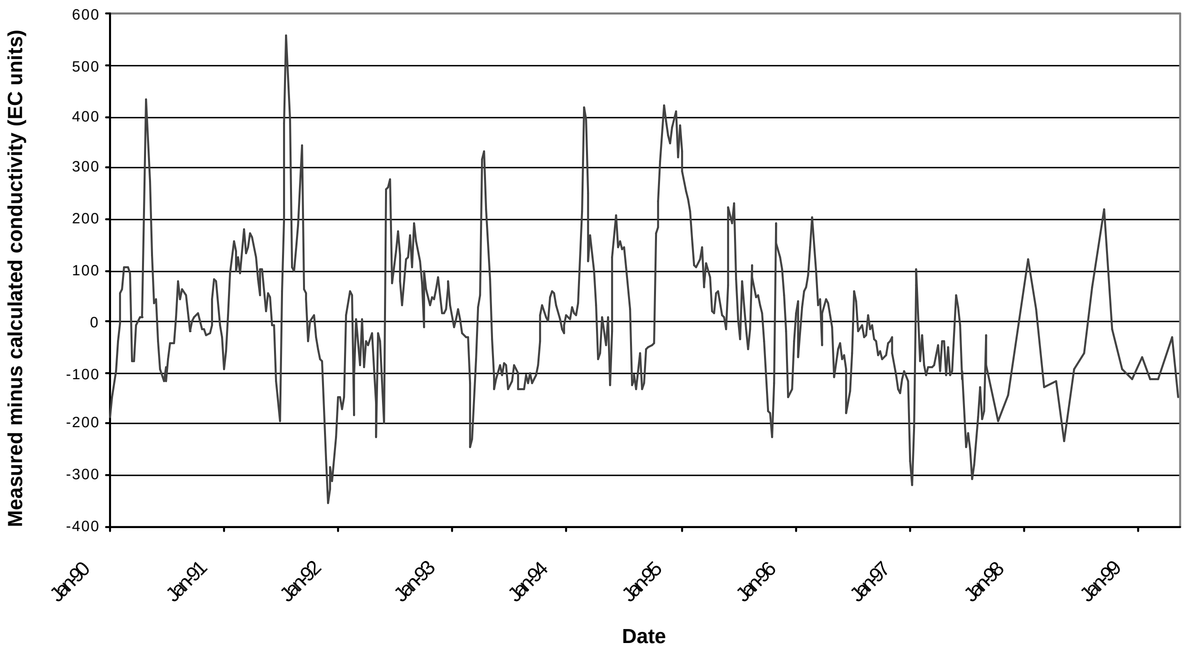


Fig 3.21 Mannum: Measured minus estimated salinity (as conductivity), 1990–1999

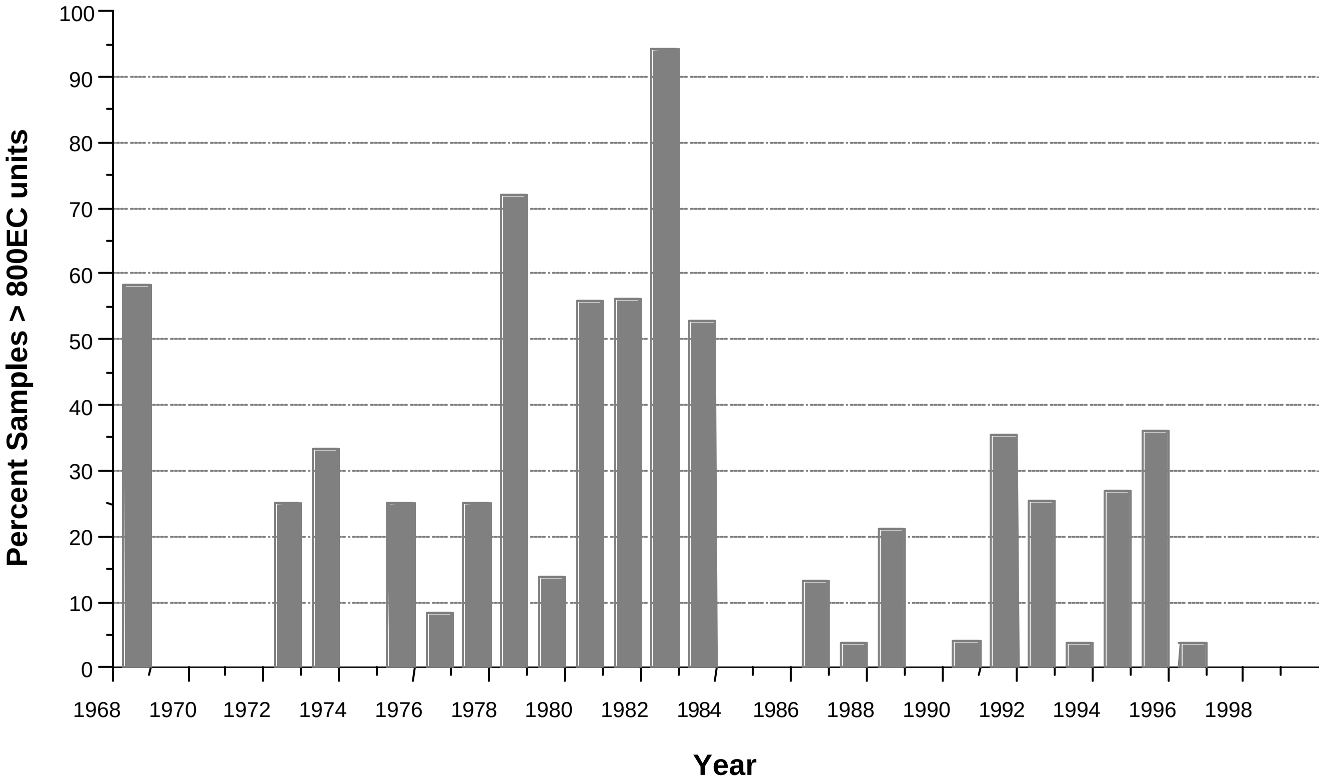


Fig 3.22 Mannum: Percentage of samples exceeding a salinity of 800 EC units in each year, 1968–1999

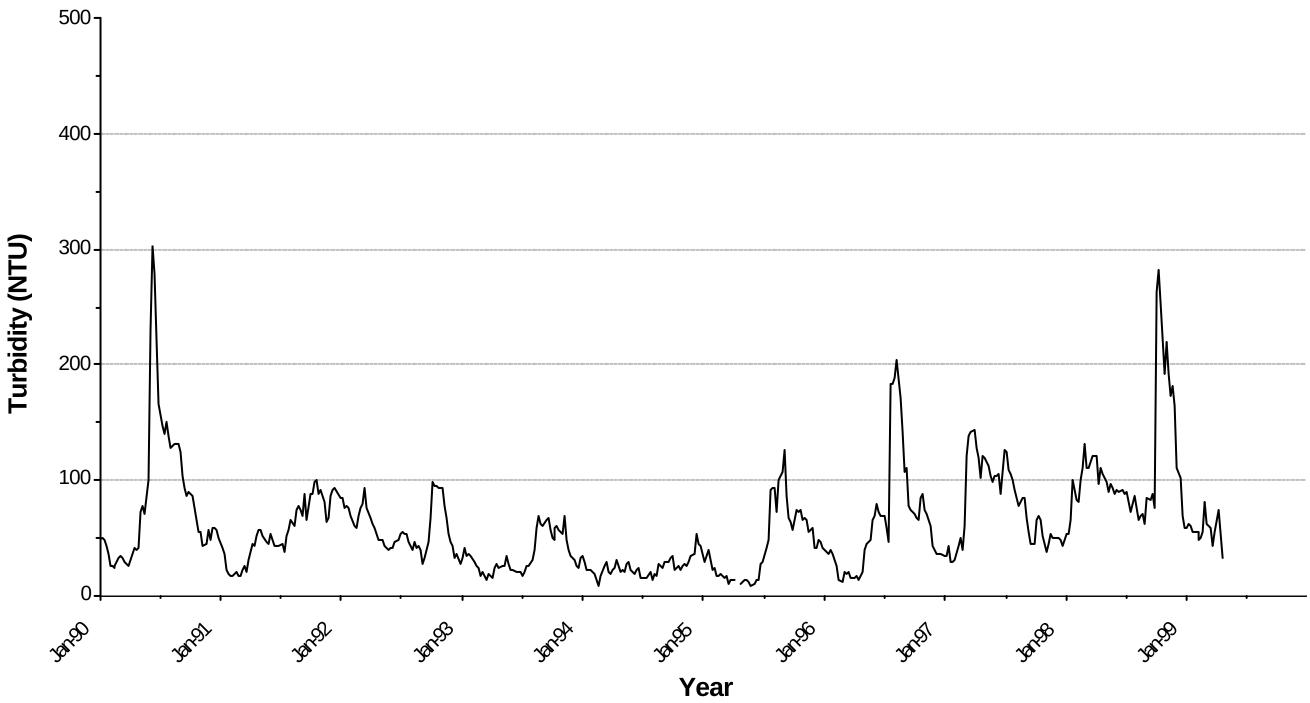


Fig 3.23 Mannum: Turbidity , 1990–1999

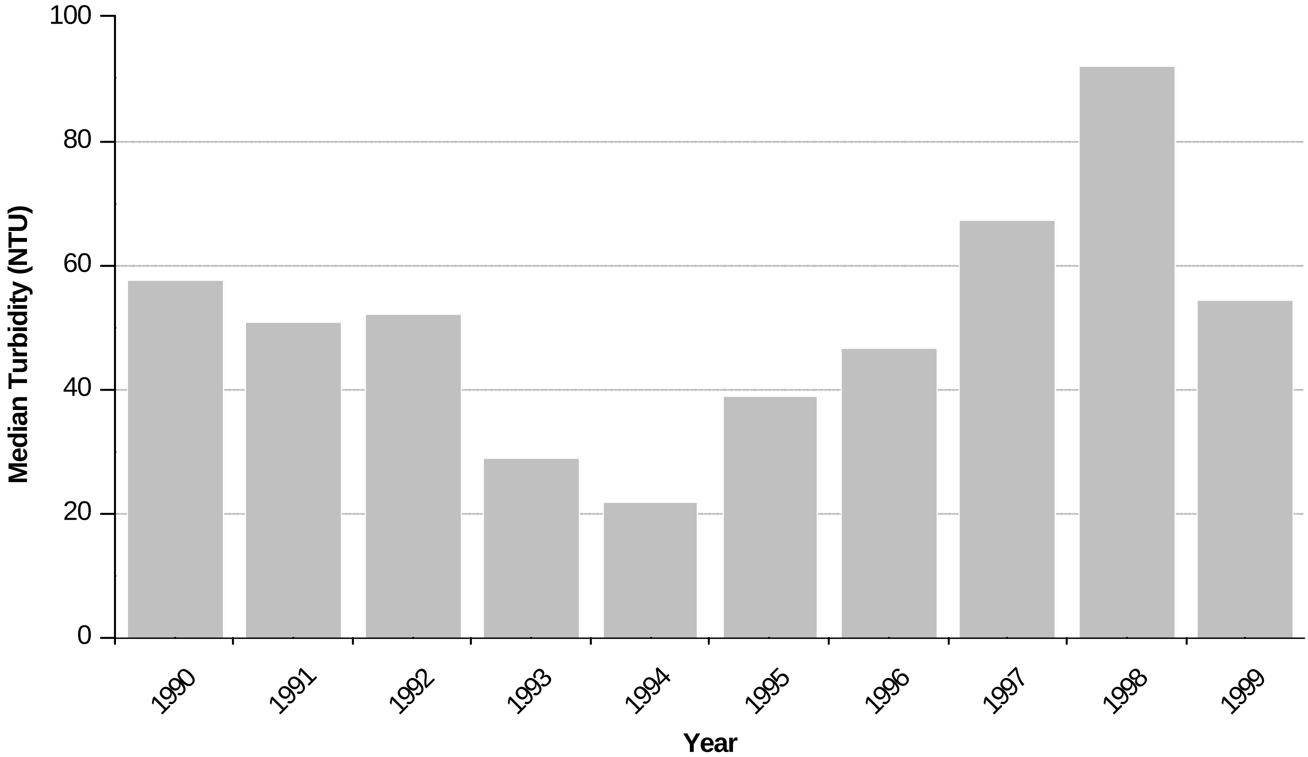


Fig 3.24 Mannum: Median turbidity at Mannum for each year, 1990–1999

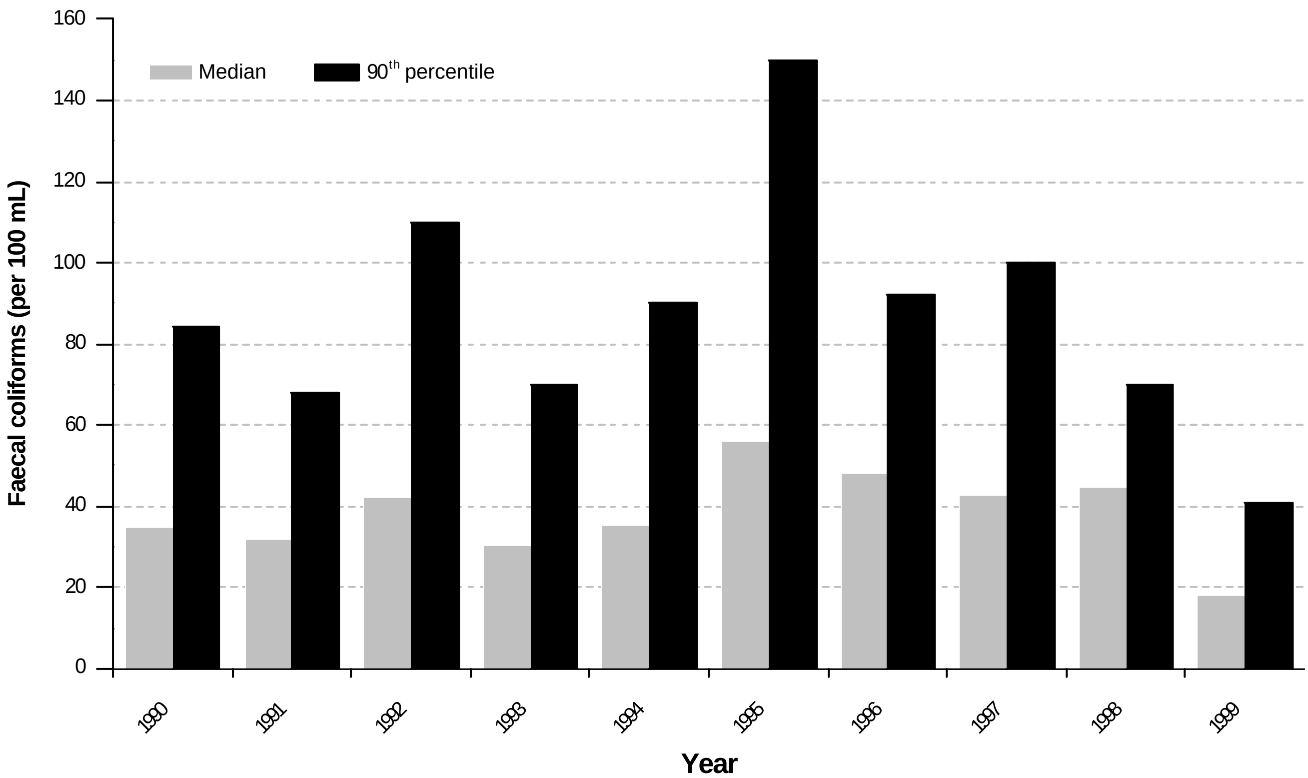


Fig 3.25 Mannum: Yearly median and 90th percentile faecal coliform numbers, 1990-1999

3.6 Murray Bridge

Murray Bridge, like Mannum, has a large pumping station supplying water to Adelaide. It is an important water quality monitoring site and there is an extensive data set for it.

Results are summarised in Table 3.6 below. Water quality was generally moderate based on the following:

- Nutrient levels (nitrogen and phosphorus) were moderate.
- Salinity was classified as good.
- Total copper was classified as moderate.
- Turbidity levels were high (see comments in section 3.1).
- Faecal coliform quality was moderate (but bordering on poor).

Table 3.6 Murray Bridge: Water quality results

	Characteristics ((mg/L) unless specified)	Mean± Confidence interval	Median	N	Std Dev	P (10)	P (90)	Water quality classification
Nutrients	Oxidised nitrogen	0.12 ± 0.02	0.09	127	0.102	0.013	0.26	moderate
	TKN	0.861 ± 0.05	0.84	129	0.284	0.53	1.27	moderate
	Total phosphorus	0.137 ± 0.012	0.122	130	0.071	0.064	0.218	moderate
	Soluble phosphorus	0.120 ± 0.022	0.072	112	0.117	0.018	0.284	moderate
Clarity	Turbidity (NTU)	58 ± 4	49	475	43	18	107	poor
Heavy metals	Total cadmium	0.0003 ± 0.00004	0.0002	91	0.0002	0.0002	0.0004	good
	Total copper	0.0105 ± 0.002	0.006	94	0.009	0.005	0.02	moderate
	Total lead	0.0028 ± 0.0005	0.002	91	0.0023	0.001	0.005	good
	Total mercury	0.0002 ± 0.0001	0.0001	87	0.0005	0.0001	0.0002	good
	Total zinc	0.0274 ± 0.01	0.015	90	0.046	0.005	0.049	good
Pathogens	Faecal coliforms per 100mL	250 ± 38	150	433	399	52	460	moderate
Salinity	Conductivity (µS/cm)	606 ± 20	588	474	218	324	881	good
	Total dissolved solids	333 ± 11	323	474	120	178	485	good

Time series plots for all characteristics listed in the table over the period 1990–1999 are shown in Appendix 6.

The time series plot in Figure 3.26 shows oxidised nitrogen at Murray Bridge over the period 1990–1999. The 90th percentile is double that recorded for Lock 3 (see Table 3.3) and substantially higher than that recorded for Morgan (see Table 3.4). It is likely that irrigation return water from dairy farms along the river contributed substantially to these elevated levels. The impact of these irrigation waters is discussed further in Section 3.9 and Section 4.

The median and 90th percentile faecal coliform numbers at Murray Bridge for each year are shown in Figure 3.27. Faecal coliform levels have increased substantially at Murray Bridge compared with upstream sites (see appendixes). This is likely to be the result of the discharge of irrigation drainage water from dairy farms along this stretch of the river. In 1994 and 1997 the median number of faecal coliforms was 240 and 200 organisms per

100 mL respectively, which exceeded the NHMRC guideline for primary contact recreation (e.g. swimming).

To combat this trend, several improvements in irrigation practices and dairy shed waste management in the Lower Murray have been implemented. Further details and examples of proposed initiatives are included in the concluding remarks (see section 5).

Although the microbiological quality of the water does not meet the NHMRC guideline for primary contact recreation at times during the period, the Department of Human Services has advised that the risk to humans is considered to be low. This is based on the premise that dairy cattle are the major source of faecal contamination of the River Murray in the Lower Murray irrigation area and waste from cattle poses a lower risk of containing human enteric pathogens than human waste.

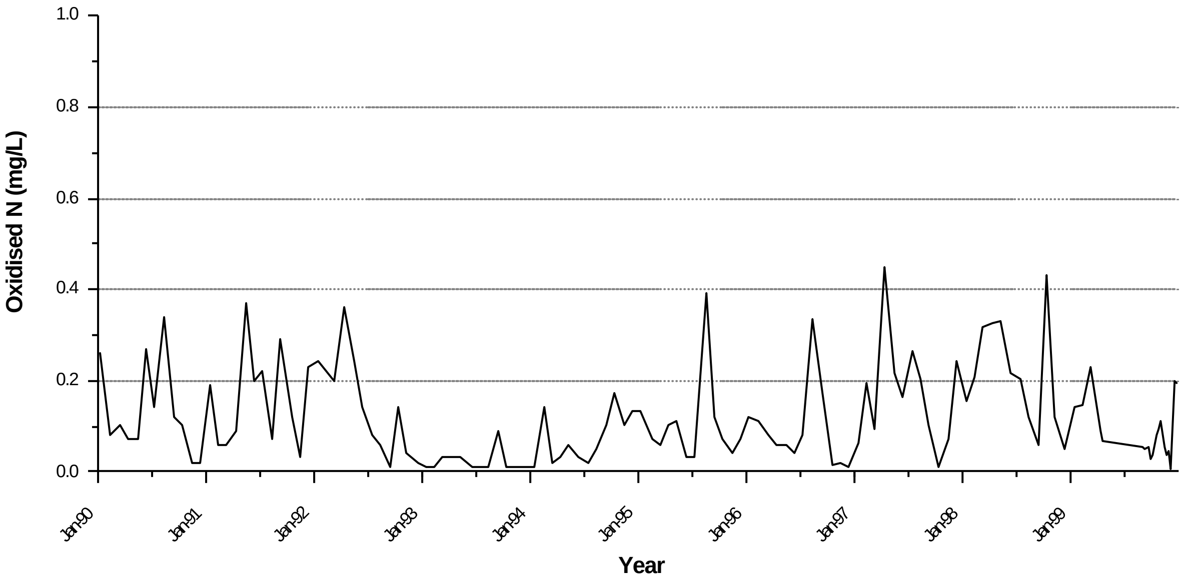


Fig 3.26 Murray Bridge: Oxidised nitrogen, 1990–1999

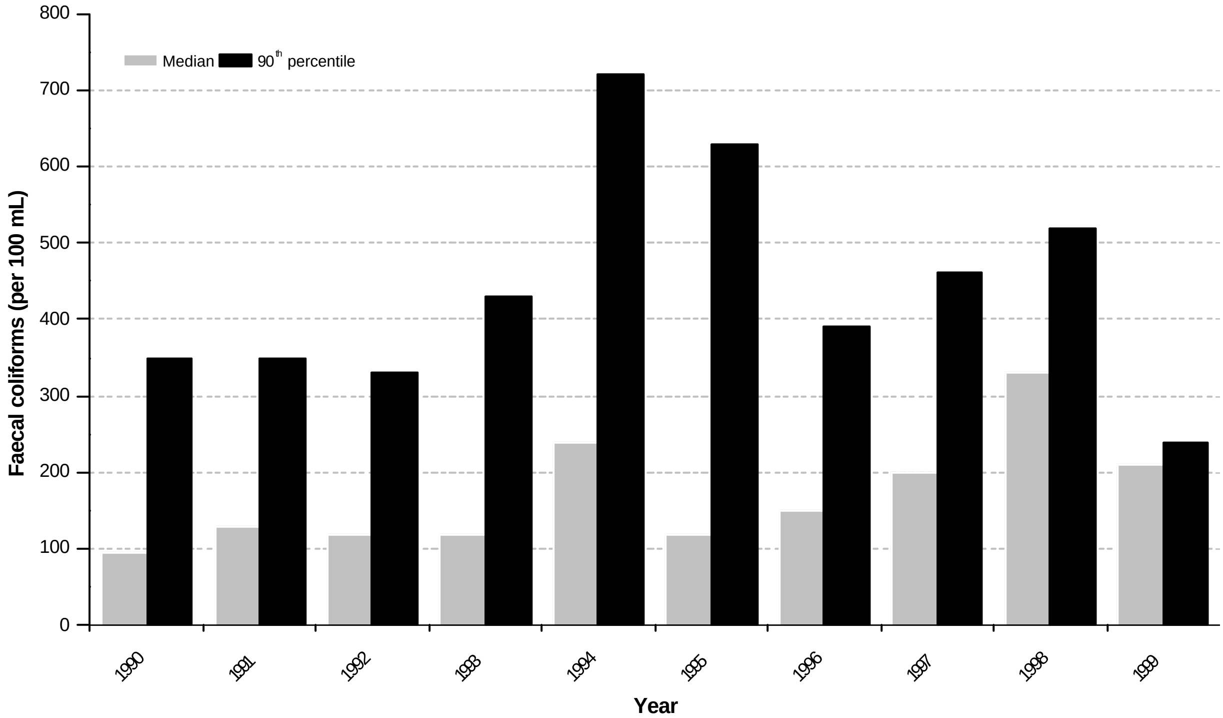


Fig 3.27 Murray Bridge: Yearly median and 90th percentile faecal coliform numbers, 1990-1999

3.7 Tailem Bend

Water is pumped from Tailem Bend to supply areas in the upper South East including Keith. There is a significant dairy industry between Mannum and Tailem Bend that uses water from the River Murray for irrigation. Some of this water is returned to the river as irrigation drainage water and can impact on water quality. Tailem Bend is the last monitoring site before the river discharges into Lake Alexandrina.

Results are summarised in Table 3.7 below. Water quality was generally moderate based on the following:

- Nutrient levels (nitrogen and phosphorus) were moderate.
- Salinity was classified as good.
- Total copper was classified as moderate.
- Turbidity levels were high (see comments in section 3.1).
- Faecal coliform quality was poor.

Time series plots for all characteristics listed in the table over the period 1990–1999 are shown in Appendix 7.

The time series histograms in Figure 3.28 show faecal coliform levels at Tailem Bend.

The median and 90th percentile faecal coliform numbers at Tailem Bend for each year are shown in Figure 3.29.

Faecal coliform numbers increased over the period, and in the years 1994–1999 did not meet NHMRC primary contact recreational use guidelines (eg swimming).

To combat this trend, several improvements in irrigation practices and dairy shed waste management in the Lower Murray have been implemented. Further details and examples of proposed initiatives are included in the concluding remarks (see section 5).

Table 3.7 Tailem Bend: Water quality results

	Characteristics ((mg/L) unless specified)	Mean± Confidence interval	Median	N	Std Dev	P (10)	P (90)	Water quality classification
Nutrients	Oxidised nitrogen	0.144 ± 0.011	0.11	479	0.123	0.016	0.3	moderate
	TKN	0.845 ± 0.028	0.79	479	0.317	0.52	1.21	moderate
	Total phosphorus	0.138 ± 0.008	0.123	479	0.087	0.065	0.221	moderate
	Soluble phosphorus	0.149 ± 0.047	0.104	113	0.253	0.026	0.280	moderate
Clarity	Turbidity (NTU)	55 ± 4	45	482	42	16	102	poor
Heavy metals	Total cadmium	0.0003 ± 0.00004	0.0002	109	0.0002	0.0002	0.0003	good
	Total copper	0.0121 ± 0.0017	0.007	110	0.0094	0.005	0.03	moderate
	Total lead	0.0025 ± 0.0004	0.002	110	0.002	0.001	0.005	good
	Total mercury	0.0001 ± 0.0002	0.0001	111	0.0001	0.0001	0.0003	good
	Total zinc	0.027 ± 0.0052	0.020	110	0.028	0.005	0.047	good
Pathogens	Faecal coliforms per 100mL	434± 88	190	523	1022	56	786	poor
Salinity	Conductivity (µS/cm)	615 ± 20	600	480	226	326	900	good
	Total dissolved solids	338 ± 11	329	480	124	179	495	good

Although the microbiological quality of the water does not meet the NHMRC guideline for primary contact recreation at times during the period, the Department of Human Services has advised that the risk to humans is considered to be low. This is based on the premise that dairy cattle are the major source of faecal contamination of the River Murray in the Lower Murray irrigation area and waste from cattle poses a lower risk of containing human enteric pathogens than human waste.

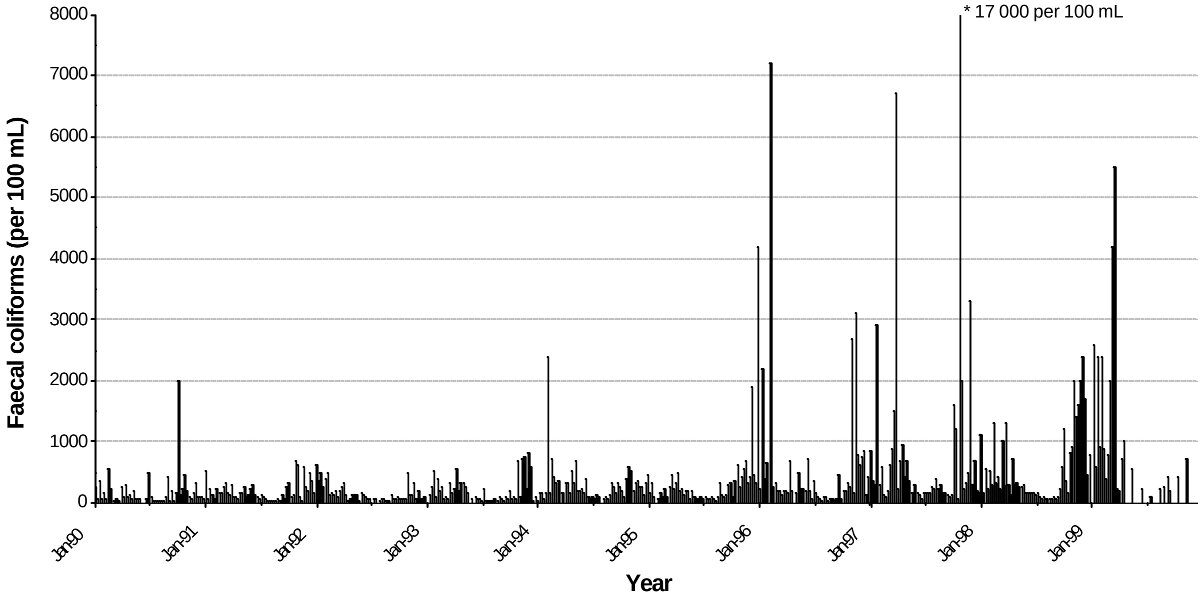


Fig 3.28 Tailem Bend: Faecal coliforms, 1990–1999

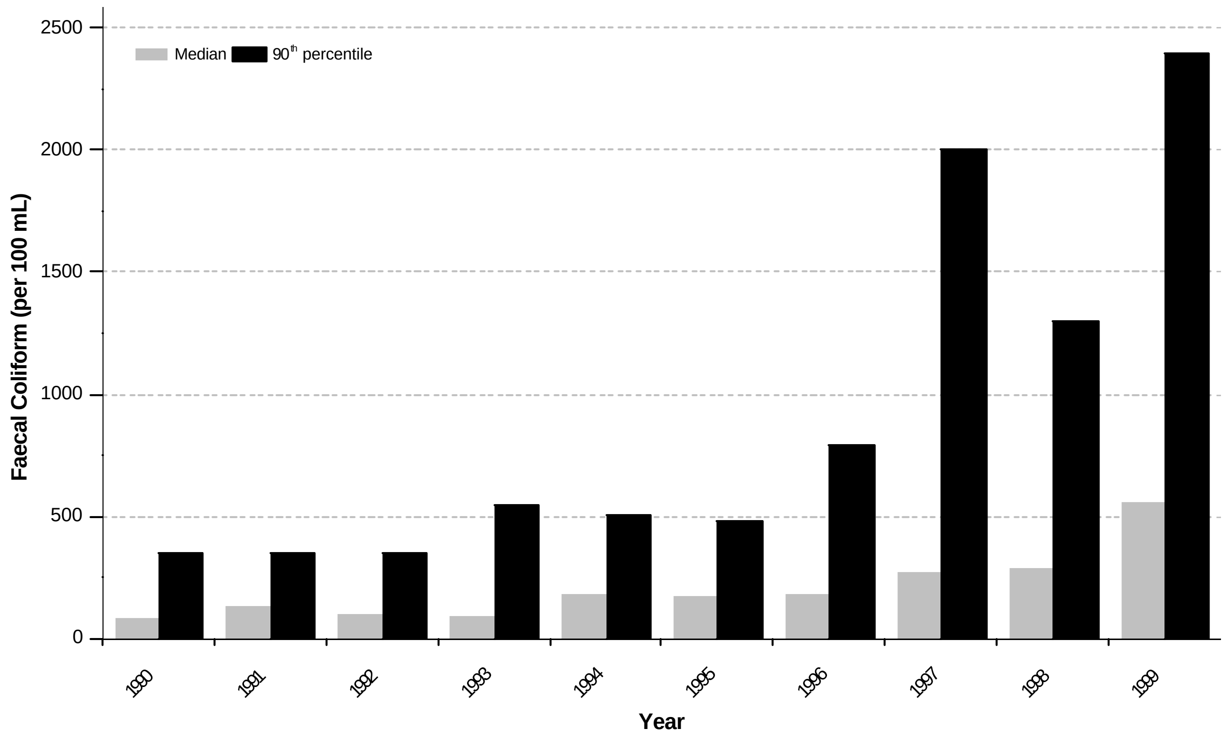


Fig 3.29 Tailem Bend: Yearly median and 90th percentile faecal coliform numbers, 1990–1999

4. CHANGES IN WATER QUALITY DOWN THE RIVER MURRAY

This section examines how some of the key water quality characteristics varied with changes down the river. Only those characteristics that showed a change are discussed. The percentile data used in this section of the report is based on the whole period 1990-1999, not particular years.

4.1 Turbidity

Changes in the median and 90th percentile turbidity levels for the period are shown in Figure 4.1. Turbidity levels decreased slightly down the river, probably because of some settling out of suspended matter.

Median turbidity over 1990–1999 varied from 39 NTU at Lock 9 to 58 NTU at Lock 3. Turbidity in the River Murray can be significantly affected by flow from the Darling River, which usually has much higher turbidity (very finely suspended particulate matter with a distinctive white appearance).

The high turbidity levels mean that the River Murray, like many other Australian inland rivers, has increased risks associated with swimming and related activities as the bottom, is not visible to a depth of 1.2 metres. Details of initiatives and water safety campaigns focussing on the river have been included as part of the concluding remarks of this report (see section 5).

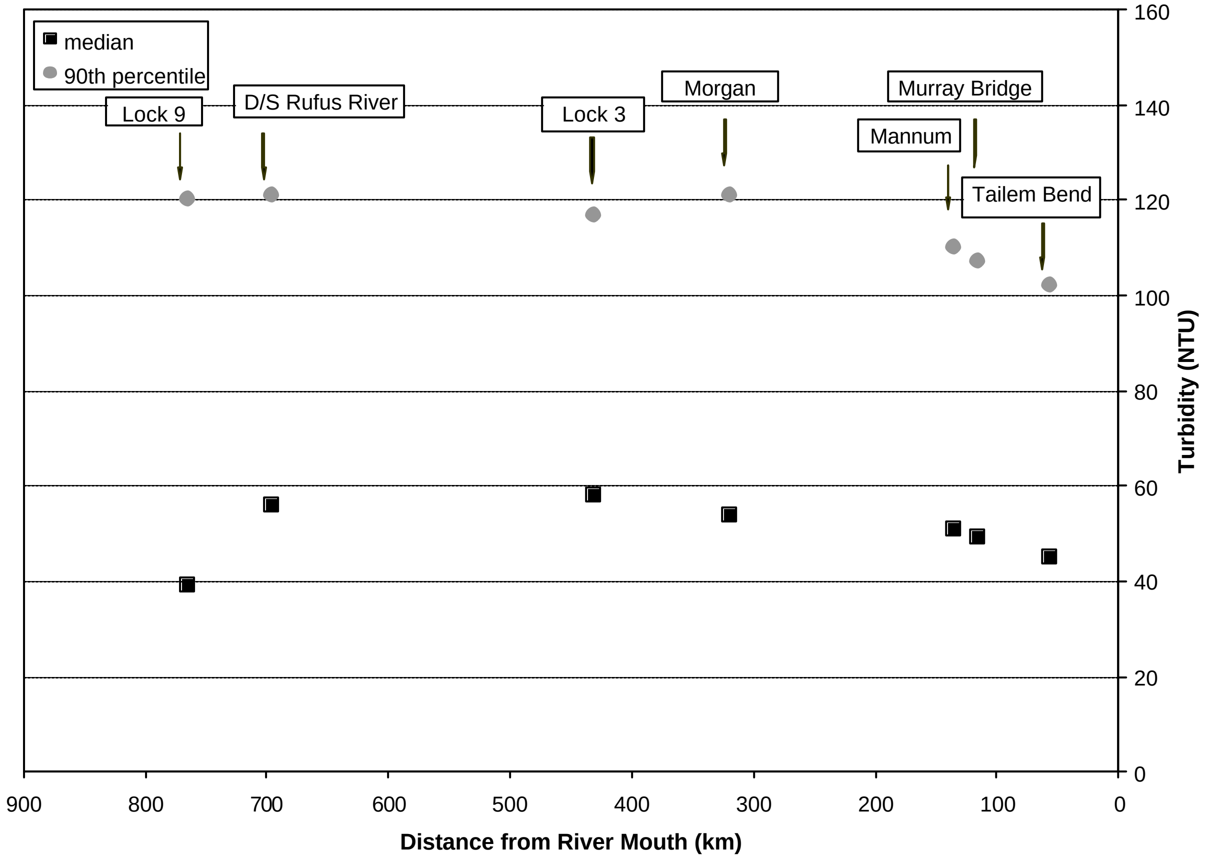


Figure 4.1 Percentile plots: Turbidity for the period 1990-1999

4.2 Salinity

Monitoring results for median and 90th percentile salinity, expressed as conductivity, for 1990–1999 (Figure 4.2) show that salinity increased down the river. Lowest levels were recorded at Lock 9 and highest at Tailem Bend.

Although salinity levels have been classified as good for the past decade (Tables 3.1–3.7), the long term prognosis is a matter of concern (MDBC 1999). Intrusion of saline groundwater into the River Murray, partly resulting from past land clearances and irrigation practices, is likely to have a significant impact over the next 50–100 years (MDBC 1999).

Increased monitoring of salinity is required between the sites downstream Rufus River and Lock 3 to investigate elevated levels of salinity between the two sites.

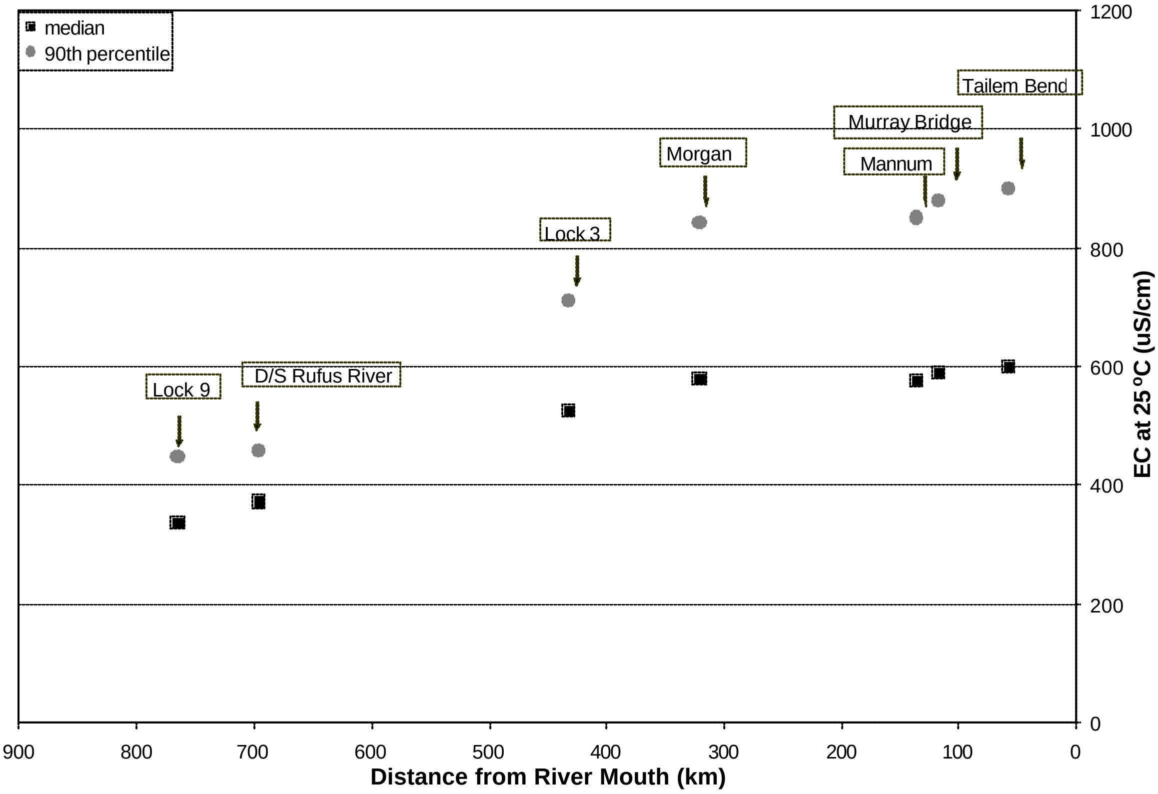


Figure 4.2 Percentile plots: Salinity (as conductivity) for the period 1990-1999

4.3 Nutrients

Oxidised nitrogen

Monitoring results for median and 90th percentile oxidised nitrogen down the River Murray for 1990–1999 (Figure 4.3) show that oxidised nitrogen concentrations increased markedly between Mannum and Tailem Bend. This increase is likely to be due to the impact of irrigation return water from the dairies along the river between Mannum and Tailem Bend.

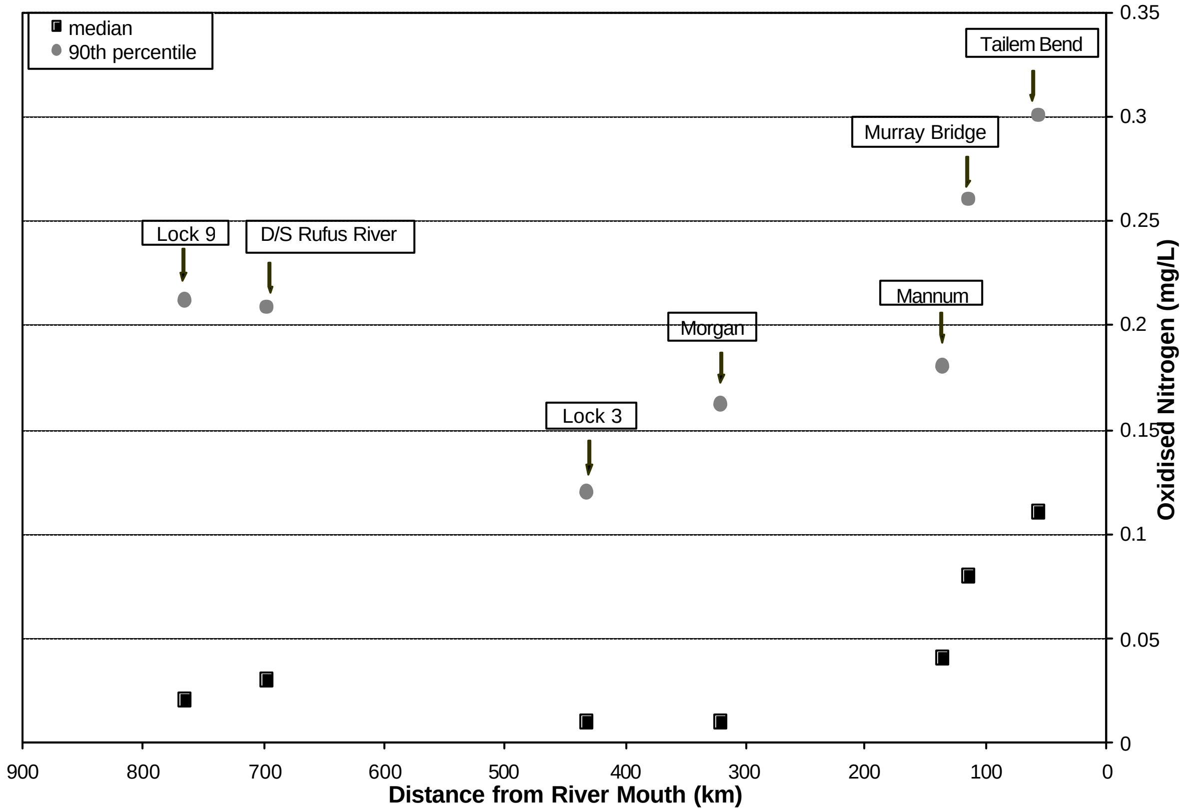


Figure 4.3 Percentile plots: Oxidised nitrogen for the period 1990-1999

Total phosphorus

Median and 90th percentile total phosphorus concentrations for 1990–1999 (Figure 4.4) are fairly consistent along the river. The strong relationship between turbidity and total phosphorus would suggest that total phosphorus concentrations would decrease down the river with the lowered turbidity. This does not appear to have occurred. The slight rise between Mannum and Tailem Bend may be the result of irrigation return water from the dairies as discussed above (see oxidised nitrogen).

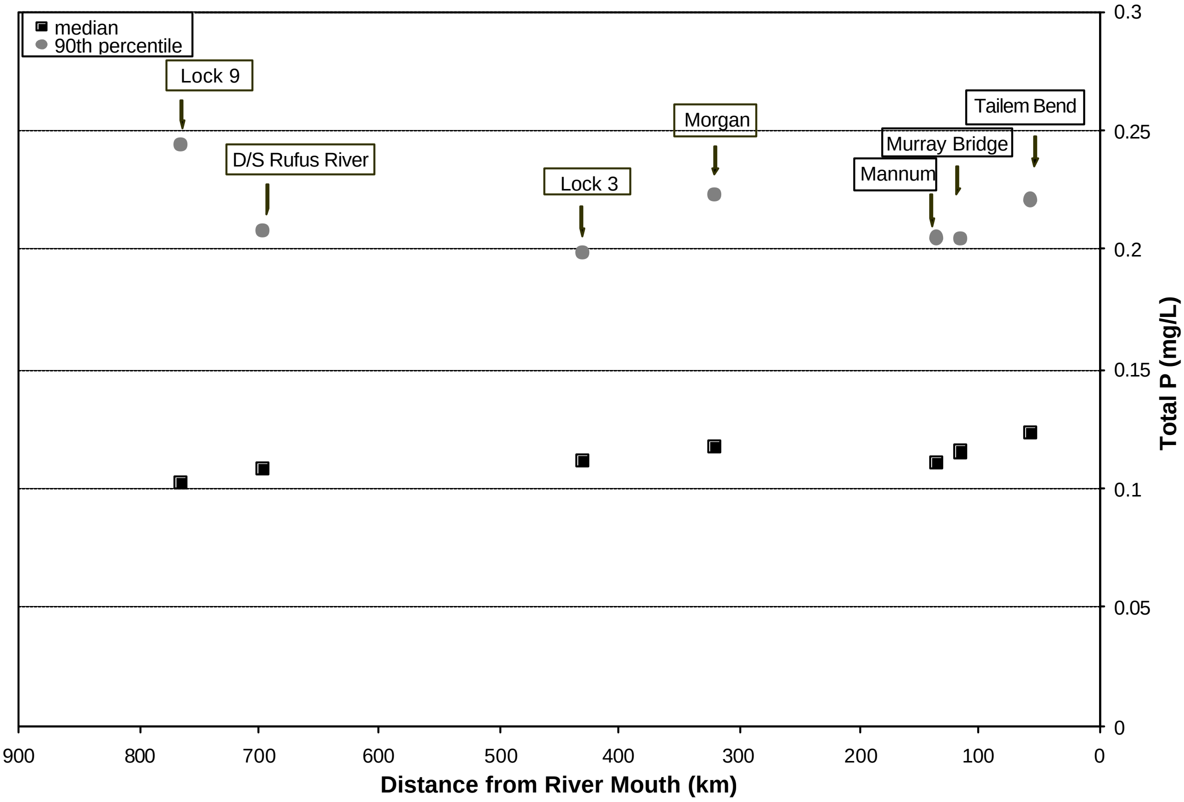


Figure 4.4 Percentile plots: Total phosphorus for the period 1990-1999

Soluble phosphorus

Changes in median and 90th percentile soluble phosphorus concentrations down the River Murray for 1990–1999 are shown in Figure 4.5. Soluble phosphorus is a more direct indicator of bioavailable phosphorus, which is needed for algal growth. Median concentrations rose substantially between Mannum and Tailem Bend. It is likely that this was also due to the impact of the dairy farms along this stretch of the river.

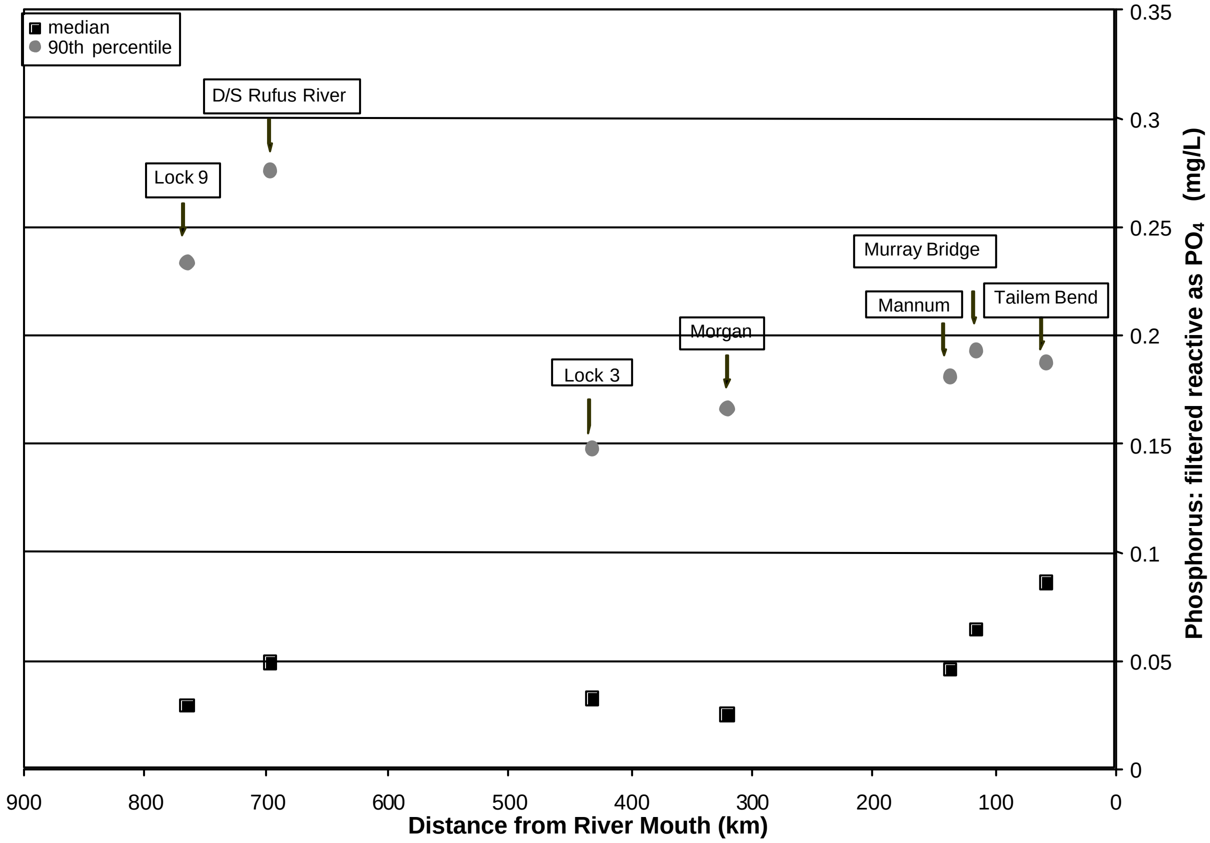


Figure 4.5 Percentile plots: Soluble phosphorus for the period 1990-1999

Total Kjeldahl nitrogen

Median and 90th percentile total Kjeldahl nitrogen (organic nitrogen plus ammonia) concentrations for 1990–1999 (Figure 4.6) showed very little change along the river.

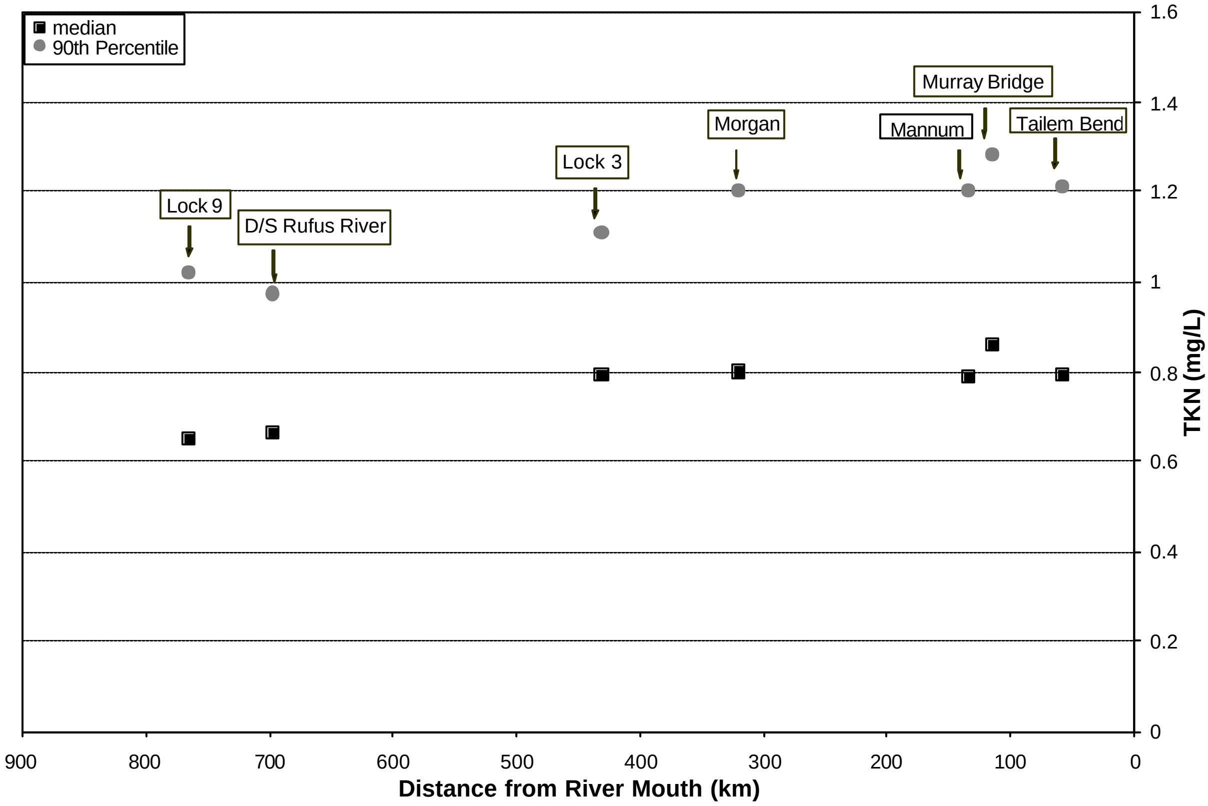


Figure 4.6 Percentile plots: Total Kjeldahl nitrogen for the period 1990-1999

4.4 Faecal coliforms

Median and 90th percentile faecal coliform numbers for 1990–1999 (Figure 4.7) showed a substantial increase between Mannum and Tailem Bend. This is likely to be the result of irrigation return water from dairy farms along the river.

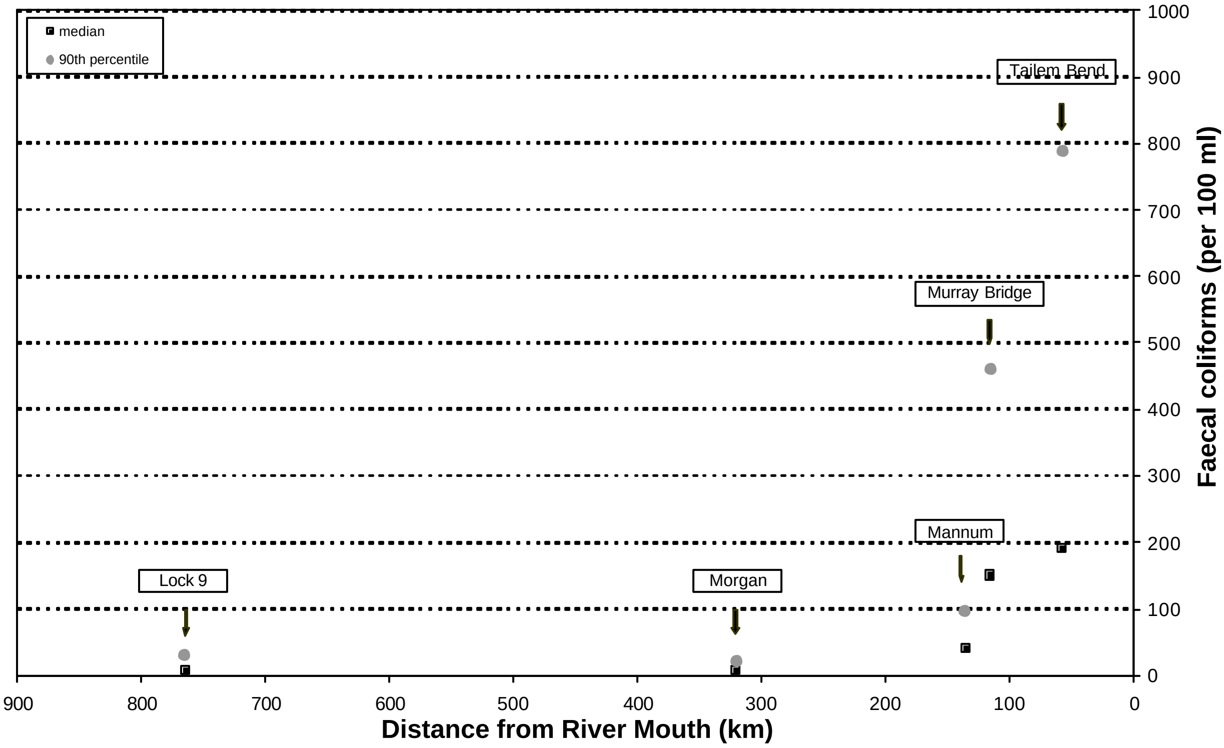


Figure 4.7 Percentile plots: Faecal coliforms for the period 1990-1999

The percentage compliance for faecal coliforms with the *Australian Drinking Water Guidelines* (NHMRC & ARMCANZ 1996) and the *Australian Guidelines for Recreational Use of Water* (NHMRC 1990) over the period 1990–1999 is shown in Table 4.1.

None of the sites monitored met drinking water criteria (see Table 4.1). Based on faecal coliform numbers, River Murray water in South Australia was unsuitable for drinking without treatment (e.g. boiling or disinfecting). It has, however, been recognised for some time that none of the rivers and streams in South Australia are suitable for drinking without such treatment and the Department of Human Services has issued three warnings in the last three years to this effect. The River Murray is no exception.

To combat this trend, several improvements in irrigation practices and dairy shed waste management in the Lower Murray have been implemented. Further details and examples of proposed initiatives are included in the concluding remarks (see section 5).

The Department of Human Services has advised that the microbiological risk to humans from recreational use of the water is considered to be low. This is based on the premise that dairy cattle are the major source of faecal contamination of the River Murray in the Lower Murray Irrigation area and waste from cattle poses a lower risk of containing human enteric pathogens than human waste.

Table 4.1 Percentage compliance with criteria used to assess water for primary contact recreational use (eg swimming) and drinking water requirements for the period 1990-1999

Site location	Percentage of samples that exceed 150 faecal coliforms per 100 mL	Percentage of samples that exceed zero faecal coliforms per 100 mL
Lock 9	0	89.7
Morgan	0.4	93.9
Mannum	3.5	99.8
Murray Bridge	48.0	99.8
Tailem Bend	58.3	99.8

4.5 Heavy metals

Most of the heavy metals assessed were not of concern and did not increase significantly down the river.

Copper

Total copper was found to be at elevated levels at all sites during the period. The median and 90th percentile copper concentrations for 1990–1999 (Figure 4.8) showed very little change down the river. The source of copper is probably natural, for example as a result of weathering of rocks containing copper ores, and is not considered to be of concern.

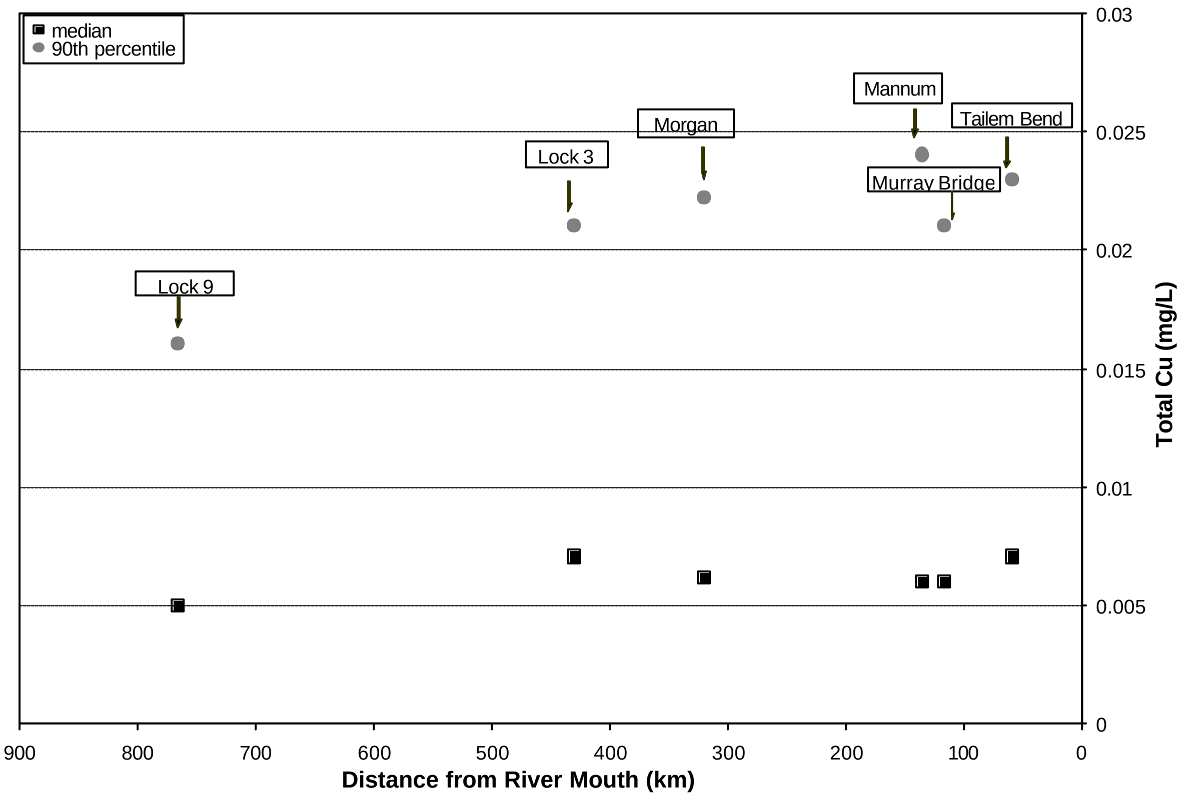


Figure 4.8 Percentile plots: Total copper for the period 1990-1999

4.6 Algae

The frequency of detection of some of the commonly found cyanobacteria over the period 1990–1999 at sites on the River Murray is listed in Table 4.2. *Anabaena* were the most commonly detected algae at all sites, occurring most frequently at Lock 3.

Table 4.2 Percentage of samples with cyanobacteria present for the period 1990-1999

Sites	No. samples	% *Anabaena*	% *Anabaenopsis*	% *Aphanizomenon*	% *Microcystis*	% *Oscillatoria*	% *Cylindrospermopsis*
Lock 9	2311	31.6	2.3	7.3	1.3	0.95	0.17
D/S Rufus River	741	26.9	1.8	3.8	1.3	0.94	1.6
Lock 3	1432	42.3	5.0	9.4	0.91	1.3	2.0
Morgan	2451	31.3	4.2	7.5	0.86	1.4	1.1
Mannum	1255	30.9	2.8	6.7	0.64	2.5	1.5
Murray Bridge	863	27.6	0	4.6	0.93	2.1	0.46
Tailem Bend	1406	23.5	0	2.9	1.4	1.8	0.07

Other common algae present in the River Murray are listed in Table 4.3. *Melosira* was the most common of these other algae, occurring most frequently at Mannum.

Table 4.3 Percentage of samples with other common algae present for the period 1990-1999

Sites	No. samples	% *Melosira*	% *Cyclotella*	% *Planctonema*
Lock 9	2311	17.8	3.8	3.5
D/S Rufus River	741	26	7.7	2.6
Lock 3	1432	15.6	4.5	2.3
Morgan	2451	15.4	4.9	4
Mannum	1255	30.9	6.6	3.5
Murray Bridge	863	21	7.4	3.6
Tailem Bend	1406	16.5	6	3.6

Nodularia, Euglena, Astrionella, Synedra were also found regularly at some sites but much less frequently than the algae listed in Tables 4.2 and 4.3.

The numbers of samples with three levels of *Anabaena* counts are shown in Table 4.4. The results show that, although *Anabaena* was frequently detected, cell numbers were usually low and not a matter of concern.

Lock 3 had the highest percentage of samples with counts above 2000 cells/mL. It also had the highest frequency of *Anabaena* detection of all the sites. The reason for this is not known, but it has been speculated that the readings might have been influenced by Watchel's Lagoon, upstream of Lock 3.

Watchel's Lagoon is a broad shallow backwater of the River Murray that receives significant volumes of irrigation-induced seepage from the Moorook and Seven Mile Reach irrigation areas. In hot weather, blooms of *Anabaena* form in the lagoon and are able to enter the River Murray through the broad lagoon mouth under unfavourable wind conditions.

The Moorook Irrigation area has recently been rehabilitated and this should reduce the impact from the lagoon over time.

Table 4.4 Percentage occurrence of *Anabaena* along the River Murray for the period 1990-1999*

Sites	No. of samples	% < 1000 cells/mL	% 1000–2000 cells/mL	% > 2000 cells/mL	% > 15,000 cells/mL
Lock 9	731	97	1.9	1.1	0.3
D/S Rufus River	199	94.5	4	1.5	0
Lock 3	606	89.8	5.6	4.6	0.16
Morgan	767	95.7	2.7	1.8	0.13
Mannum	388	96.1	3.6	1	0
Murray Bridge	238	99.6	2.1	0.42	0
Tailem Bend	330	99.4	0.91	0.3	0

*Toxicity levels start at ≥ 2000 cells/mL (Alert Level 2); at >15,000 cells/mL (Alert Level 3) restrictions to access all waters should be enforced.

5. CONCLUDING REMARKS

This report provides an assessment of water quality at a number of sites along the River Murray over the period 1990–1999, and looks at differences in some key characteristics between sites during this time. Some important findings are listed below.

- Overall water quality at most sites could be described as moderate.
- Turbidity was high at all sites. Turbidity is caused by suspended matter in the water, particularly clay, giving it a cloudy or murky appearance. The high turbidity levels mean that the River Murray, like many other Australian inland rivers, has increased risks associated with swimming and related activities as the bottom is not visible to a depth of 1.2 metres.
- The cyanobacteria *Anabaena* were the most common algae found at all the sites monitored but numbers were generally low and not a cause for concern.
- Water quality deteriorated between Mannum and Tailem Bend. Nutrient concentrations (oxidised nitrogen and total phosphorus) and faecal coliform numbers rose, and it is likely that this deterioration is due to irrigation return waters from dairy farms along this stretch of the river.
- Based on faecal coliform numbers, River Murray water in South Australia was unsuitable for drinking without treatment (e.g. boiling or disinfecting). It has, however, been recognised for some time that none of the rivers and streams in South Australia is suitable for drinking without such treatment and the Department of Human Services has issued three warnings in the last three years to this effect. The River Murray is no exception.
- There was a notable deterioration in microbiological quality in the lower River Murray between Mannum and Tailem Bend. Both Murray Bridge and Tailem Bend failed to meet the *Australian Guidelines for Recreational Use of Water* (NHMRC, 1990) for primary contact (e.g. swimming) at times during the period. The Department of Human Services has advised that, although the risk to human health from exposure to microbial hazards in the river is increased from Mannum to Tailem Bend, the risk of illness remains low.
- Salinity substantially increased down the river, with large increases between Lock 9 and Lock 3, and between Lock 3 and Morgan. It is likely that irrigation practices, coupled with saline groundwater intrusion, evaporation and mallee clearance, all contribute to these increases.
- There was no indication of a substantial rise in salinity at Mannum or other sites over the last 10 years. This indicates that the salt interception schemes have been effective to date.

A number of measures have already been taken to address many of these water quality issues:

- Water taken from the River Murray and supplied to Adelaide and major towns is treated to a high level and regularly monitored to ensure that it meets the *Australian Drinking Water Guidelines* (NHMRC & ARMCANZ, 1996).
- Several water safety campaigns and initiatives focusing on education and safety awareness specific to the river environment are delivered to the Riverland Region every year. In addition, promotional literature and forums such as tourism expos are

used to ensure the safety awareness message specific to the Murray also reaches recreational users of the river.

- There are six State Emergency Service Units located on the River Murray that provide an emergency rescue component and risk management focus to river safety.
- During 2001, a draft State Water Safety Plan has been proposed to ensure a coordinated strategy to water safety across the State.
- A number of irrigation districts have been rehabilitated, with replacement of old and inefficient infrastructure leading to salinity reductions.
- On-farm irrigation practices have been improved through government support and funding for irrigated crop management services, resulting in salinity benefits.
- Better dairy shed waste management practices in the Lower Murray have been implemented, reducing nutrients.
- Irrigation management practices have been improved in the Lower Murray, resulting in reductions in nutrients and bacteria in drainage water.
- A number of other initiatives have been taken in the Lower Murray such as metering, water allocation, trials of improved irrigation practices and rehabilitation planning.
- Salt interception schemes have been installed at Woolpunda and Waikerie, together with other salinity reduction actions under the Murray Darling Basin Commission.

Additional new initiatives are being implemented to improve water quality in the River Murray:

- In collaboration with dairy farmers and the local community, the State Government has committed $40 million to rehabilitate the Lower Murray Swamps. The five-year plan will see major infrastructure changes designed to dramatically improve water efficiency and convert some of the irrigated land to wetlands. These initiatives are expected to reduce 80% of polluted water from dairy pastures running back into the River Murray.
- New salt interception schemes are being developed to stop highly saline groundwater from entering the river.
- An action plan is being developed, with the support of dairy farmers, to deal with problems caused by irrigation return water from the lower Murray swamps.
- A Water Quality Policy is being developed with provisions against the discharge of a waste that causes pollution of a waterway.
- Industries such as dairies are required to comply with waste management requirements aimed at reducing or eliminating runoff into waterways and urban source pollution from streets.
- The Murray–Darling Basin Commission plans to reduce nutrient and salt inputs throughout the catchment.
- The River Murray Catchment Water Management Board is preparing a Catchment Water Management Plan and a Water Allocation Plan.
- Community-based programs such as Landcare have been implemented to assist revegetation and other works to improve water quality.

- Communities are being better educated and their awareness raised about the issues facing the River Murray. This includes the dangers associated with swimming and related activities.

The quality of water in the River Murray has a substantial impact on South Australia, and the availability of good quality water is closely linked to the prosperity of the State. The River Murray is a major water source, and improving the quality of its water would result in environmental, economic and social benefits for South Australia.

FURTHER READING

ANZECC. 1992. *Australian water quality guidelines for fresh and marine waters*. Australian and New Zealand Environment and Conservation Council.

Banens B. 1996. Eutrophication. *Australian Science*, 17(2): 29–32.

Crabb P. 1997. *Murray–Darling Basin resources*, Murray–Darling Basin Commission.

CSIRO. 1998. *Historical stream salinity trends and catchment salt balances in the Murray-Darling Basin*. CSIRO Division of Land and Water, Technical Report 33/98.

EPA. 1998. *Water monitoring report. Ambient water quality monitoring of South Australia's rivers and streams (Chemical and physical quality).* Environment Protection Agency, South Australia.

Gippel C. 1989. *The use of turbidity instruments to measure stream water suspended sediment concentration*. Monograph Series No. 4, Department of Geography and Oceanography, University College, Australian Defence Force Academy, Canberra.

Mackay N, Hillman T and Rolls J. 1988. *Water quality of the River Murray*. River Murray Commission.

MDBC. 1988. *Salinity and drainage strategy*, Murray–Darling Basin Commission.

MDBC. 1994. *Algal management strategy*, Murray–Darling Basin Commission, Technical Advisory Group Report

MDBC. 1999. *The audit report of the Murray–Darling Basin: A 100-year perspective*, Murray–Darling Basin Ministerial Council, Canberra, ACT

NHMRC. 1990. *Australian guidelines for recreational use of water.* National Health and Medical Research Council.

NHMRC & ARMCANZ. 1996. *Australian drinking water guidelines*, National Health and Medical Research Council

RMCWMB. 1999. *Proposal Statement ¾ Water quality*, River Murray Catchment Water Management Board, Paper No.2.

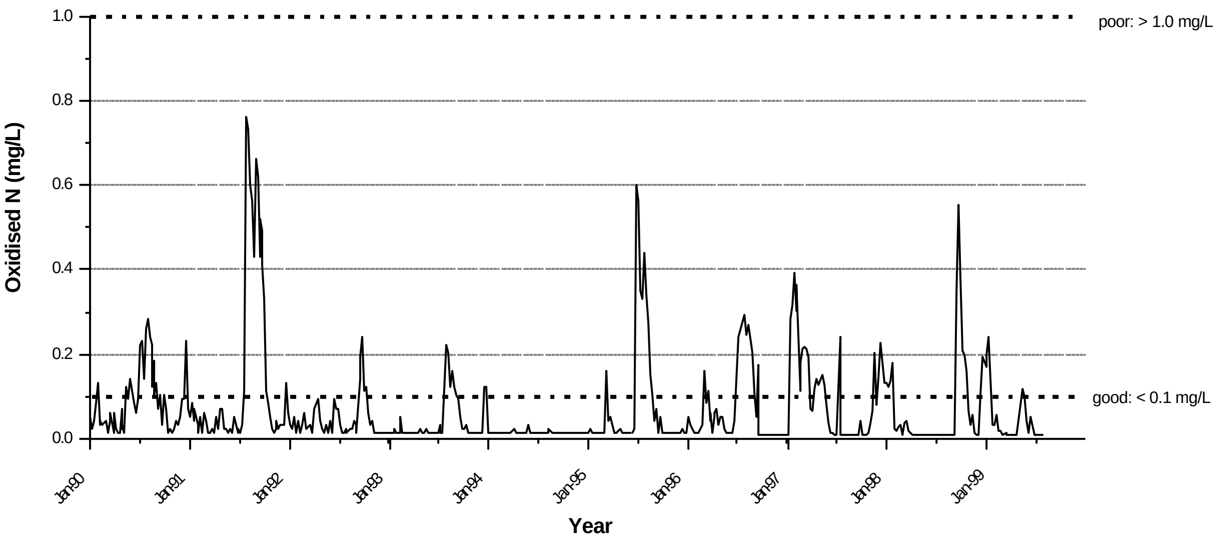
Shiel RJ, Walker KF and Williams WD. 1982. Plankton of the Lower River Murray, South Australia. *Australian Journal of Marine and Freshwater Resources*, 33: 301–327.

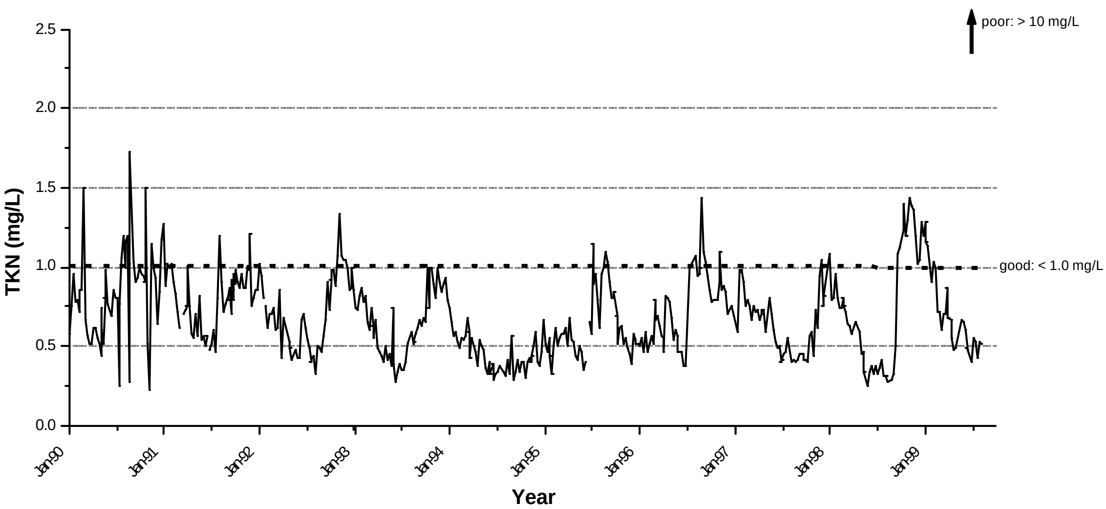
Walker KF. 1985. A review of the ecological effects of river regulation in Australia. *Hydrolobiologia*, 125, 111–129.

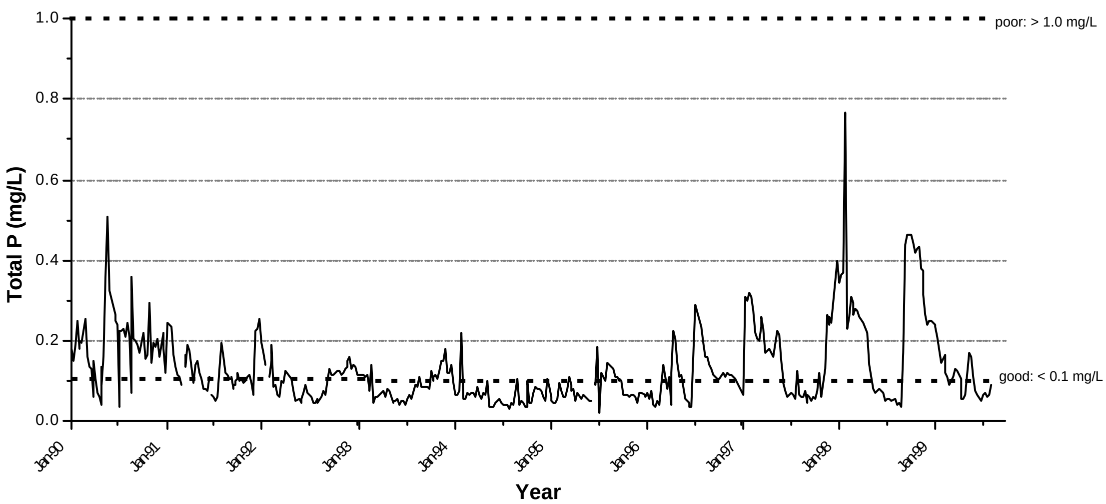
APPENDICES

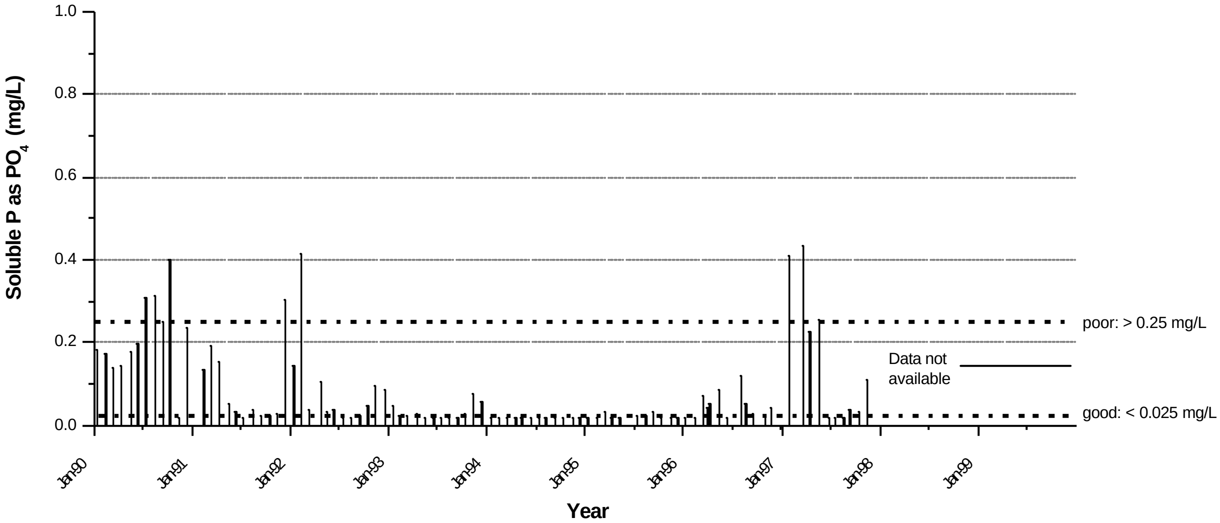
TIME SERIES PLOTS FOR EACH SITE

Appendix 1: Lock 9





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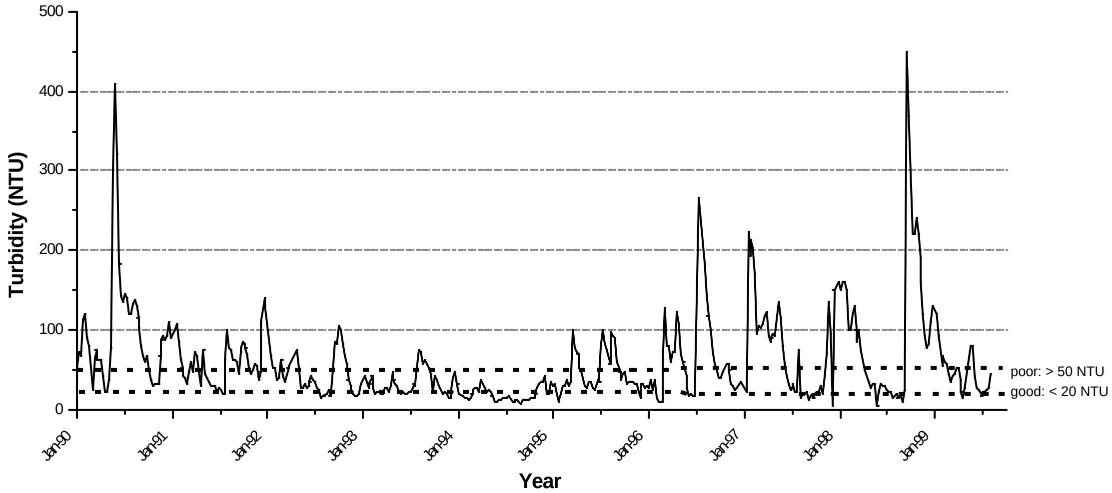
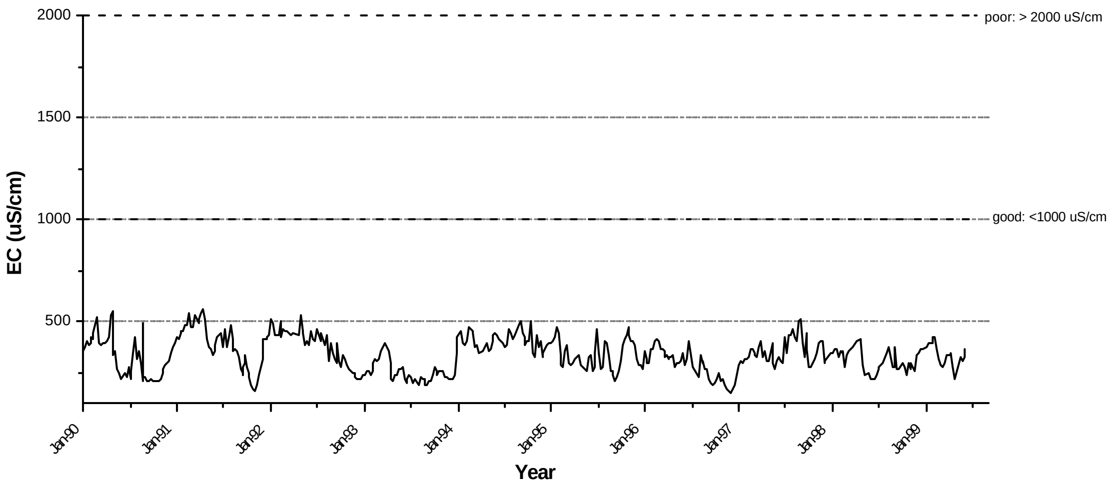
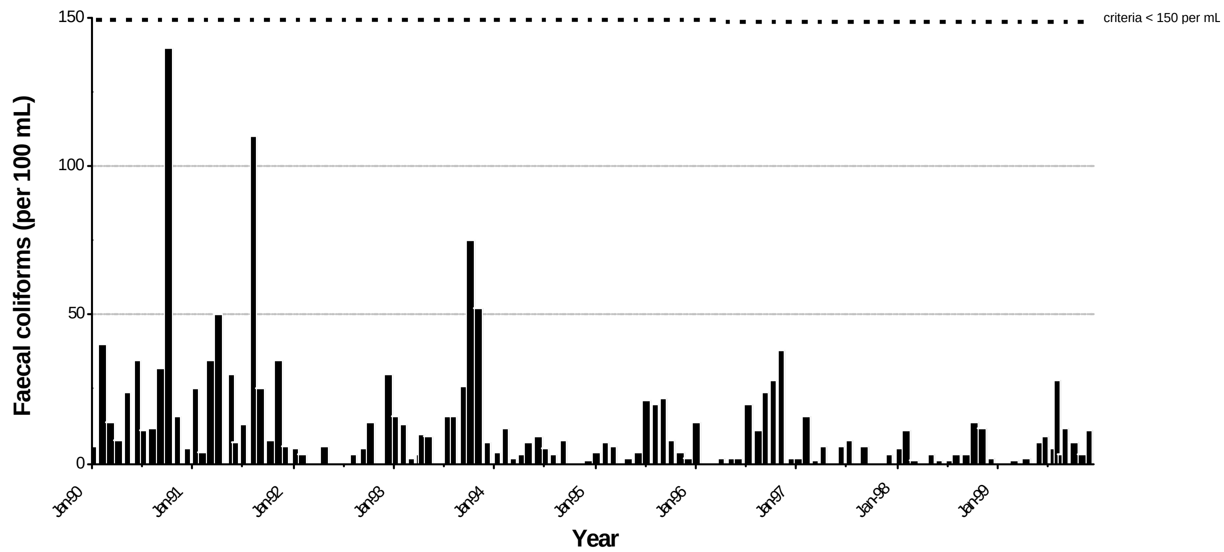
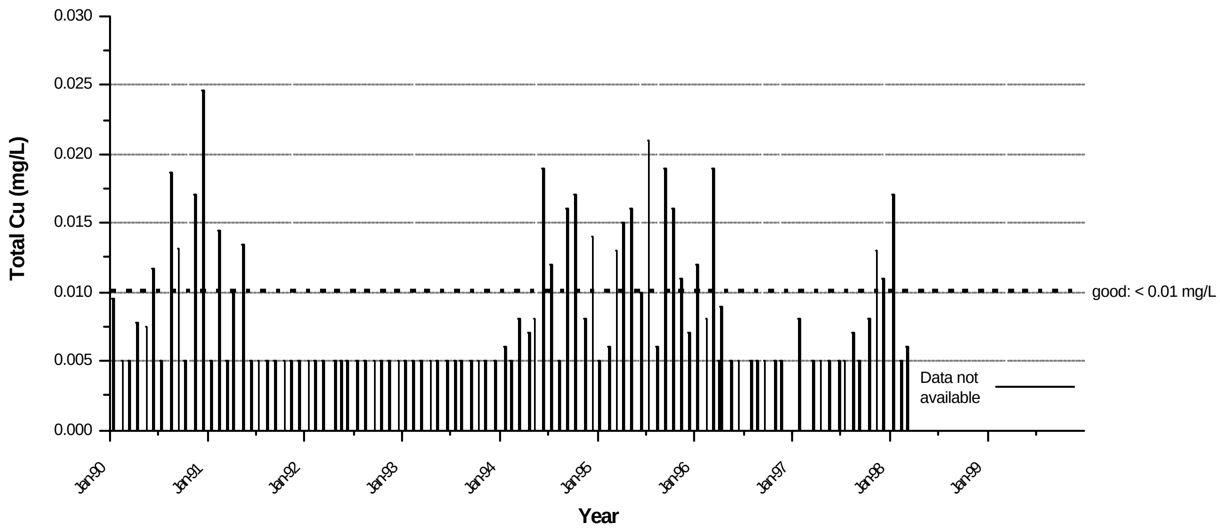
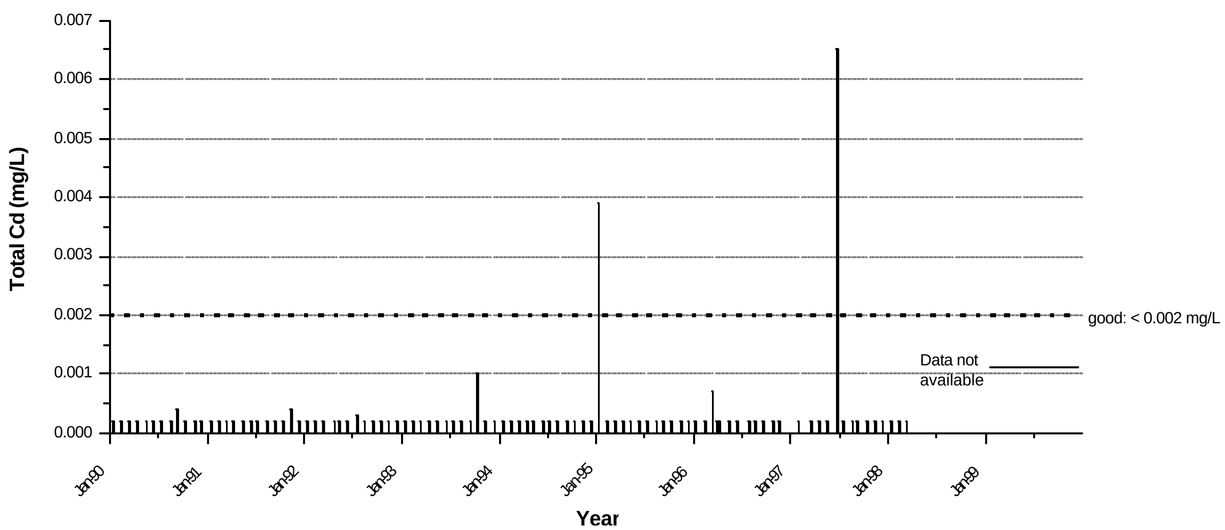
0.8
0.6
0.4
0.2
0.0
poor: > 0.25 mg/L
Data not available
good: < 0.025 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

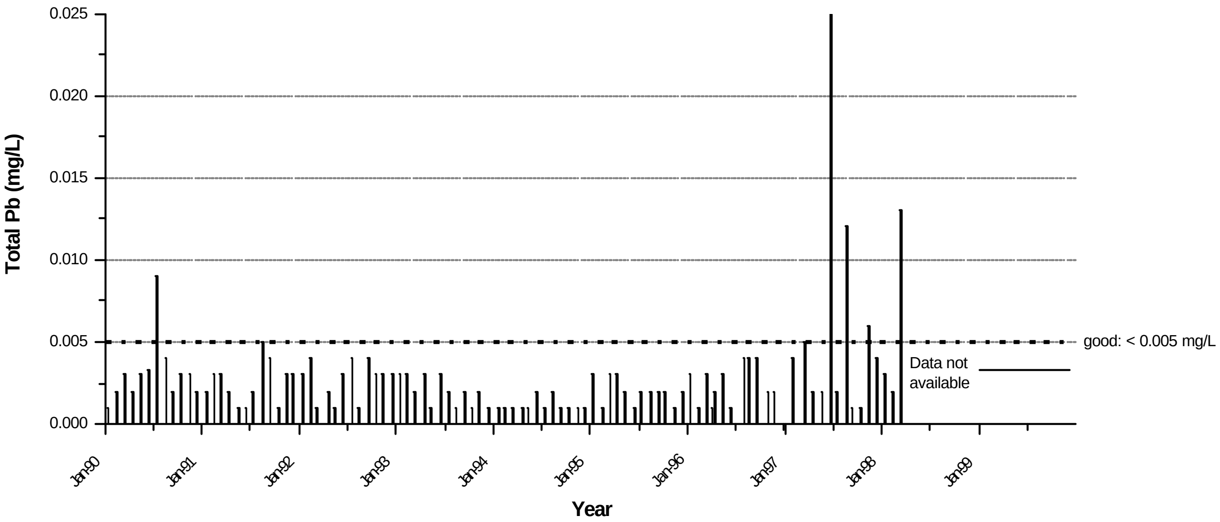

Turbidity (NTU)
500
400
300
200
100
0
poor: > 50 NTU
good: < 20 NTU
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

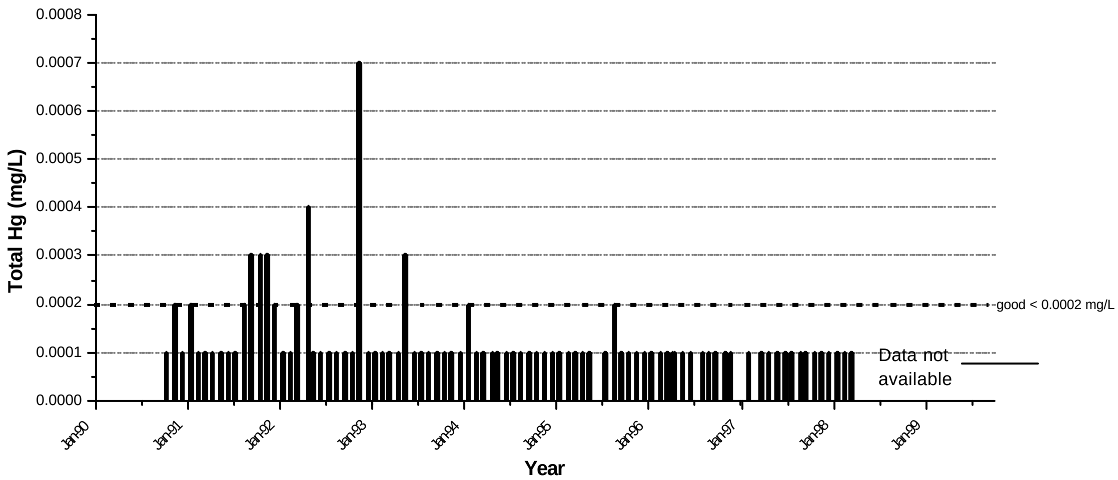

EC (uS/cm)
2000
1500
1000
500
poor: > 2000 uS/cm
good: <1000 uS/cm
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

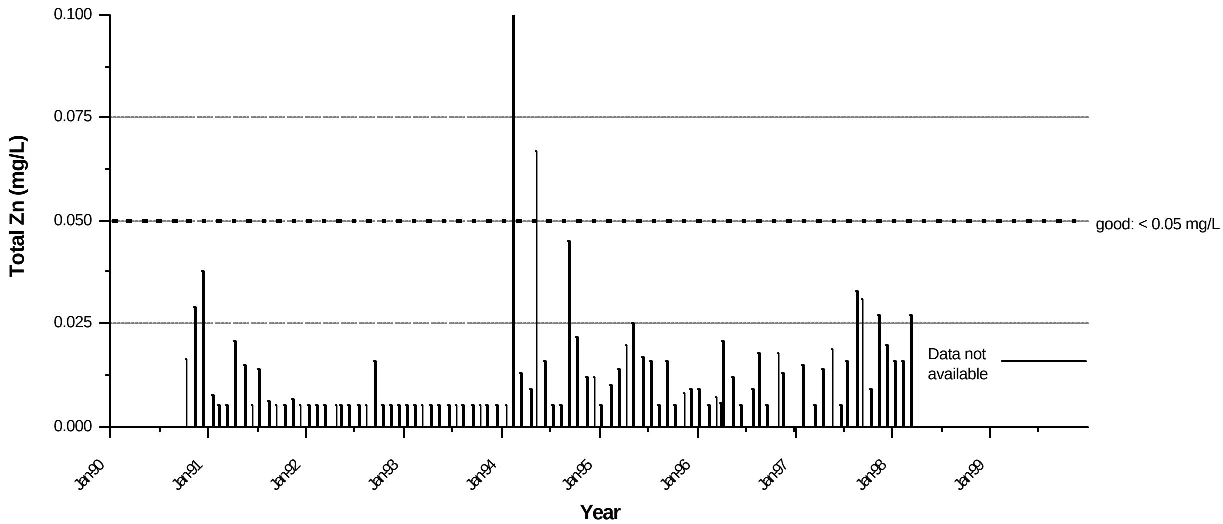

criteria < 150 per mL
Faecal coliforms (per 100 mL)
150
100
50
0
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

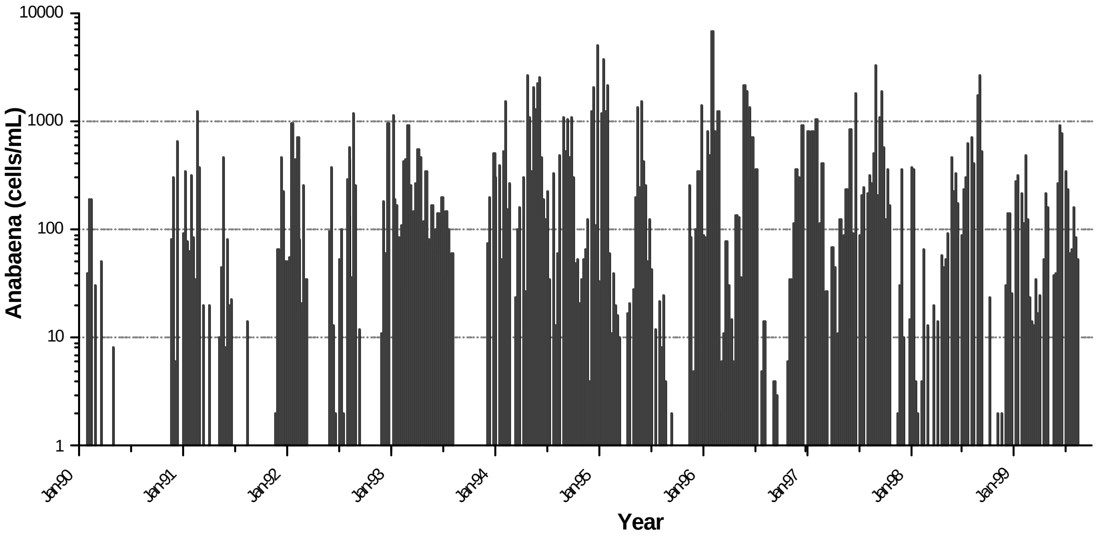

Total Cu (mg/L)
0.030
0.025
0.020
0.015
0.010
0.005
0.000
good: < 0.01 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

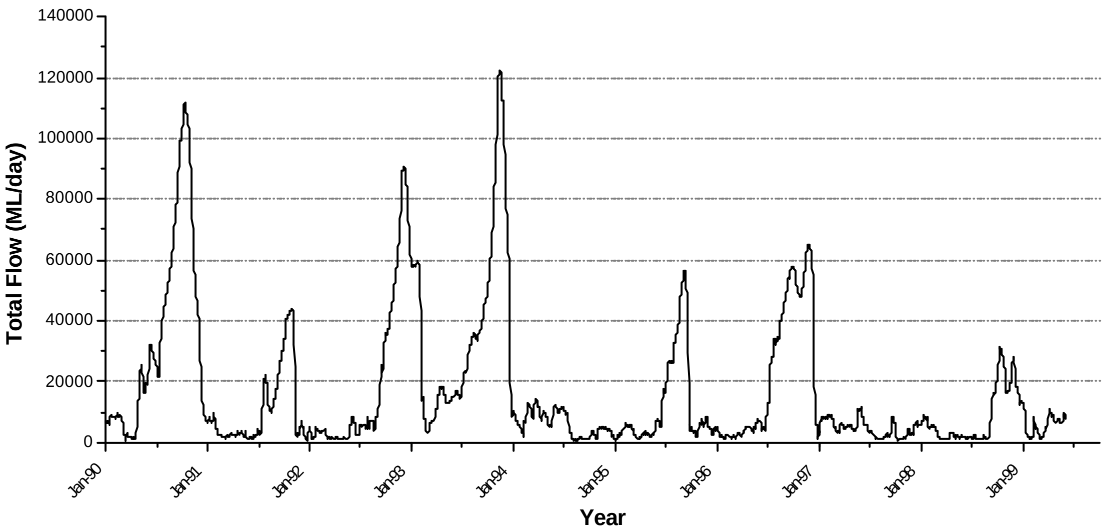

Total Cd (mg/L)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
good: < 0.002 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year


Total Pb (mg/L)
0.025
0.020
0.015
0.010
0.005
0.000
good: < 0.005 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

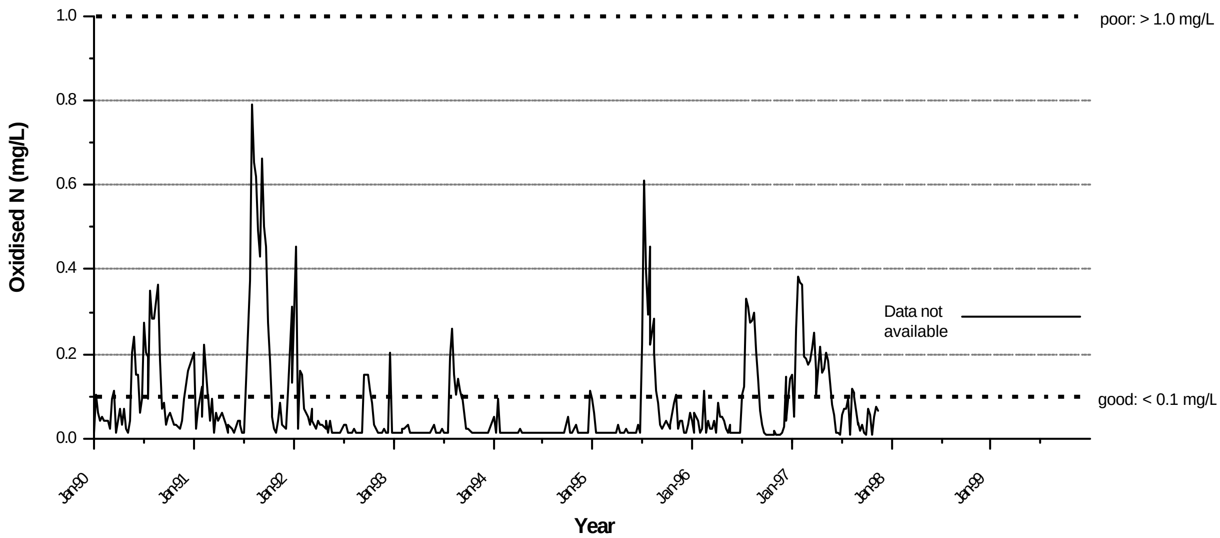

Total Hg (mg/L)
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
good < 0.0002 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

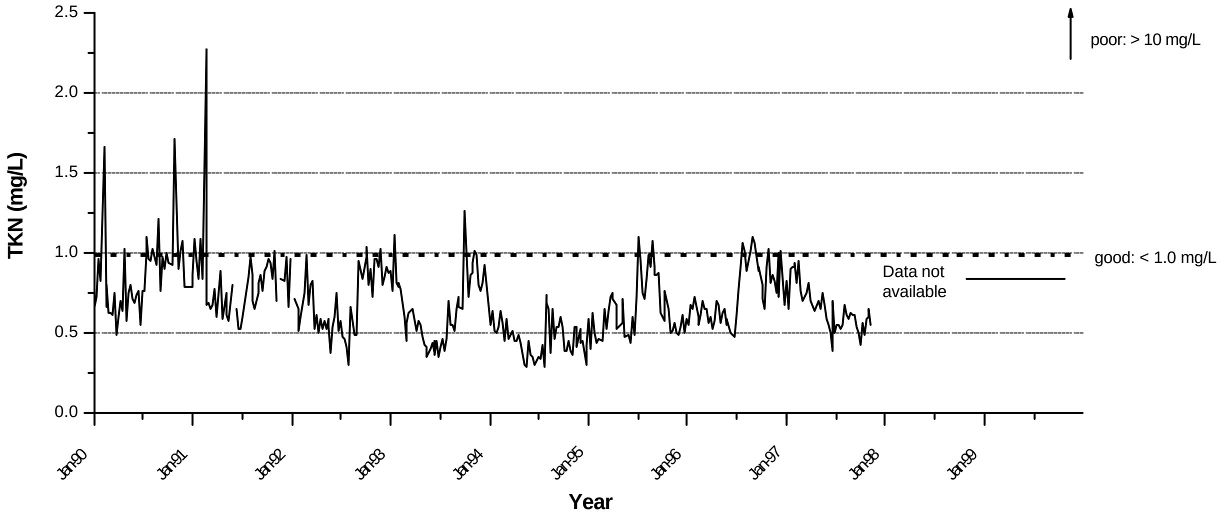

Total Zn (mg/L)
0.100
0.075
0.050
0.025
0.000
good: < 0.05 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

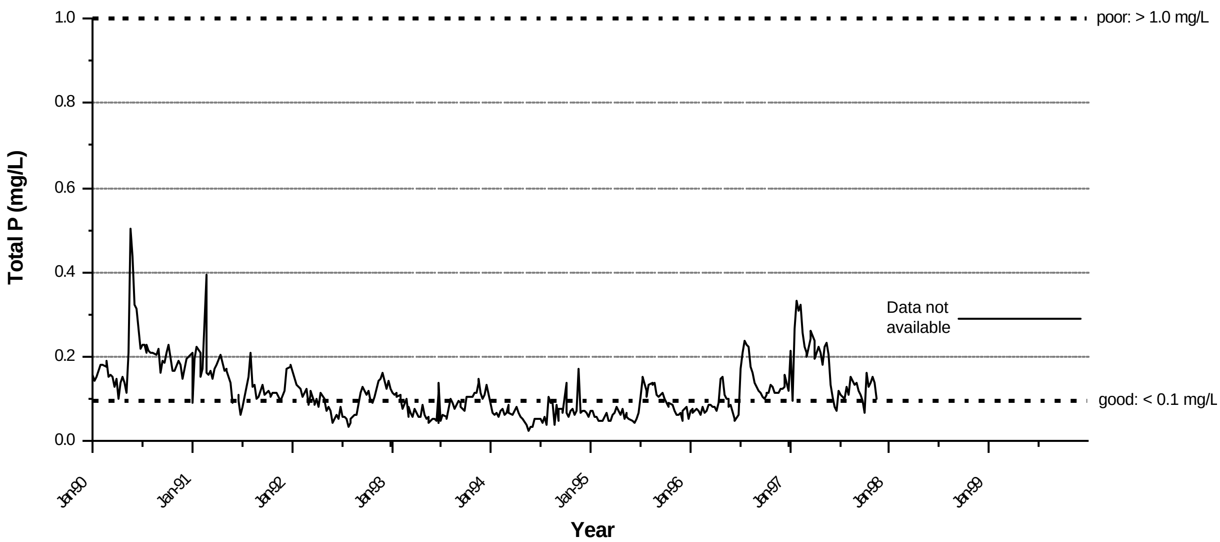

10000
1000
100
10
1
Anabaena (cells/mL)
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

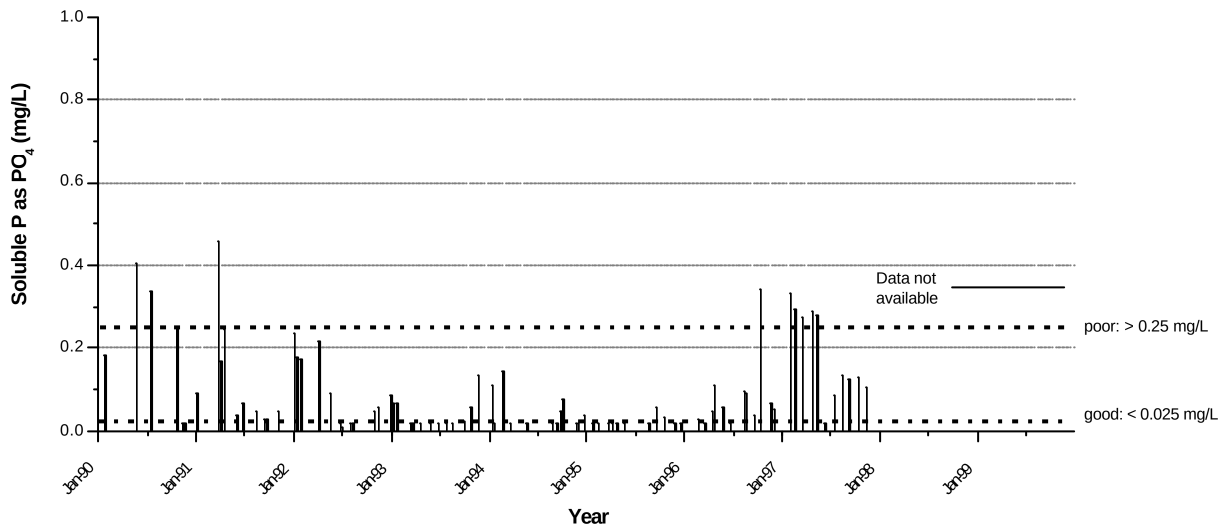

140000
120000
100000
80000
60000
40000
20000
0
Total Flow (ML/day)
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

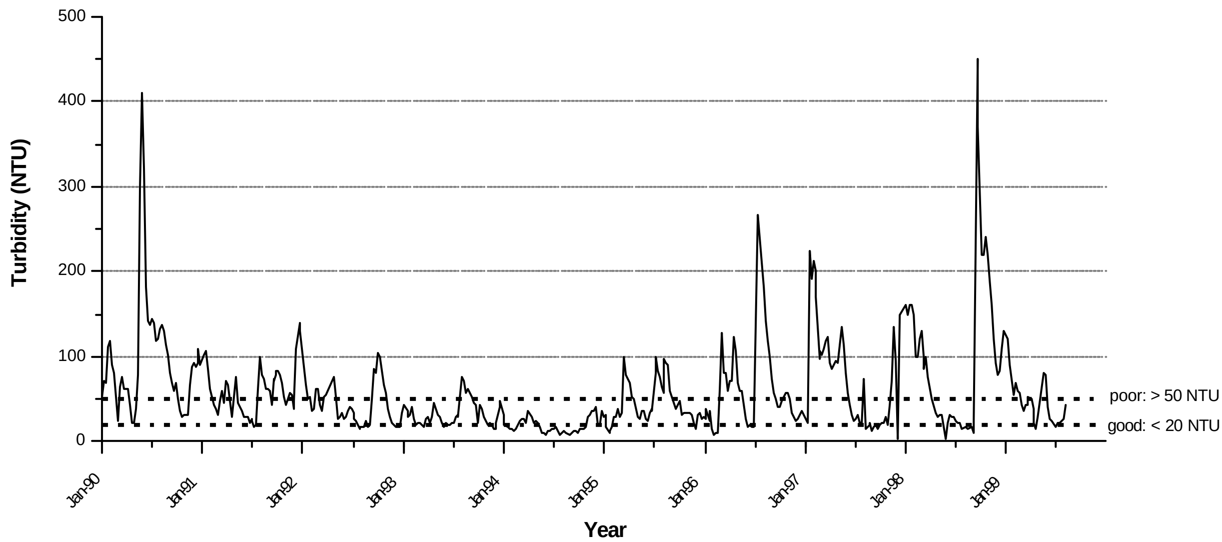
Appendix 2: Downstream Rufus River

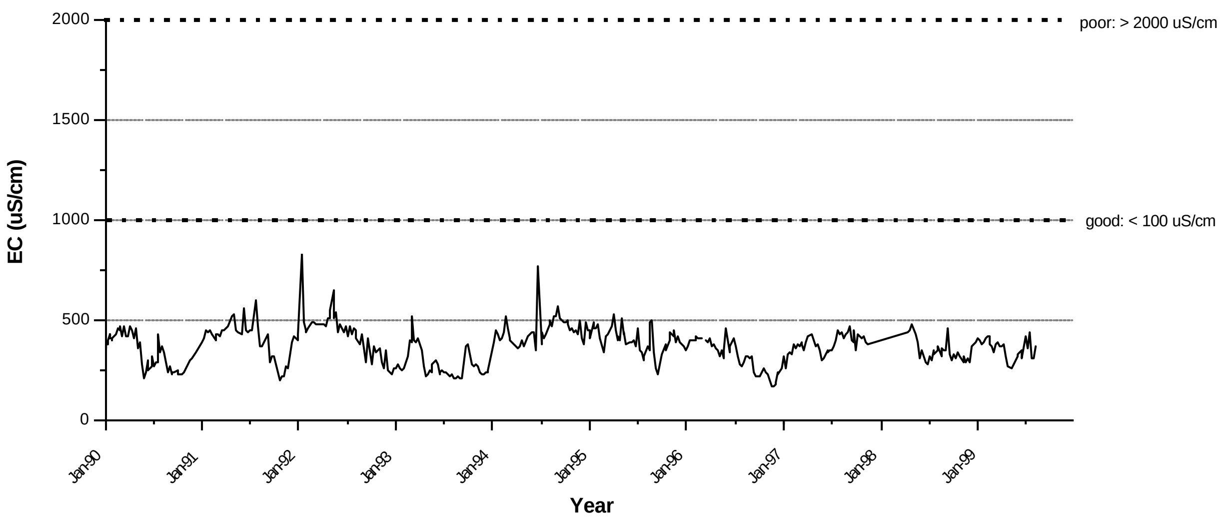


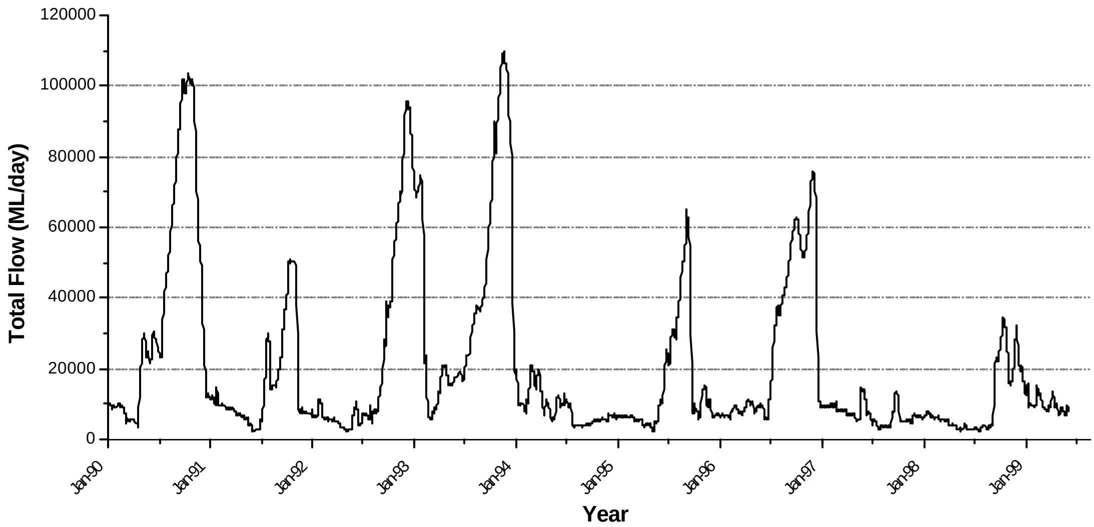


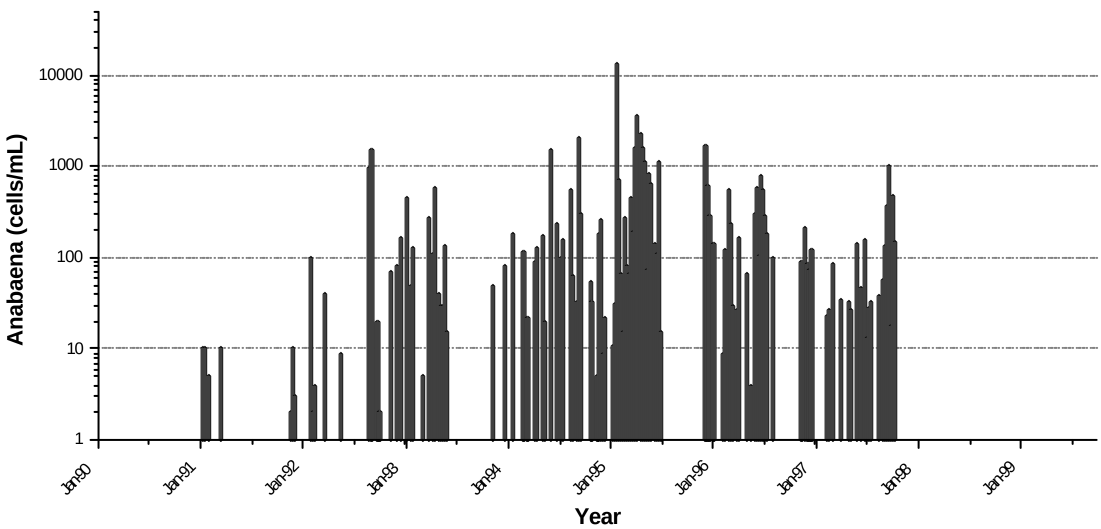



Soluble P as PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
Data not available
poor: > 0.25 mg/L
good: < 0.025 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

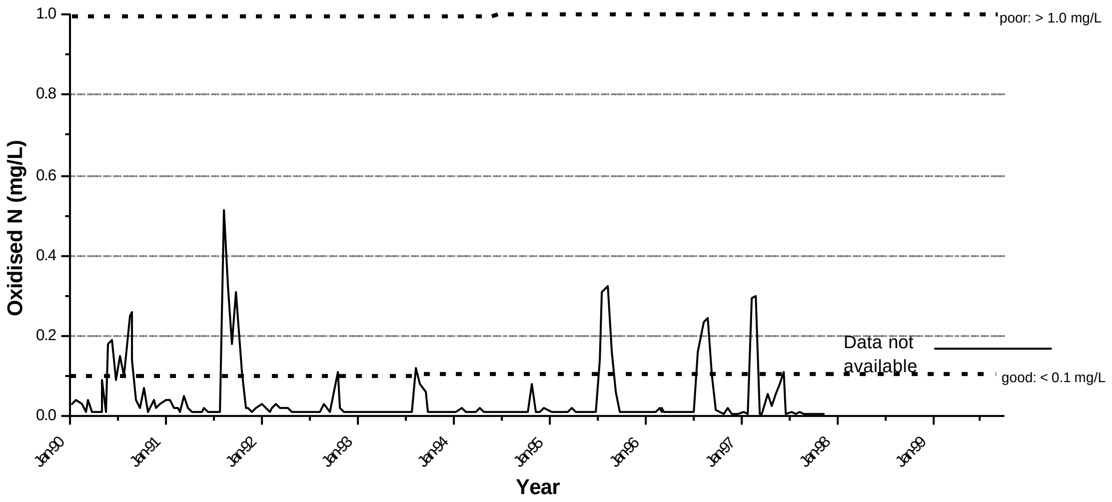

Turbidity (NTU)
500
400
300
200
100
0
poor: > 50 NTU
good: < 20 NTU
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

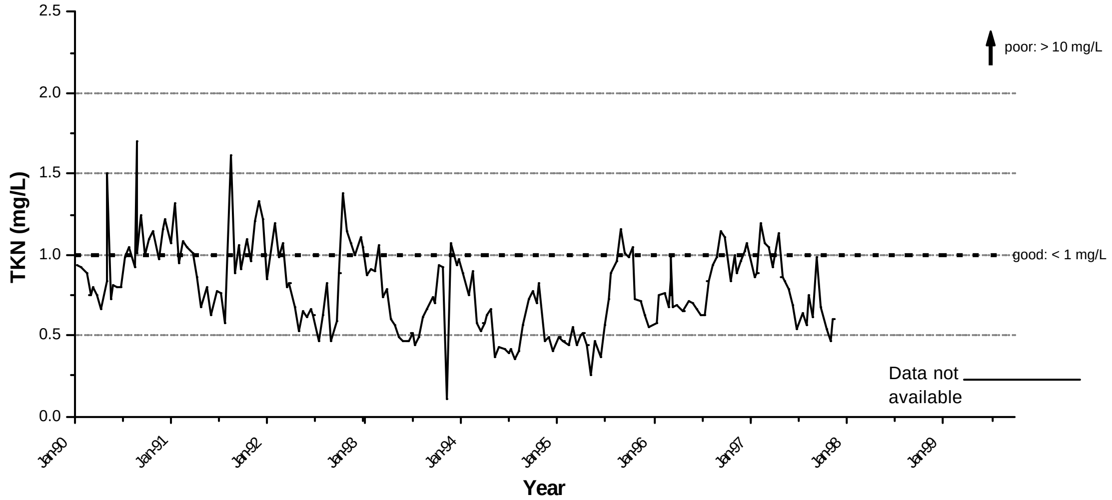

EC (uS/cm)
2000
1500
1000
500
0
poor: > 2000 uS/cm
good: < 100 uS/cm
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

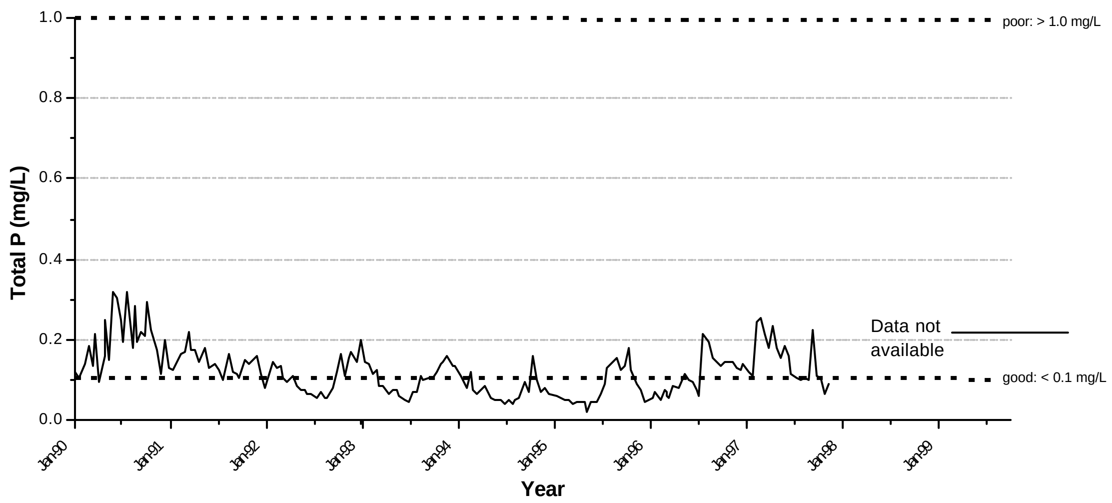

120000
100000
80000
60000
40000
20000
0
Total Flow (ML/day)
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

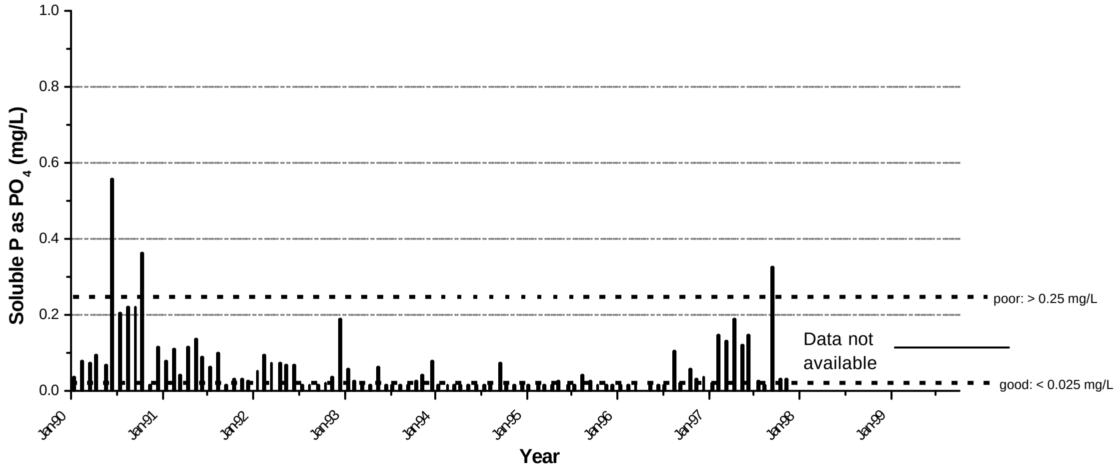

10000
1000
100
10
1
Anabaena (cells/mL)
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

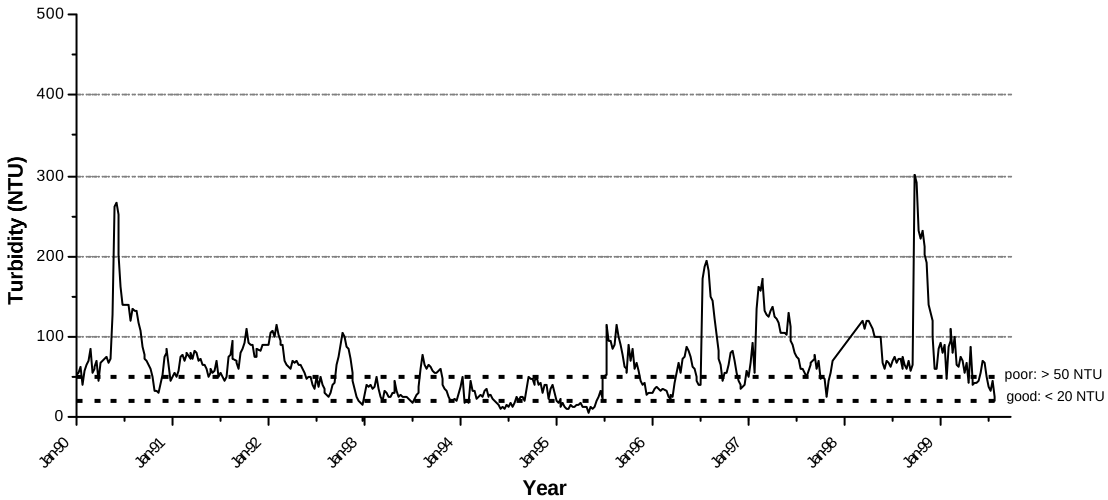
Appendix 3: Lock 3

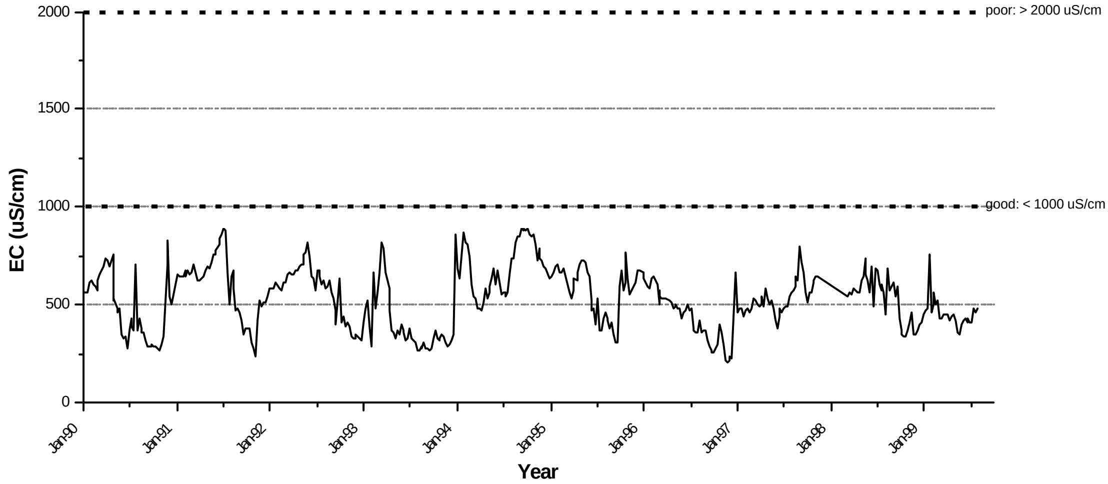


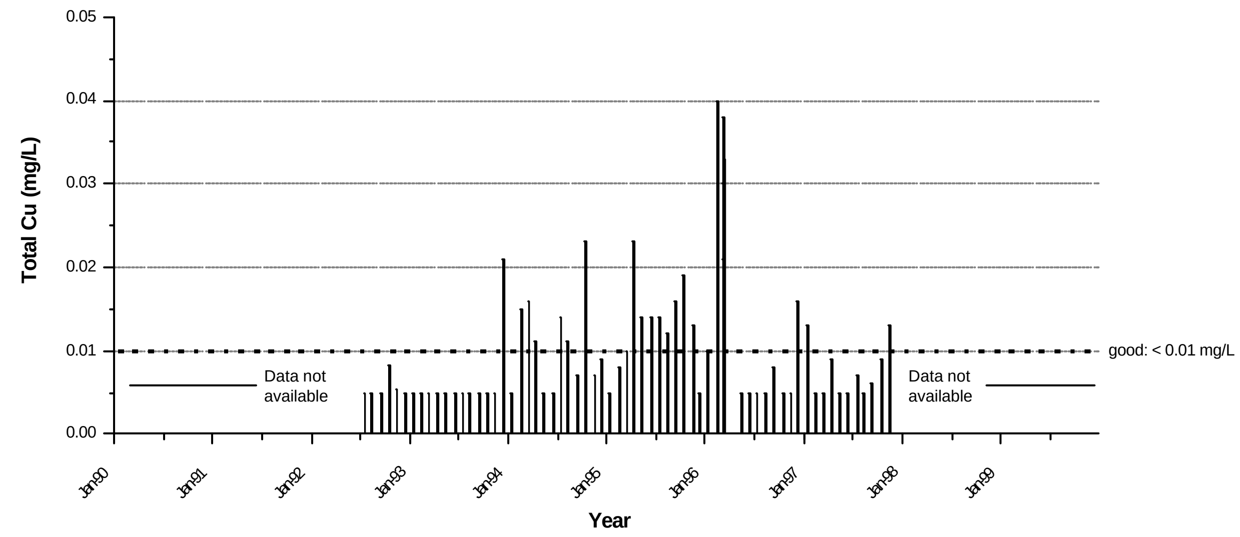


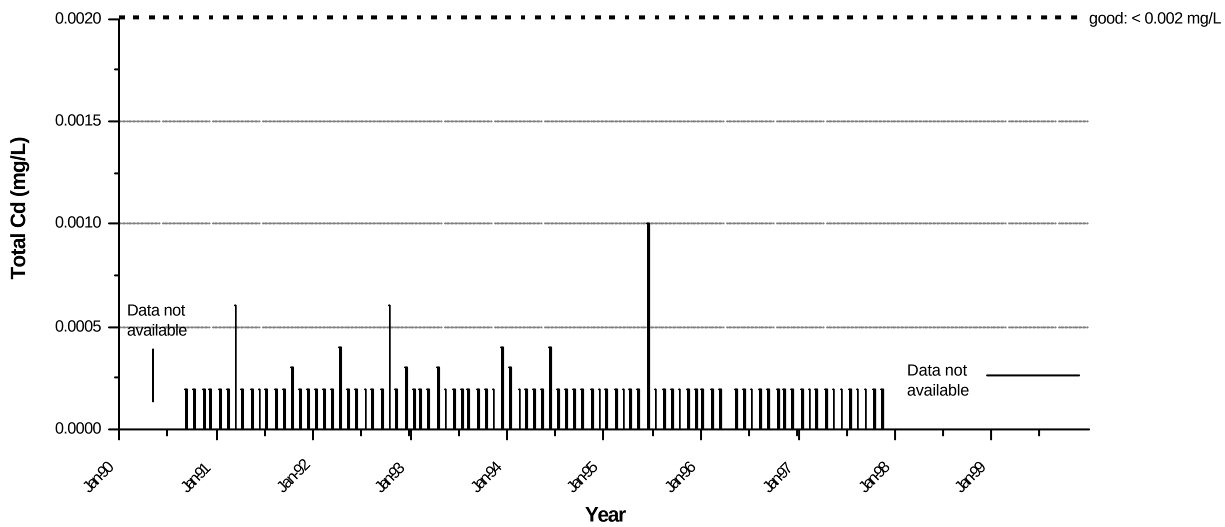


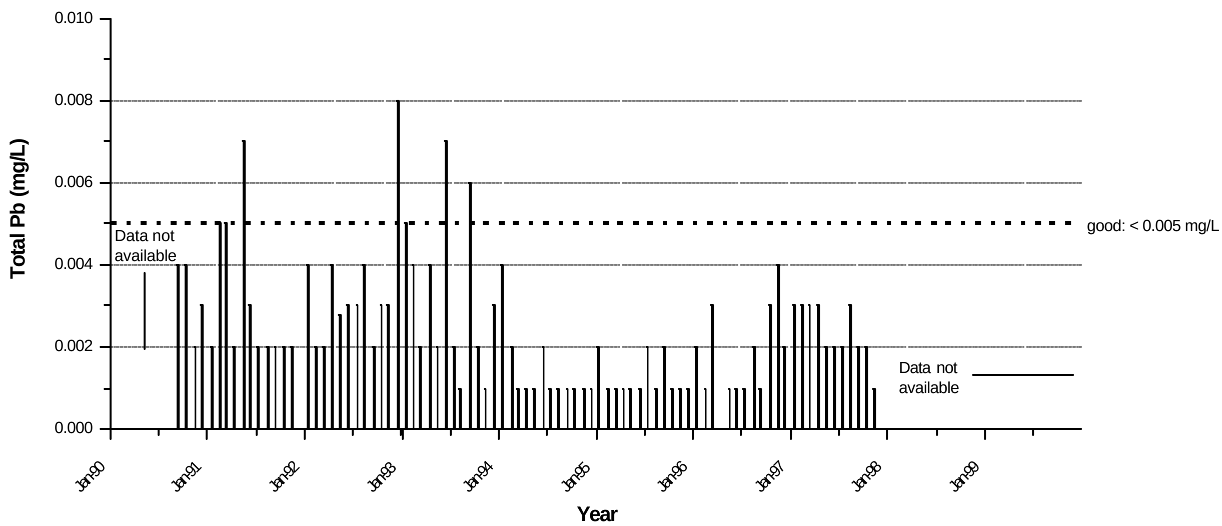

Soluble P as PO4 (mg/L)
poor: > 0.25 mg/L
Data not available
good: < 0.025 mg/L
Year

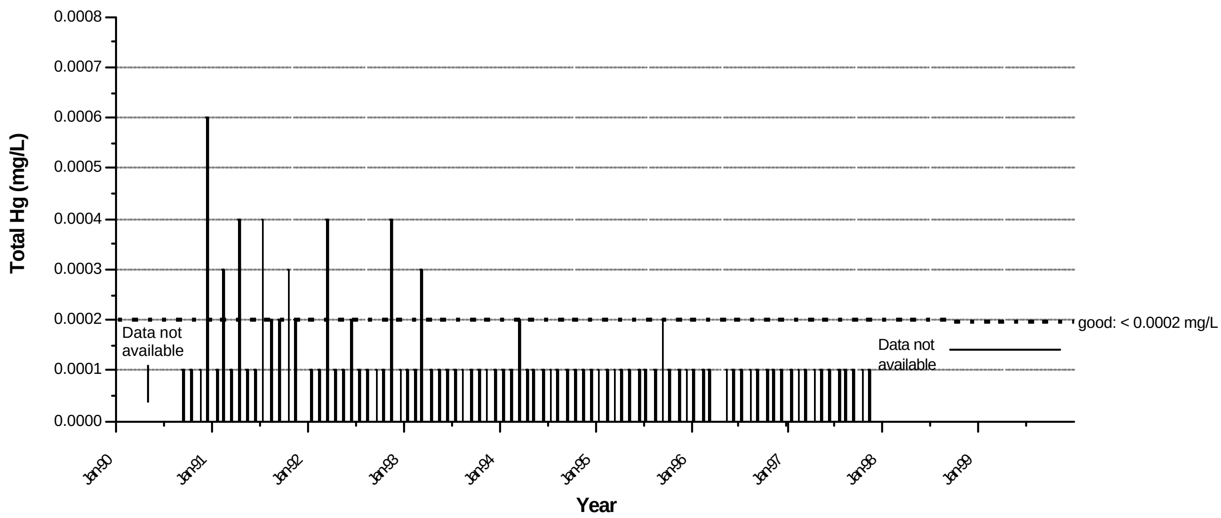

Turbidity (NTU)
poor: > 50 NTU
good: < 20 NTU
Year

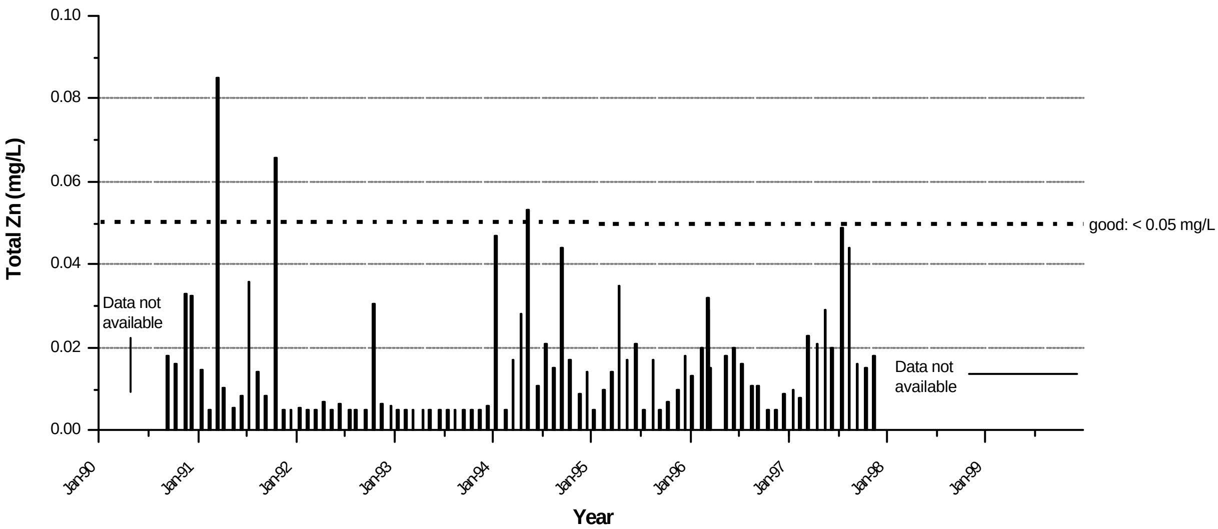

EC (uS/cm)
poor: > 2000 uS/cm
good: < 1000 uS/cm
Year

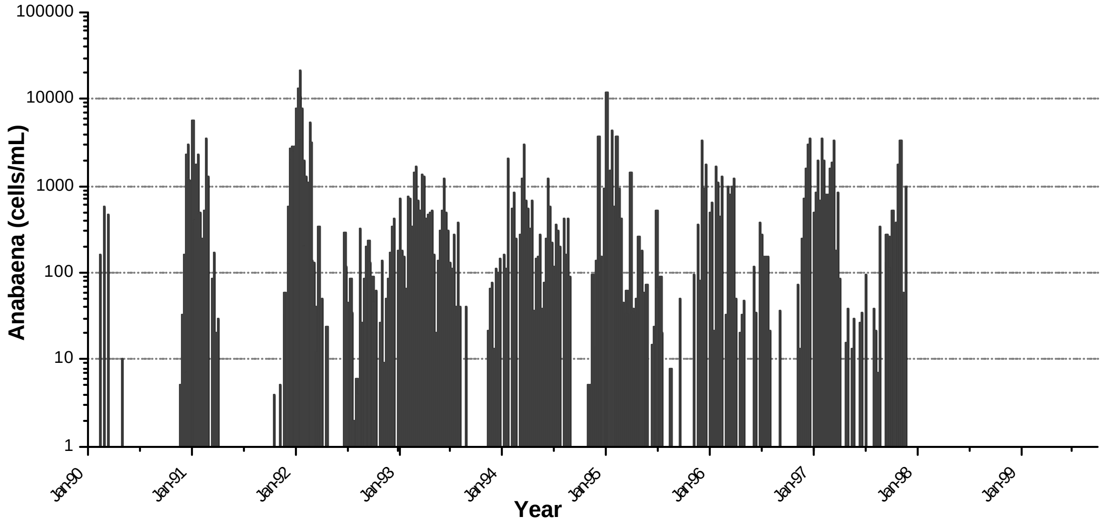

Total Cu (mg/L)
0.05
0.04
0.03
0.02
0.01
0.00
good: < 0.01 mg/L
Data not available
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year


Total Cd (mg/L)
0.0020
0.0015
0.0010
0.0005
0.0000
good: < 0.002 mg/L
Data not available
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

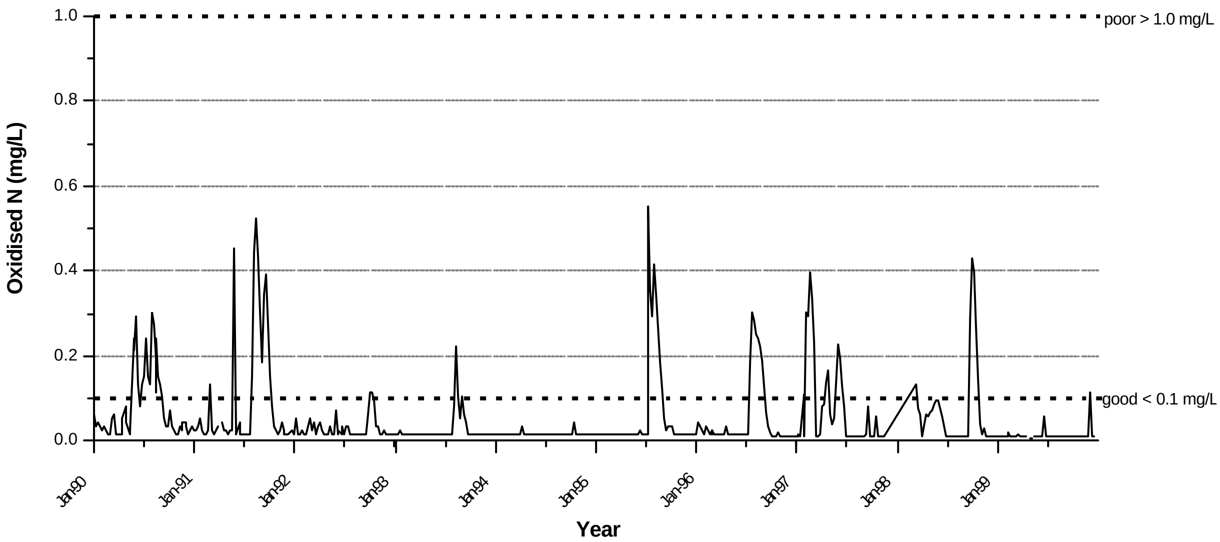

Total Pb (mg/L)
0.010
0.008
0.006
0.004
0.002
0.000
good: < 0.005 mg/L
Data not available
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

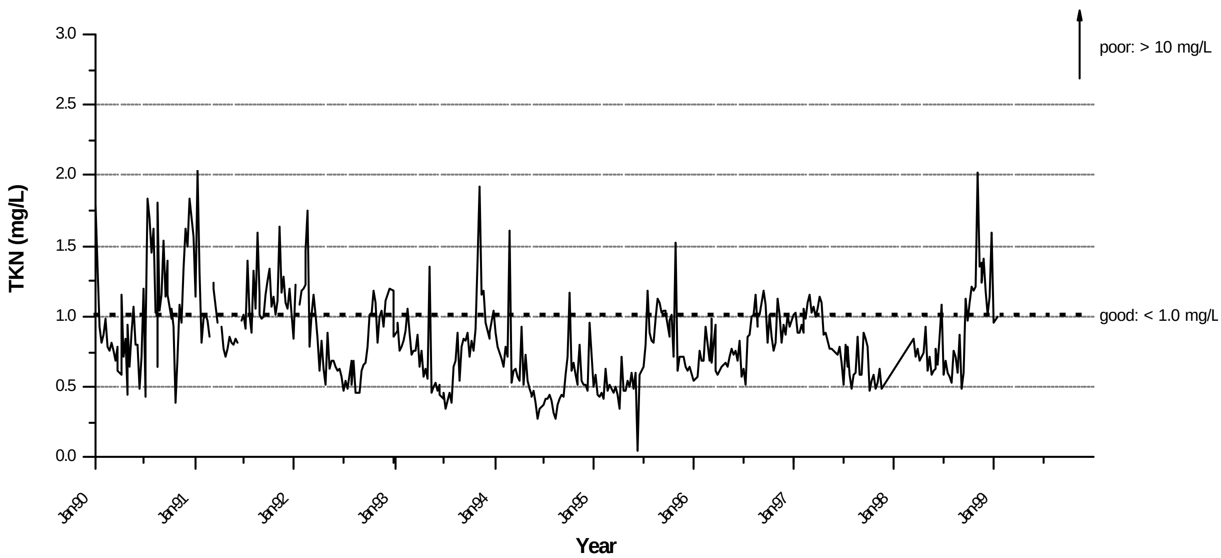

Total Hg (mg/L)
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
Data not available
Data not available
good: < 0.0002 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

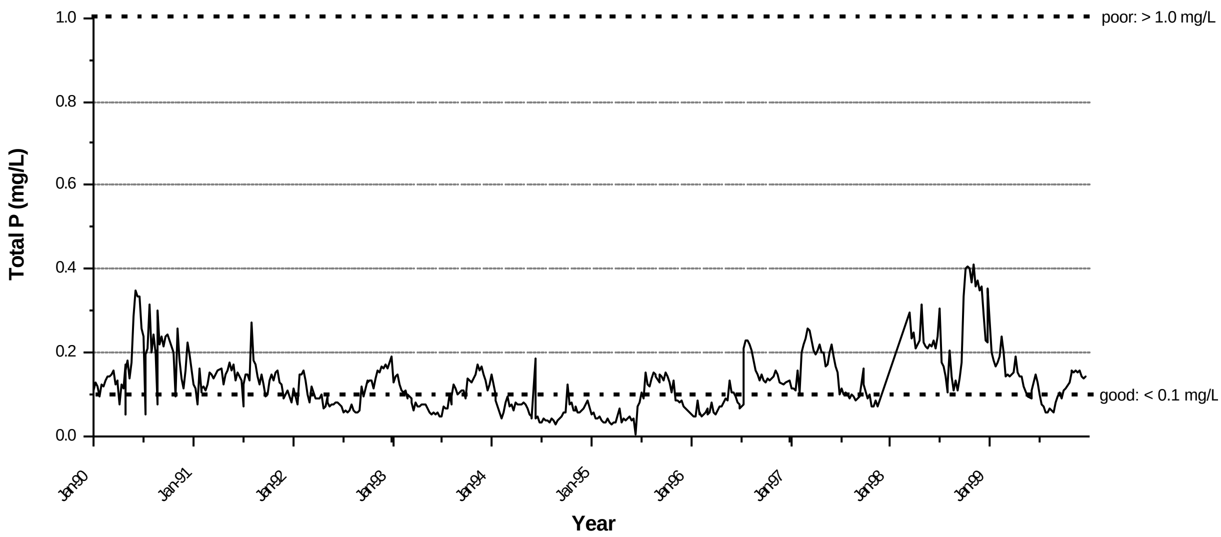

Total Zn (mg/L)
0.10
0.08
0.06
0.04
0.02
0.00
Data not available
Data not available
good: < 0.05 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

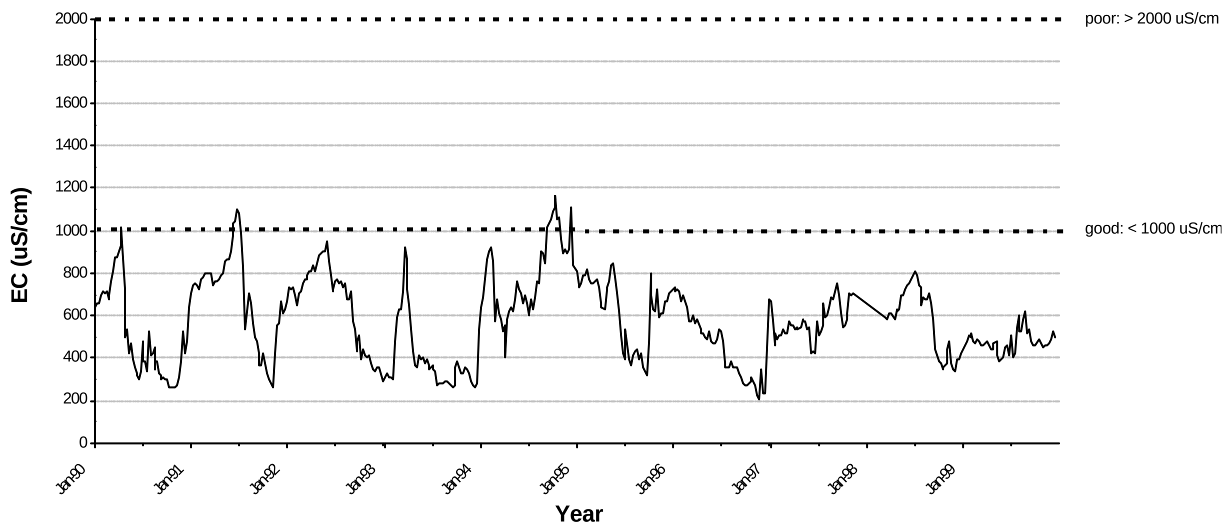

Anabaena (cells/mL)
100000
10000
1000
100
10
1
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

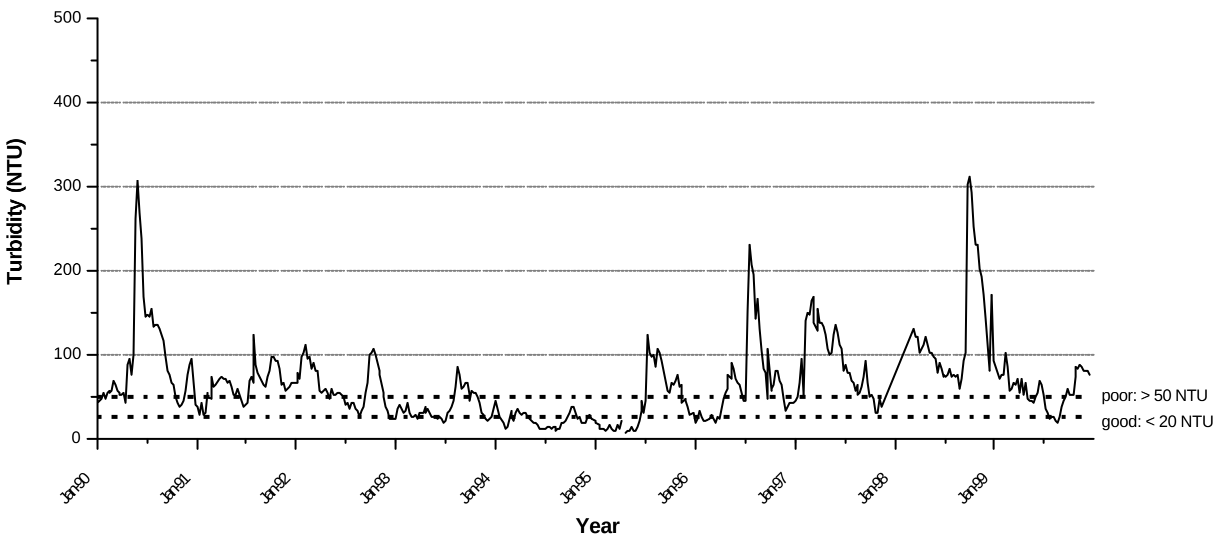
Appendix 4: Morgan

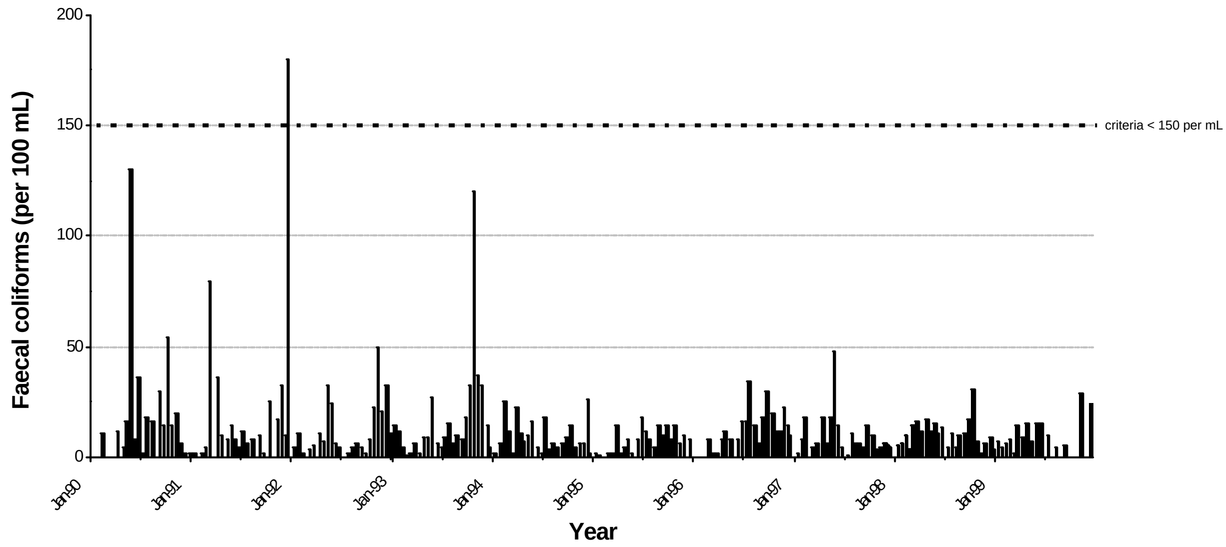


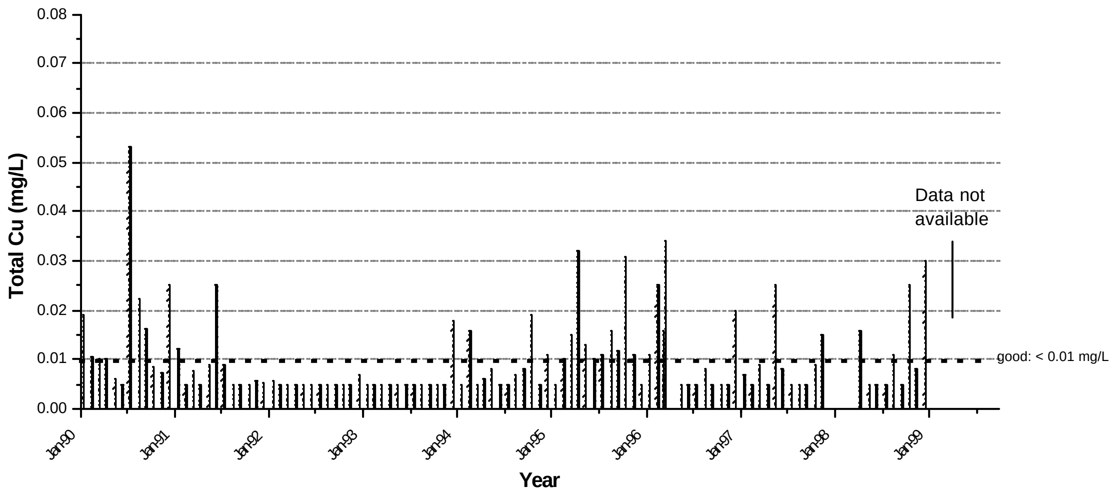


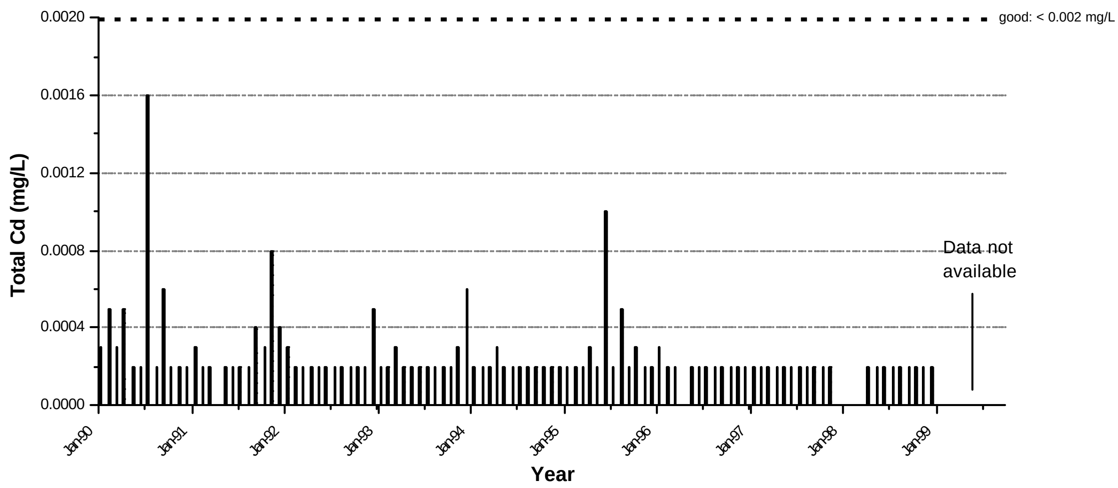


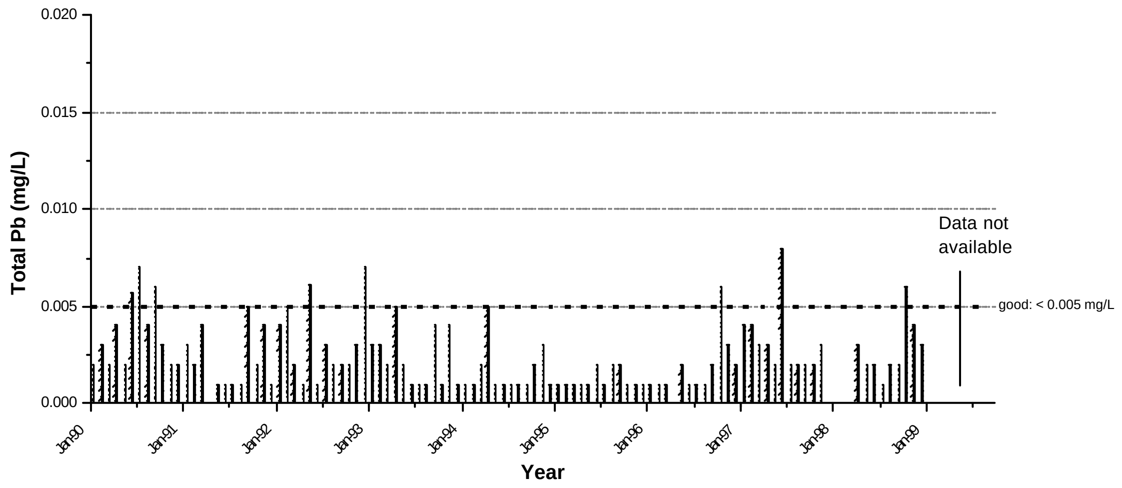

EC (uS/cm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
poor: > 2000 uS/cm
good: < 1000 uS/cm
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

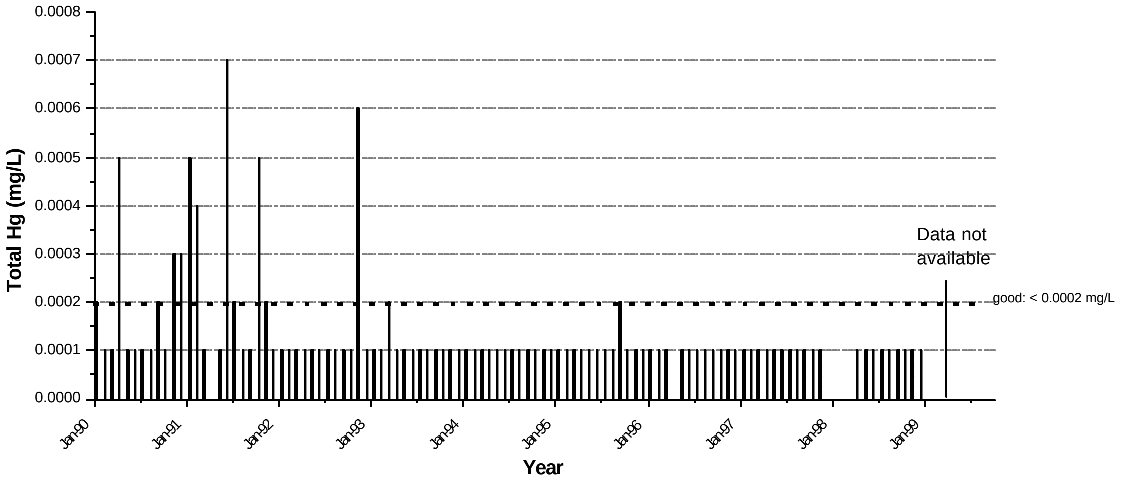

Turbidity (NTU)
500
400
300
200
100
0
poor: > 50 NTU
good: < 20 NTU
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

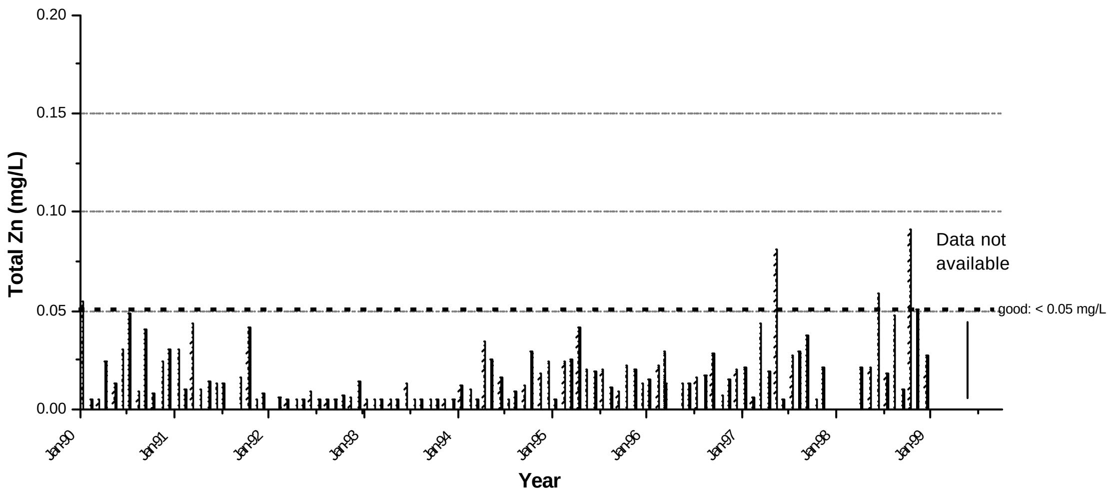

Faecal coliforms (per 100 mL)
200
150
100
50
0
criteria < 150 per mL
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

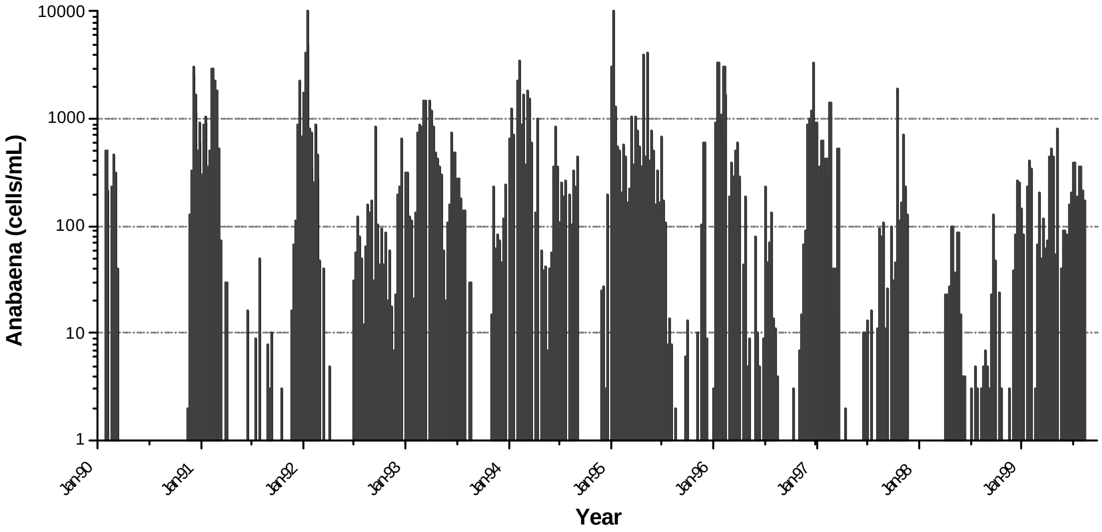

Total Cu (mg/L)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Data not available
good: < 0.01 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

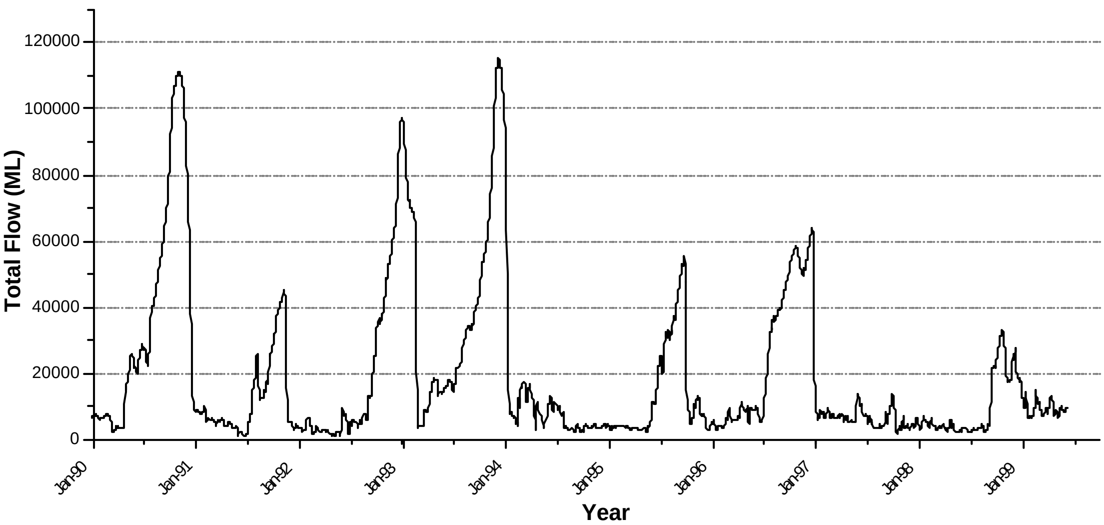

Total Cd (mg/L)
0.0020
0.0016
0.0012
0.0008
0.0004
0.0000
good: < 0.002 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year


0.020
0.015
0.010
0.005
0.000
Total Pb (mg/L)
Data not available
good: < 0.005 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

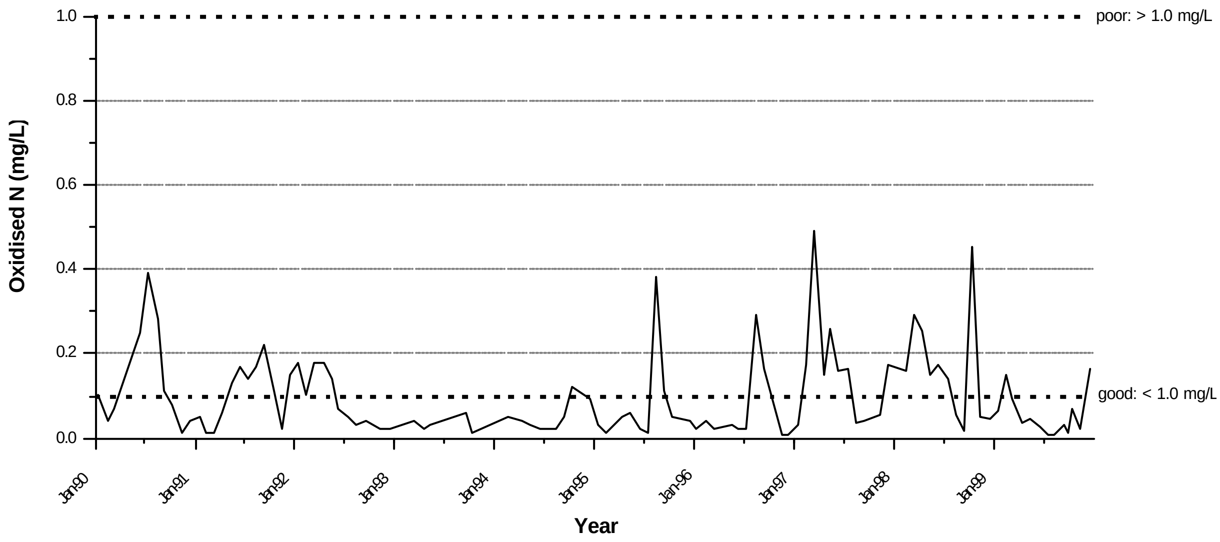

0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
Total Hg (mg/L)
Data not available
good: < 0.0002 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

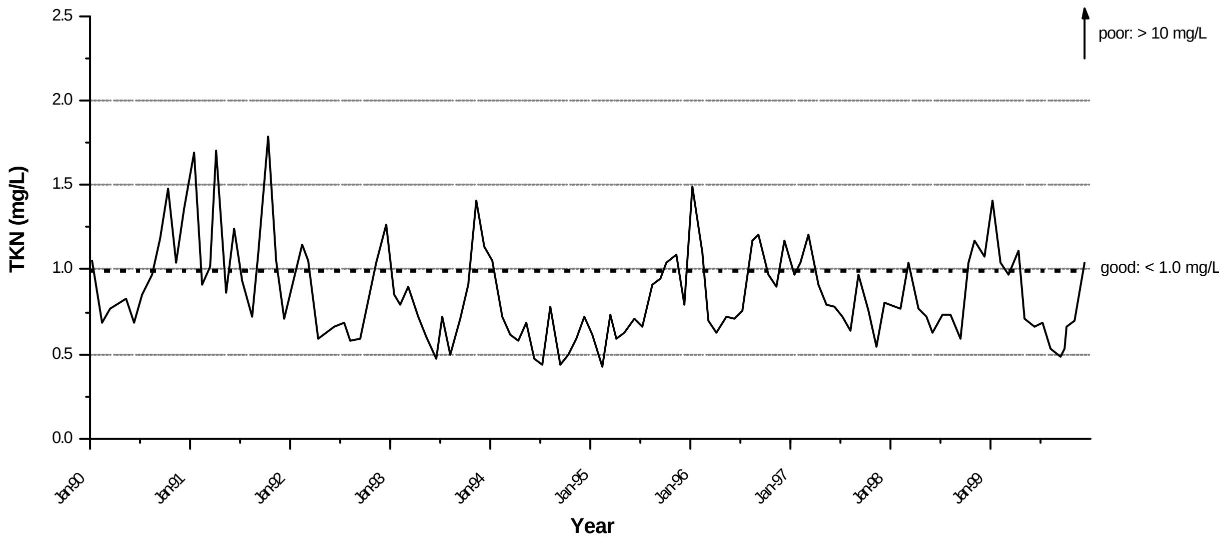

0.20
0.15
0.10
0.05
0.00
Total Zn (mg/L)
Data not available
good: < 0.05 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

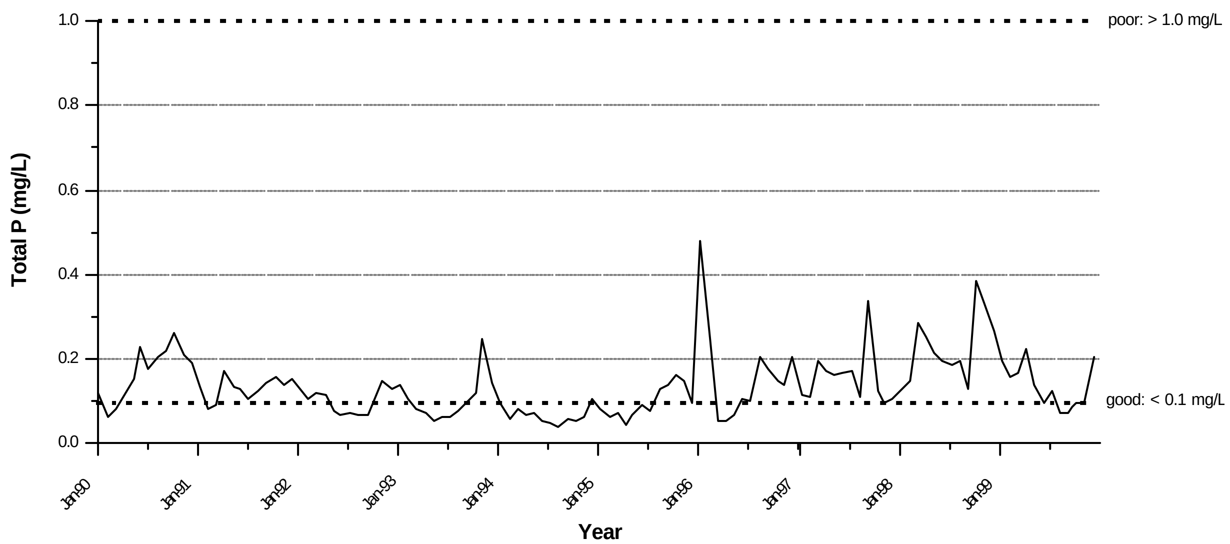

Anabaena (cells/mL)
10000
1000
100
10
1
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

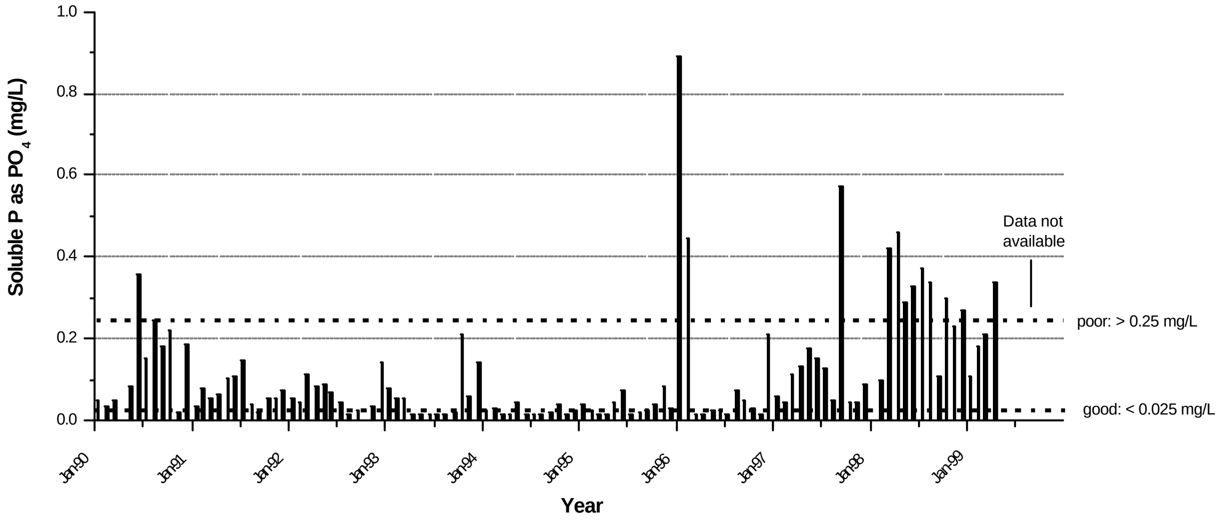

Total Flow (ML)
120000
100000
80000
60000
40000
20000
0
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

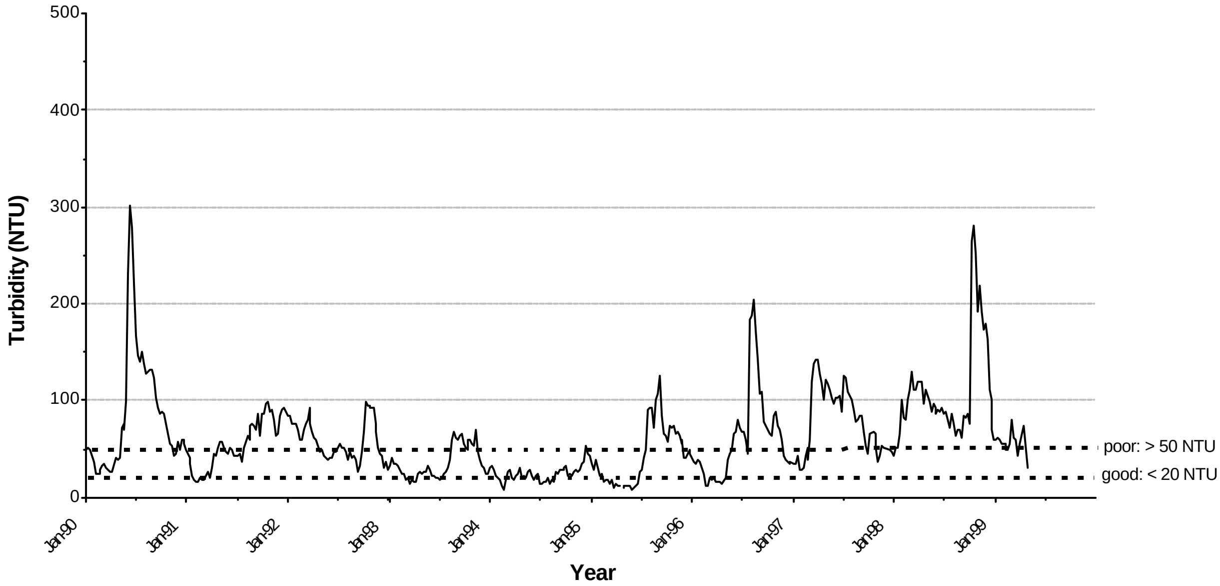
Appendix 5: Mannum

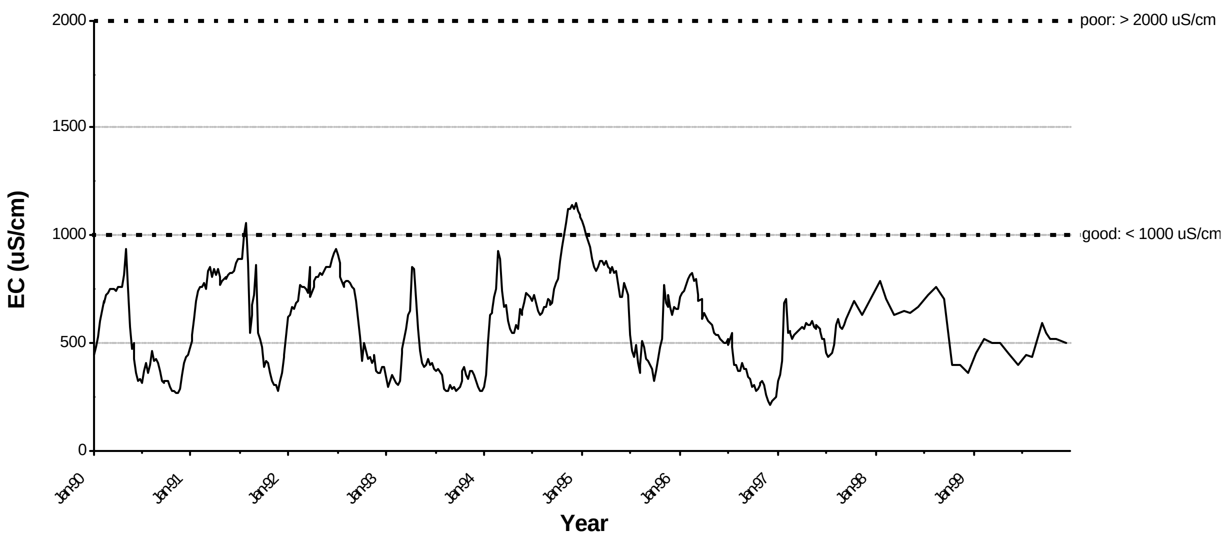


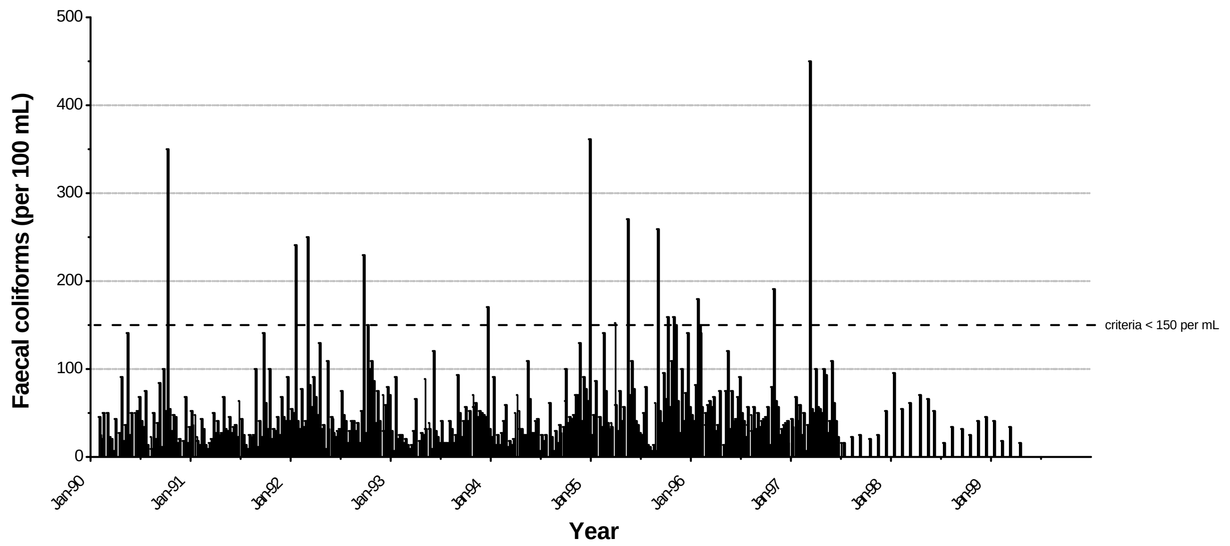




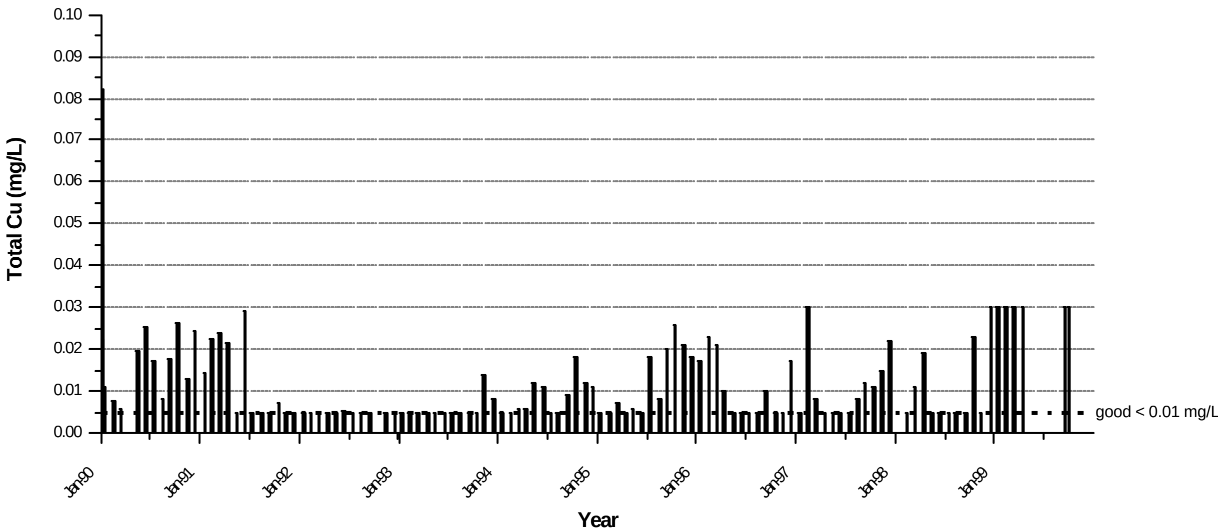

Soluble P as PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
Data not available
poor: > 0.25 mg/L
good: < 0.025 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year


Turbidity (NTU)
500
400
300
200
100
0
poor: > 50 NTU
good: < 20 NTU
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

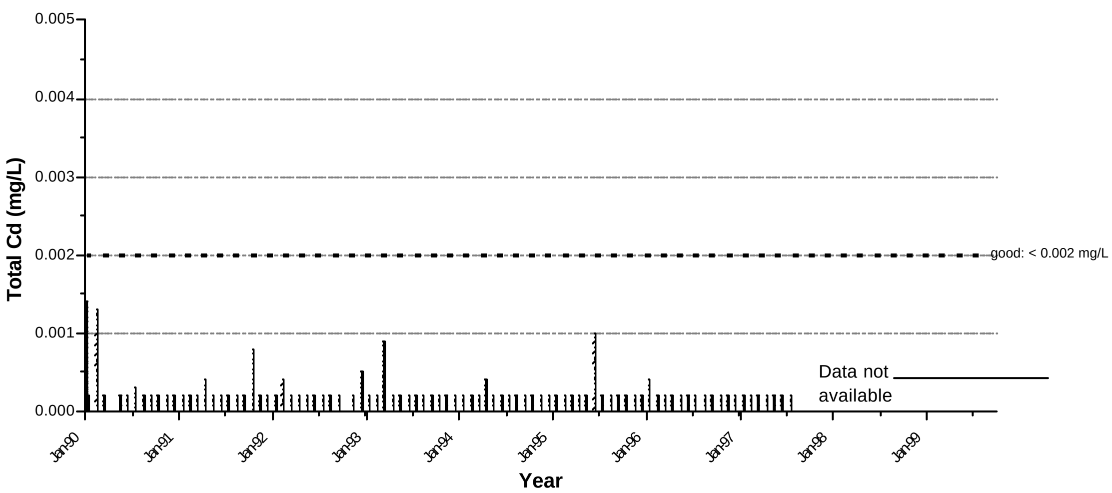

EC (uS/cm)
2000
1500
1000
500
0
poor: > 2000 uS/cm
good: < 1000 uS/cm
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year



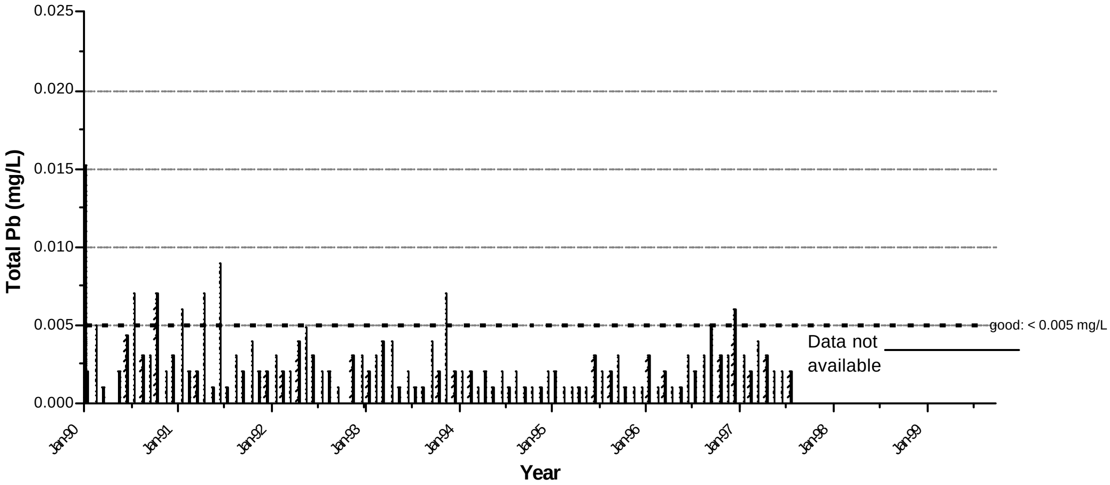
Faecal coliforms (per 100 mL)
500
400
300
200
100
0
criteria < 150 per mL
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

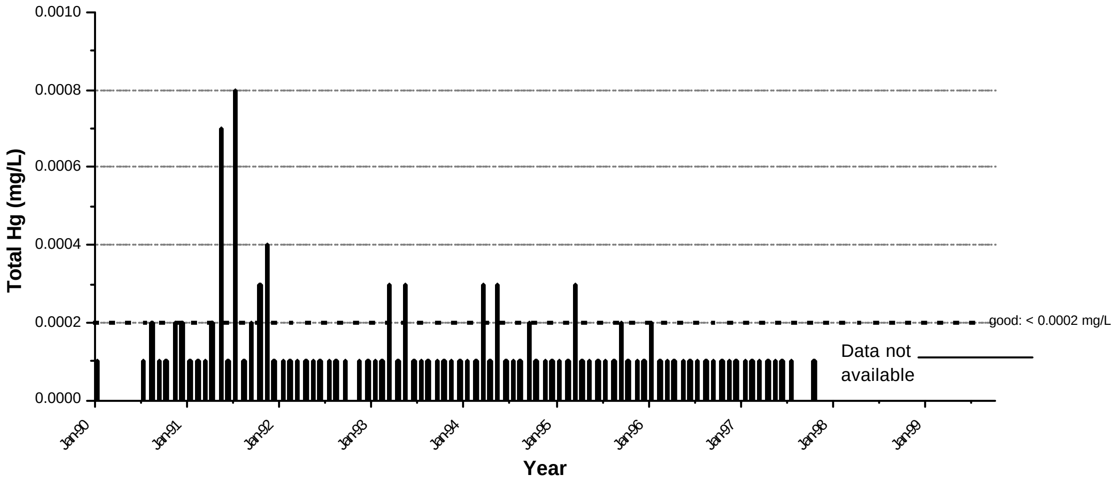


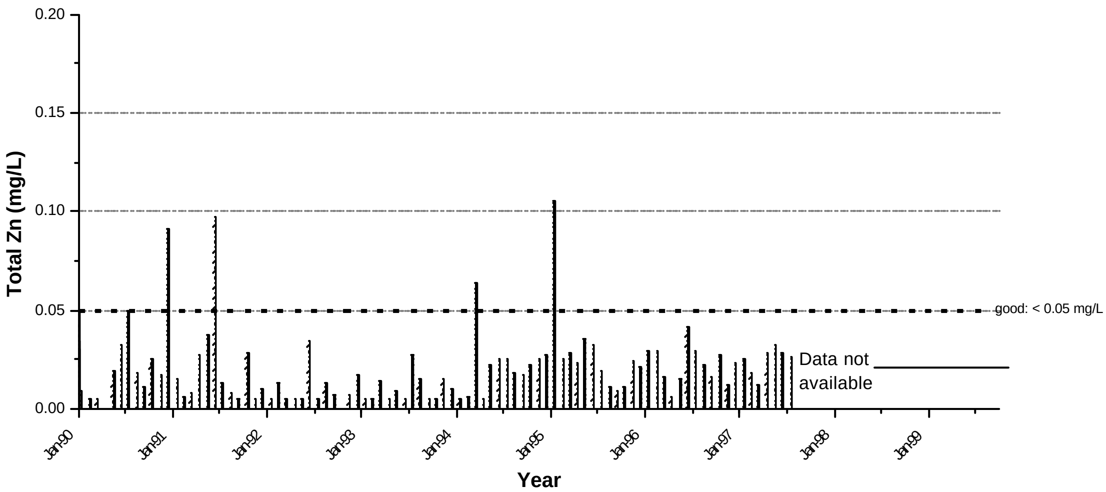
Total Cu (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
good < 0.01 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

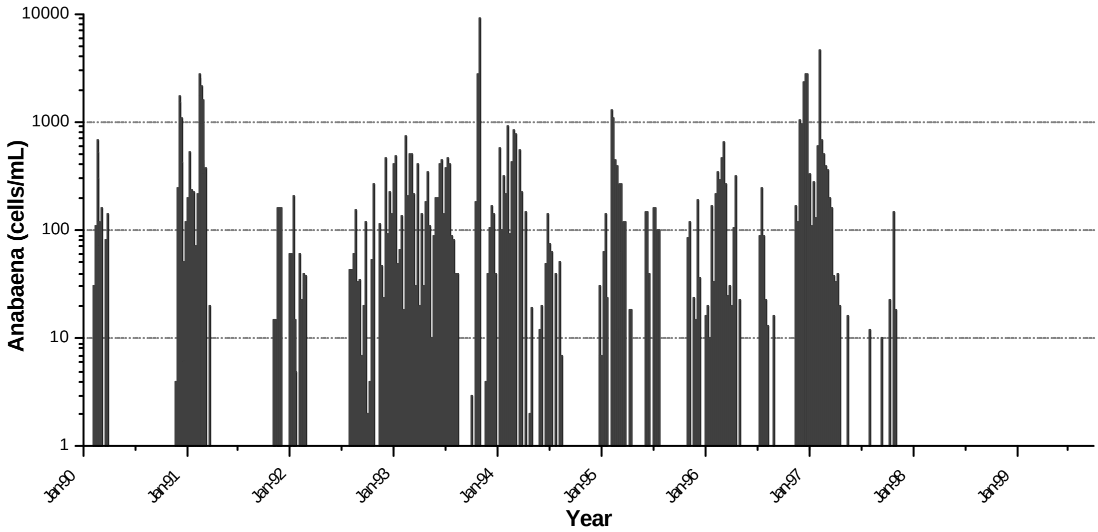


Total Cd (mg/L)
0.005
0.004
0.003
0.002
0.001
0.000
good: < 0.002 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year


Total Pb (mg/L)
0.025
0.020
0.015
0.010
0.005
0.000
good: < 0.005 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

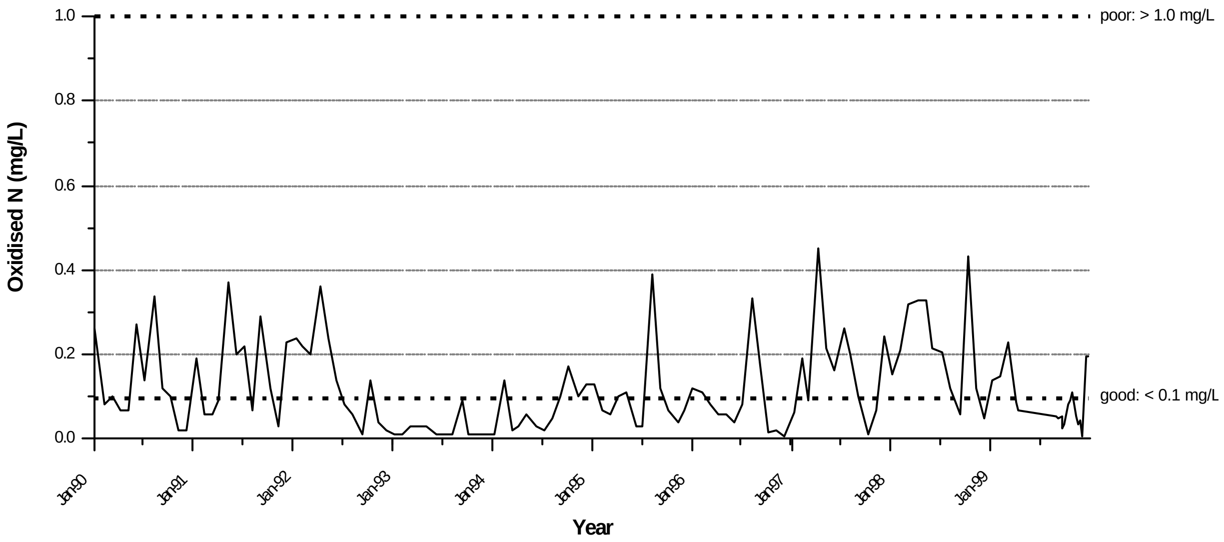

Total Hg (mg/L)
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
good: < 0.0002 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

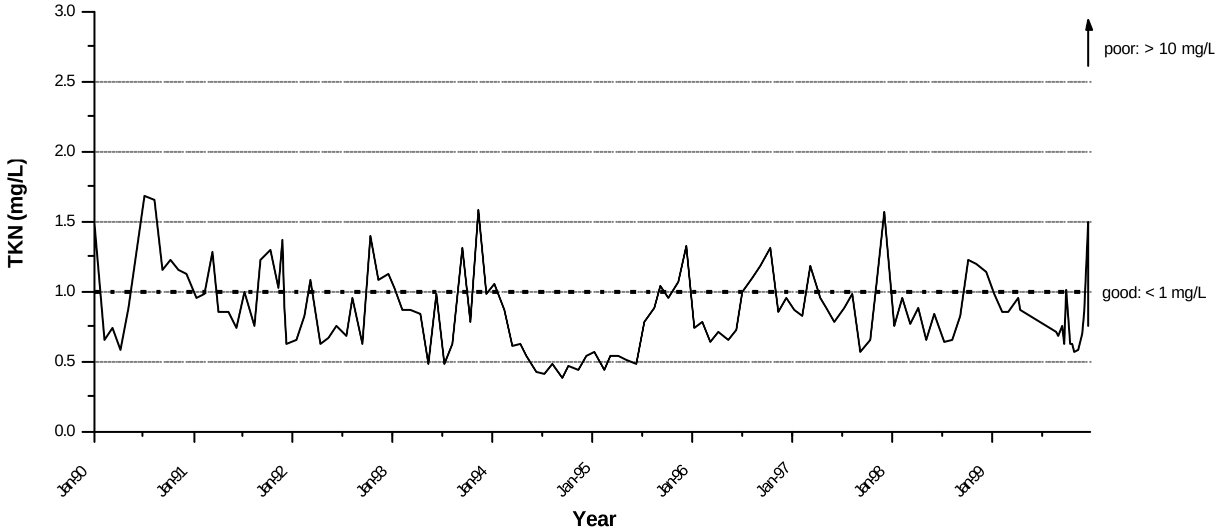

Total Zn (mg/L)
0.20
0.15
0.10
0.05
0.00
good: < 0.05 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

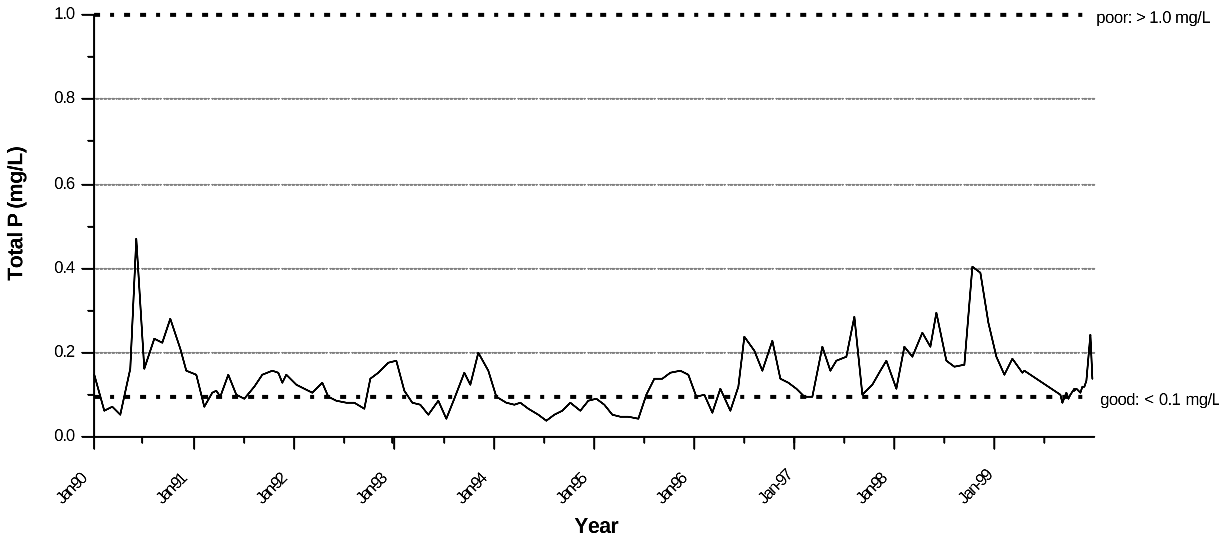


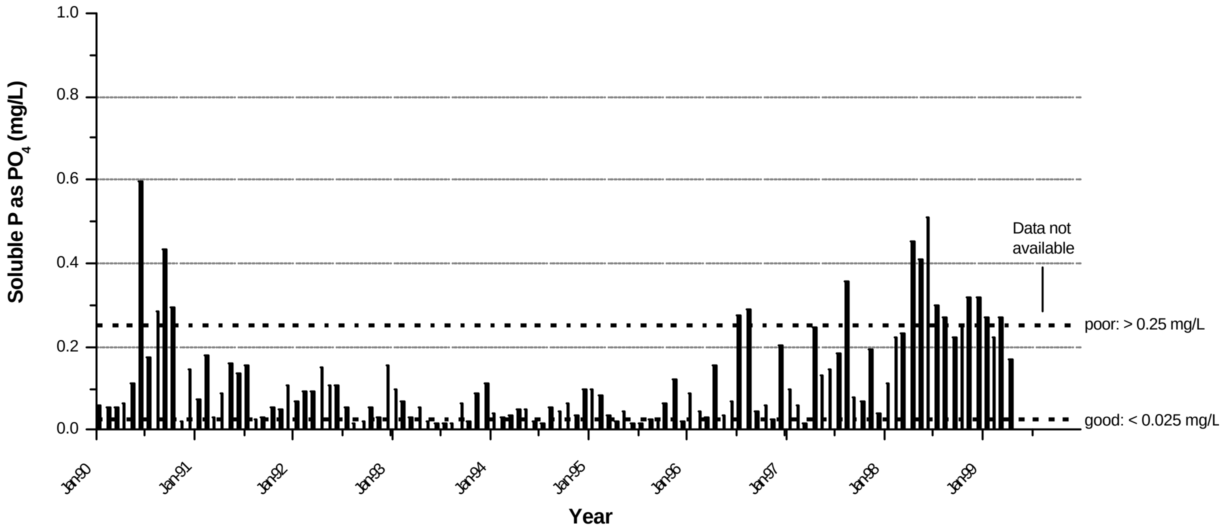
10000
1000
100
10
1
Anabaena (cells/mL)
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

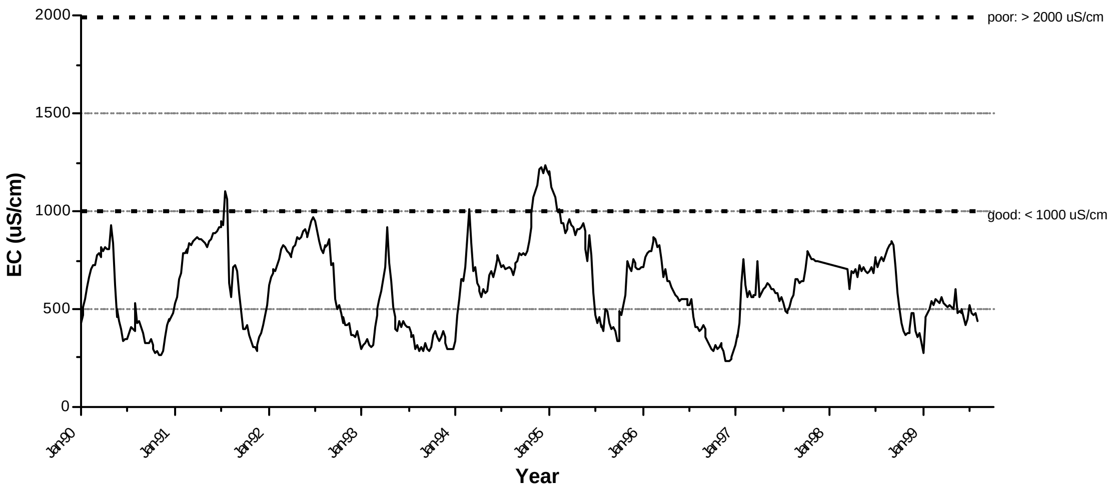
Appendix 6: Murray Bridge

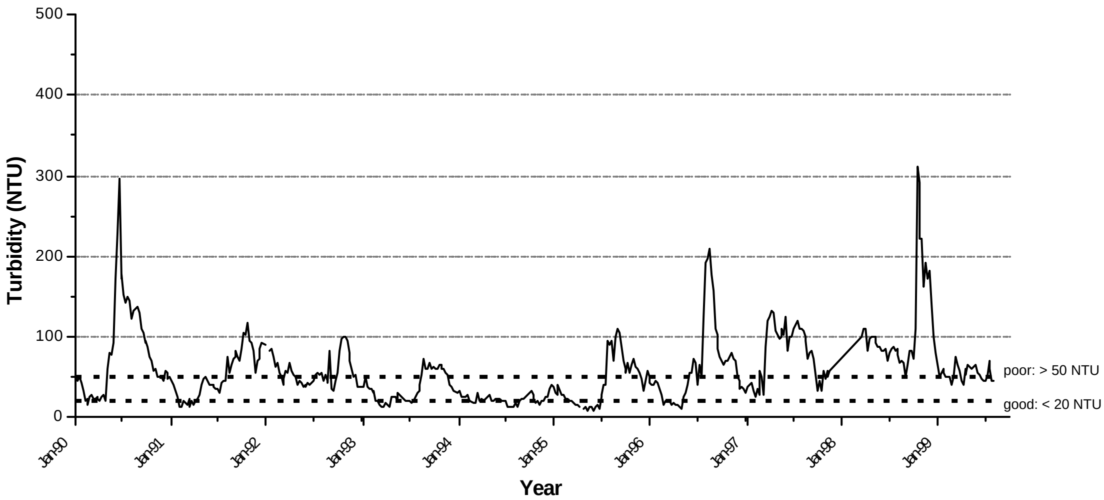


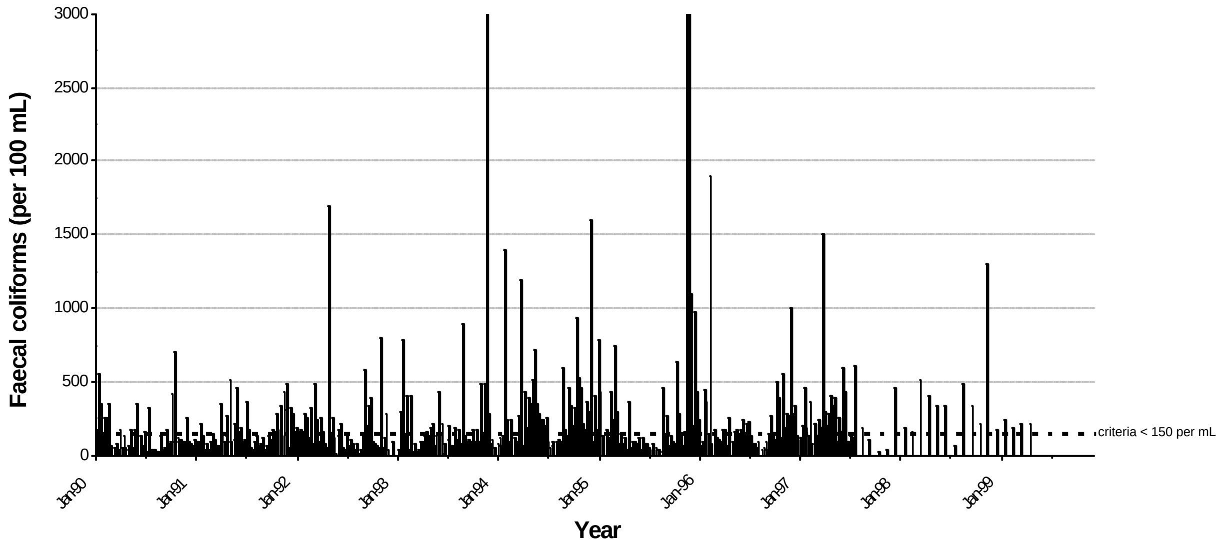




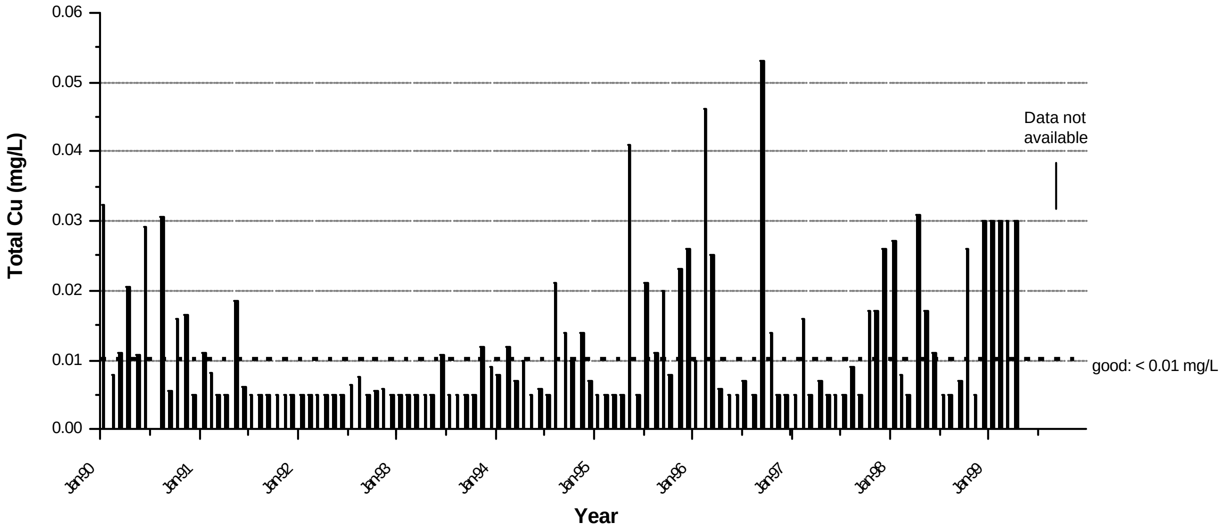

1.0
0.8
0.6
0.4
0.2
0.0
Soluble P as PO4 (mg/L)
Data not available
poor: > 0.25 mg/L
good: < 0.025 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year


2000
1500
1000
500
0
EC (uS/cm)
poor: > 2000 uS/cm
good: < 1000 uS/cm
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

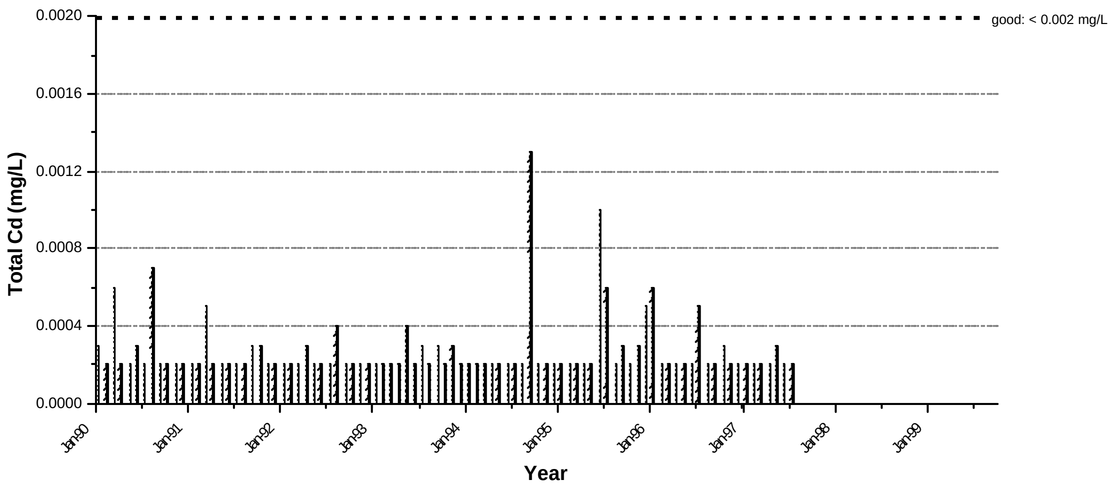

500
400
300
200
100
0
Turbidity (NTU)
poor: > 50 NTU
good: < 20 NTU
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year



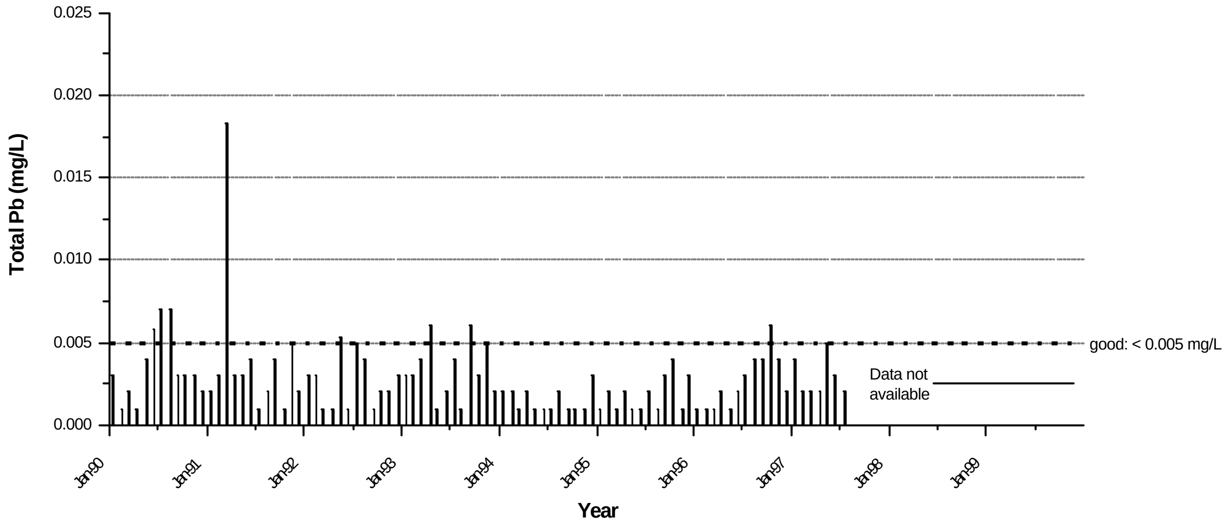
Faecal coliforms (per 100 mL)
3000
2500
2000
1500
1000
500
0
criteria < 150 per mL
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

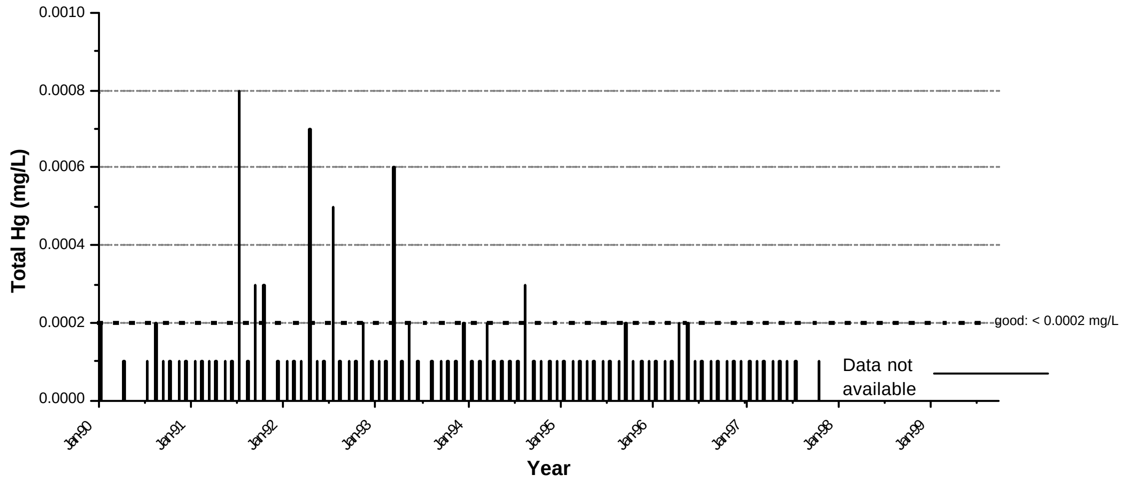


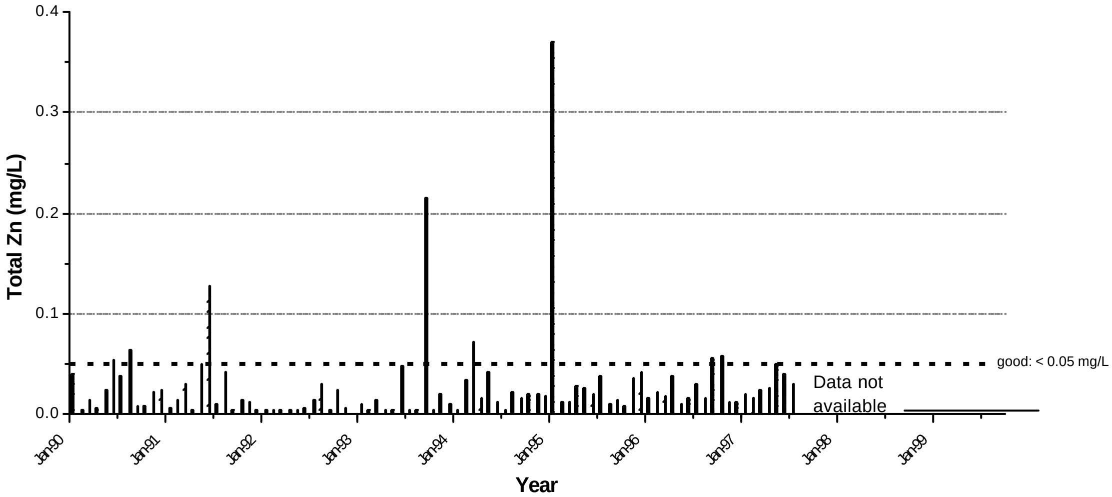
Total Cu (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Data not available
good: < 0.01 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

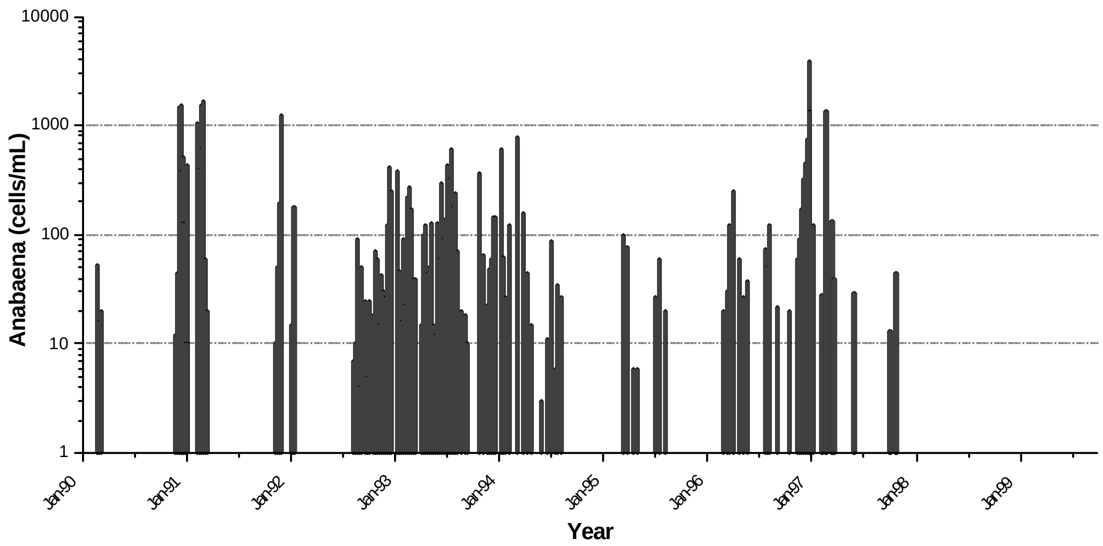


Total Cd (mg/L)
0.0020
0.0016
0.0012
0.0008
0.0004
0.0000
good: < 0.002 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

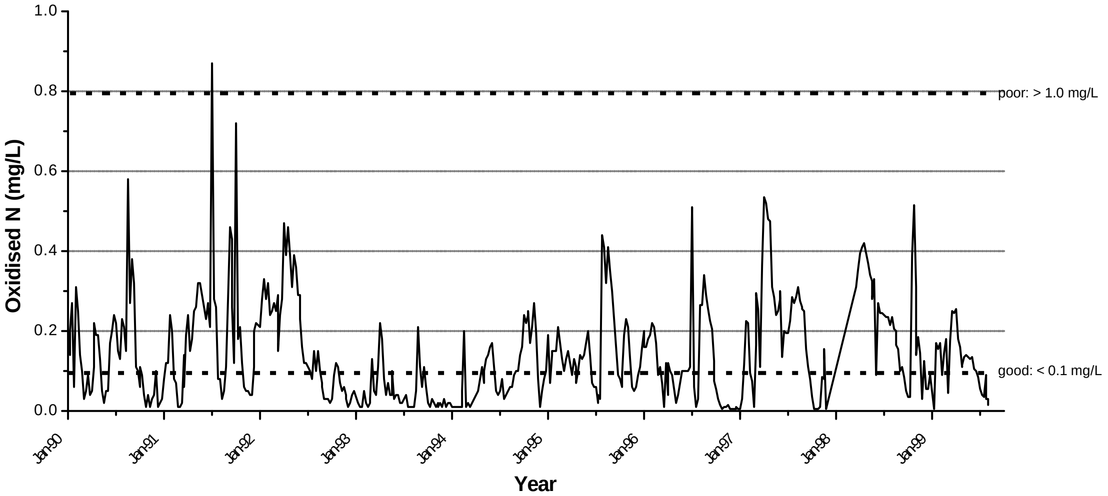

Total Pb (mg/L)
0.025
0.020
0.015
0.010
0.005
0.000
good: < 0.005 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

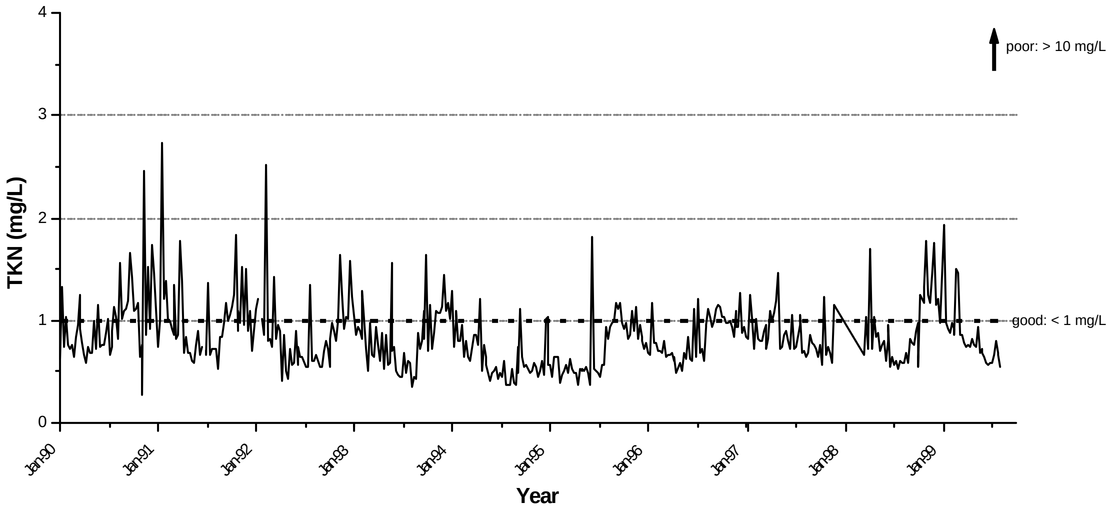

Total Hg (mg/L)
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
good: < 0.0002 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

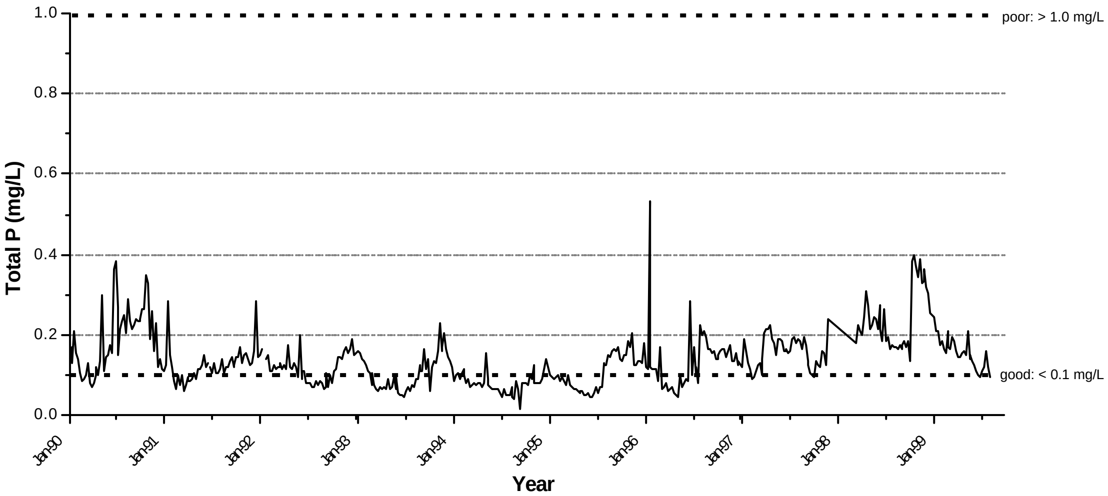

Total Zn (mg/L)
0.4
0.3
0.2
0.1
0.0
good: < 0.05 mg/L
Data not available
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

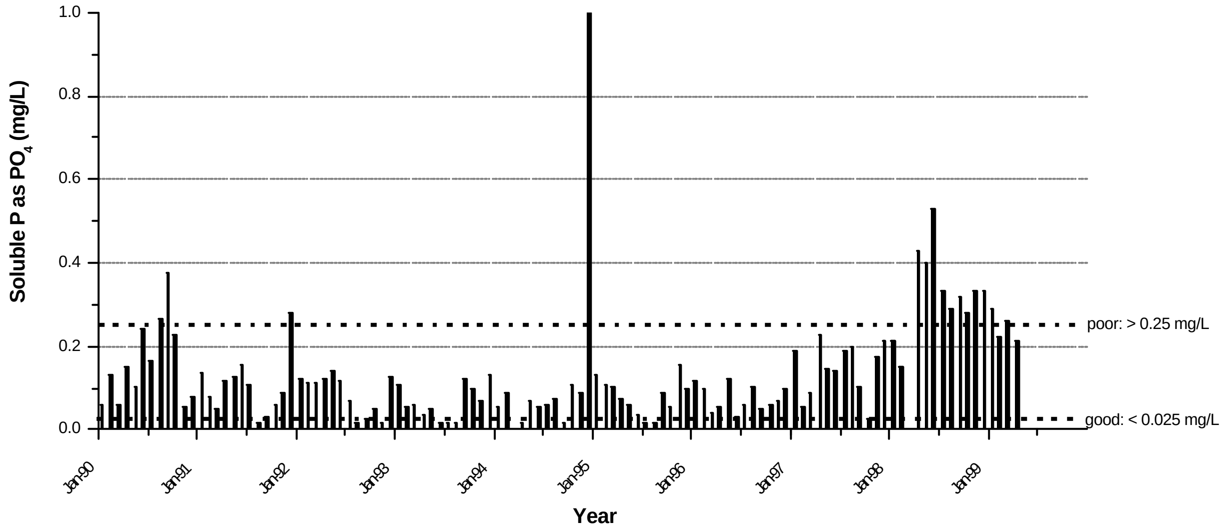

10000
1000
100
10
1
Anabaena (cells/mL)
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

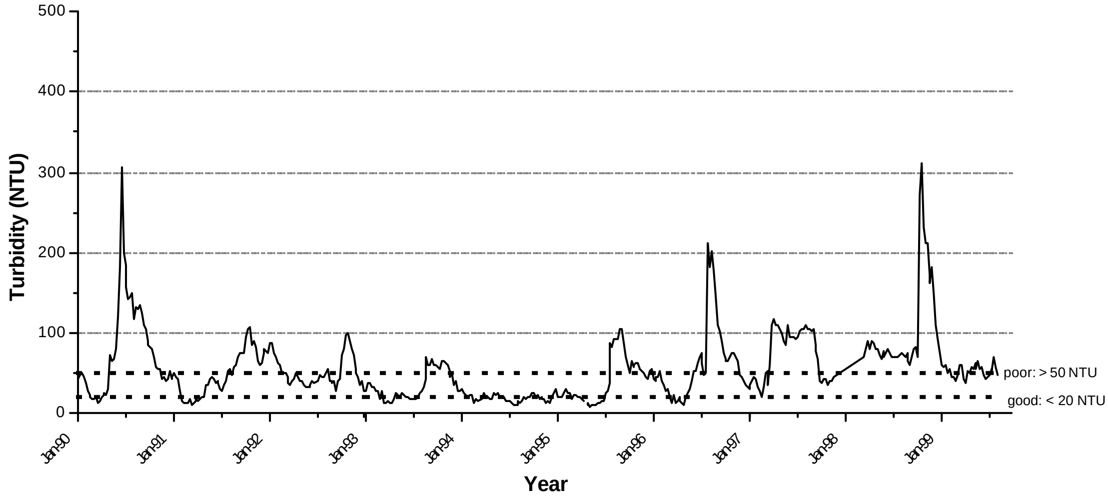
Appendix 7: Tailem Bend

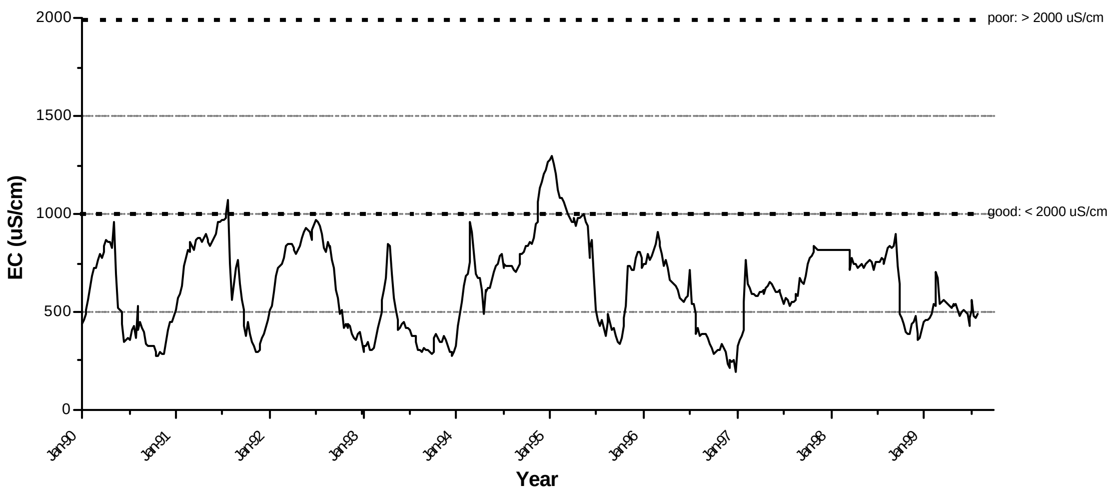


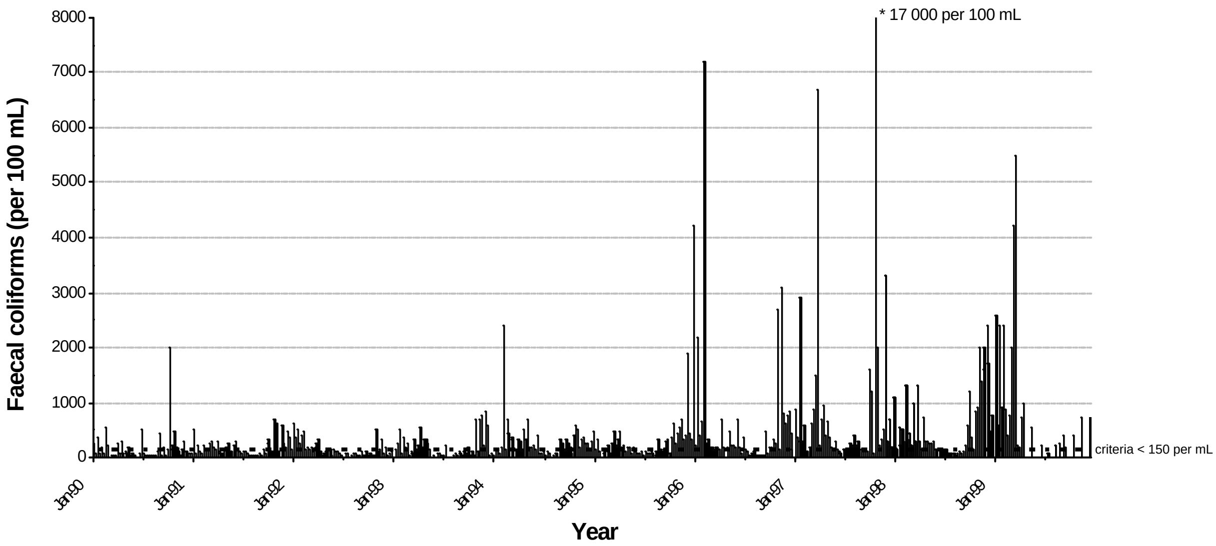


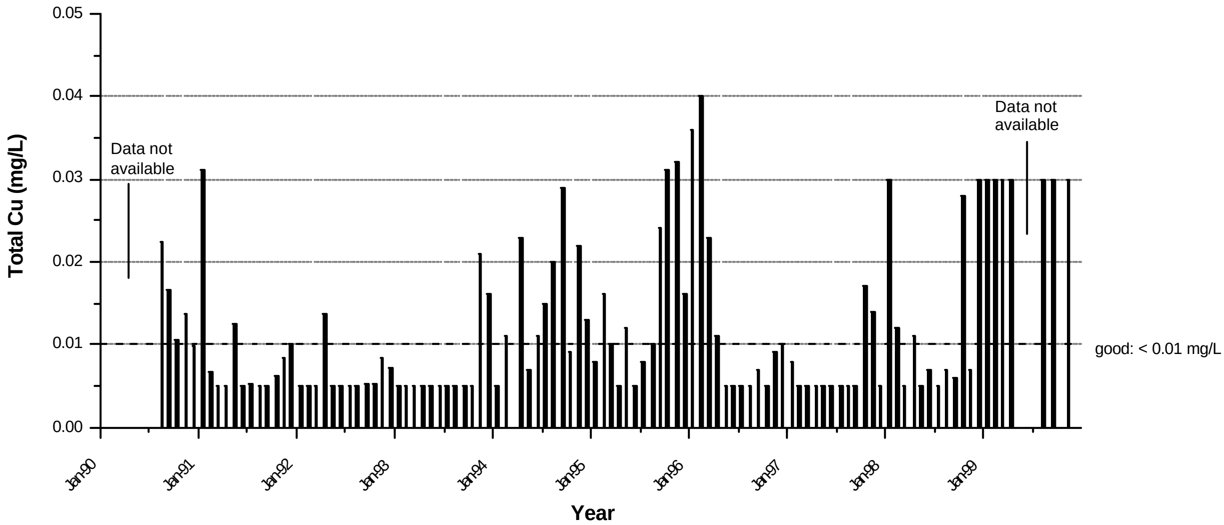


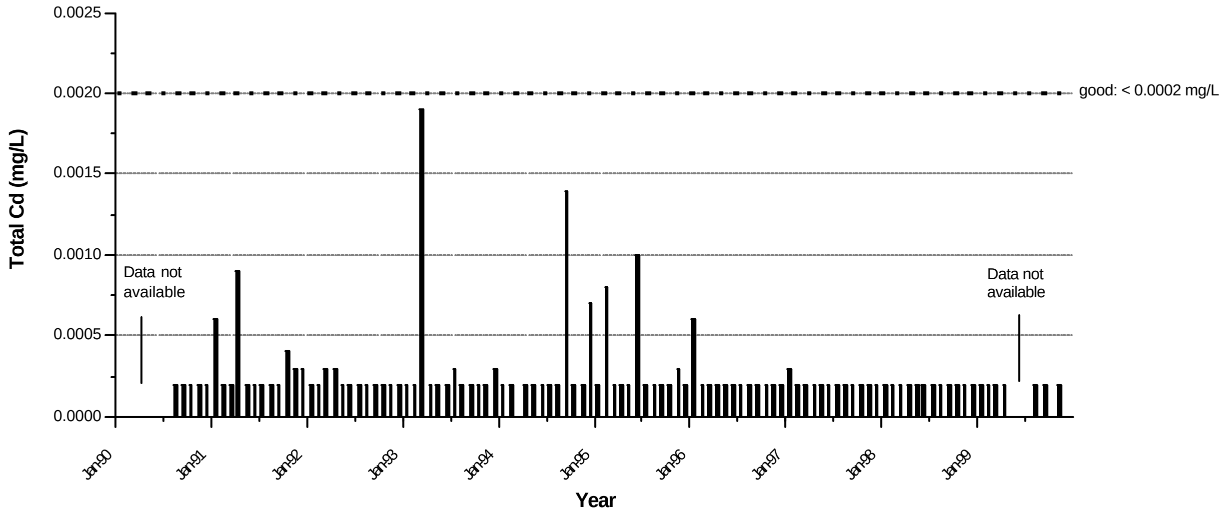

Soluble P as PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
poor: > 0.25 mg/L
good: < 0.025 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

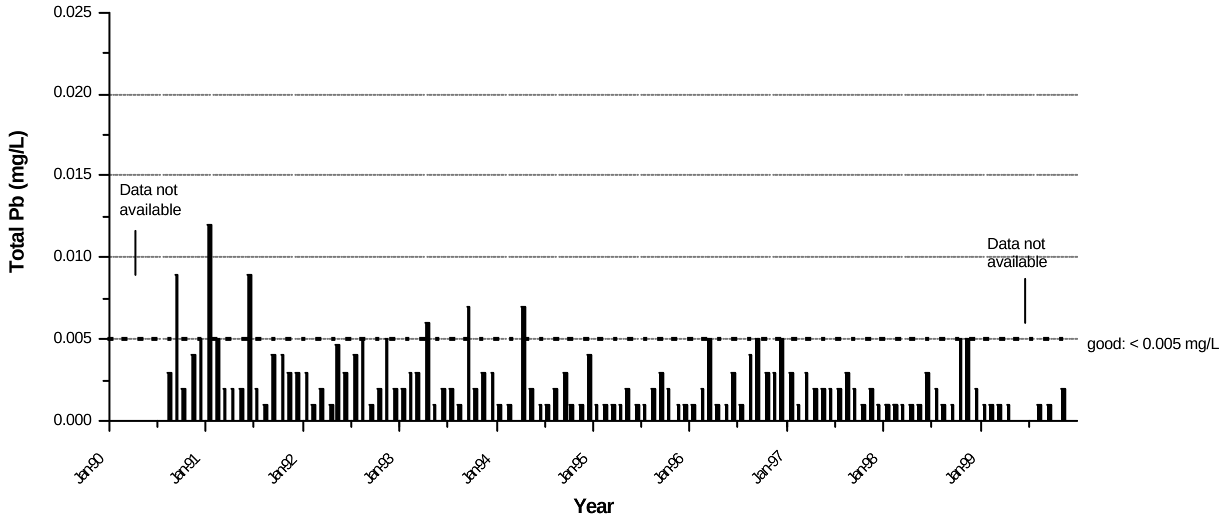

Turbidity (NTU)
500
400
300
200
100
0
poor: > 50 NTU
good: < 20 NTU
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year


EC (uS/cm)
2000
1500
1000
500
0
poor: > 2000 uS/cm
good: < 2000 uS/cm
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year

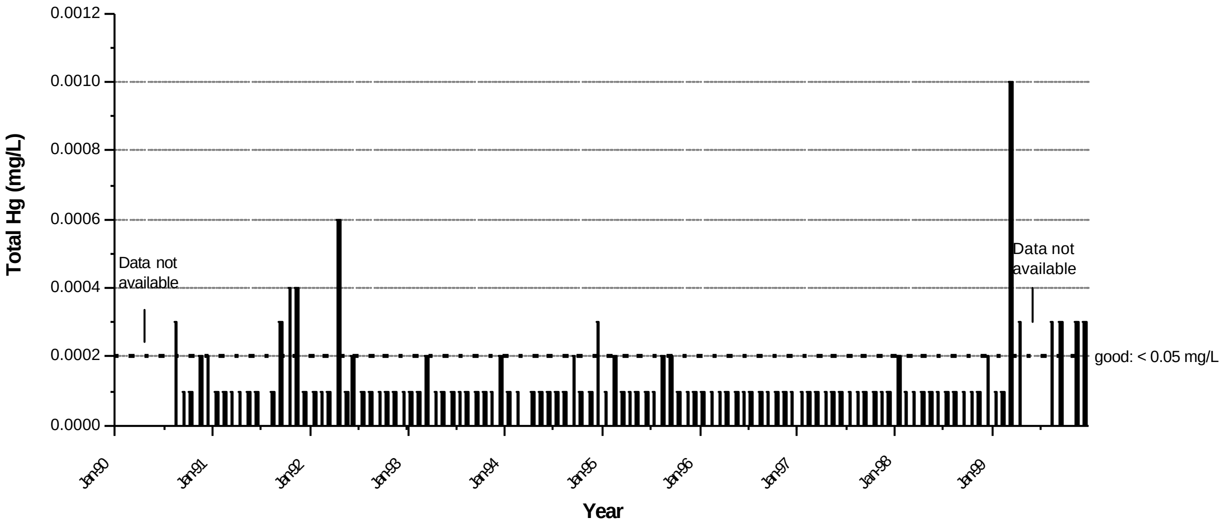

* 17 000 per 100 mL
Faecal coliforms (per 100 mL)
criteria < 150 per mL
Year
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99


Total Cu (mg/L)
Data not available
Data not available
good: < 0.01 mg/L
Year
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99

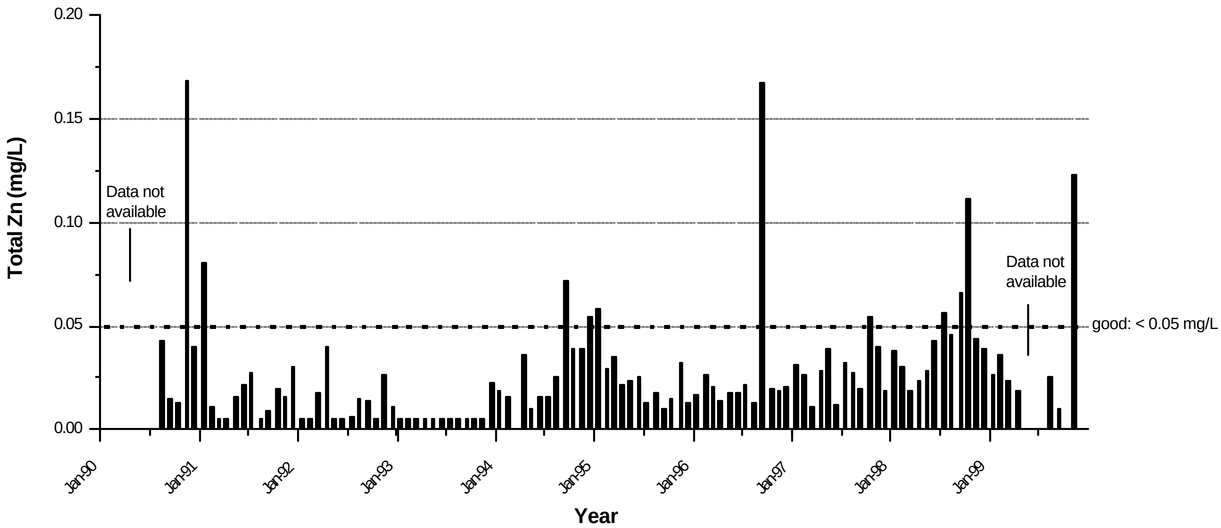

Total Cd (mg/L)
good: < 0.0002 mg/L
Data not available
Data not available
Year
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99



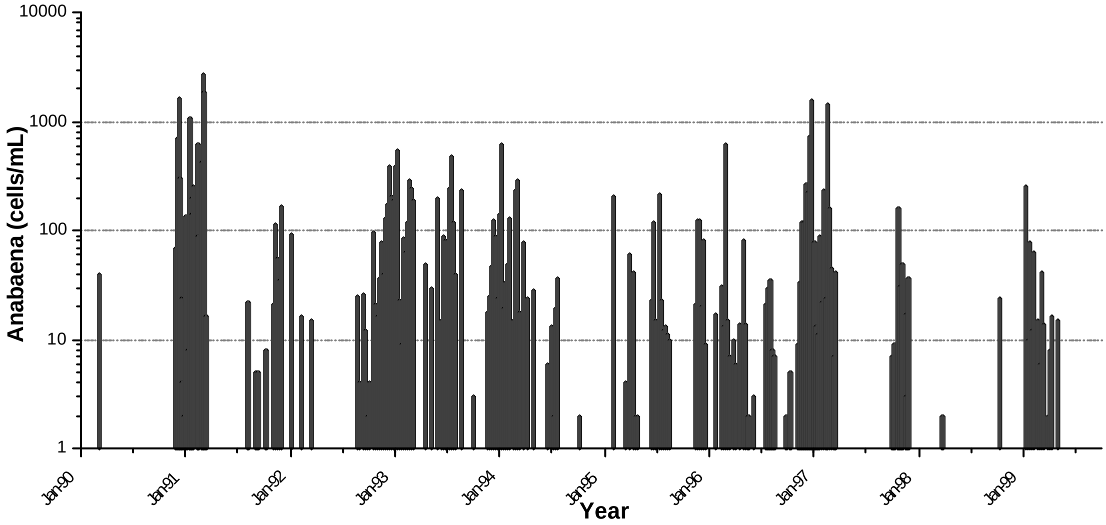
Total Pb (mg/L)
0.025
0.020
0.015
0.010
0.005
0.000
Data not available
Data not available
good: < 0.005 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year



Total Hg (mg/L)
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
Data not available
Data not available
good: < 0.05 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year



Total Zn (mg/L)
0.20
0.15
0.10
0.05
0.00
Data not available
Data not available
good: < 0.05 mg/L
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year


Anabaena (cells/mL)
10000
1000
100
10
1
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Year