Ambient Water Quality Monitoring of the

GULF ST VINCENT METROPOLITAN COASTAL WATERS

Report No 2: 1995-2002

Government of South Australia

EPA South Australia

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Author: Sam Gaylard

For further information please contact:
Environment Protection Authority
GPO Box 2607
Adelaide SA 5001

Telephone:	(08) 8204 2004
Facsimile:	(08) 8204 9393
Freecall (country):	1800 623 445
E-mail:	epainfo@epa.sa.gov.au
Web site:	www.epa.sa.gov.au

ISBN 1 876562 64 1

January 2004

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SUMMARY

This report summarises the water quality of the metropolitan coastal waters of Gulf St Vincent between February 1995 and July 2002 (Figure 1). In an ongoing ambient water monitoring program, water samples are taken from seven sites across Adelaide's metropolitan beaches and compared with samples taken at a reference site at Port Hughes on Yorke Peninsula. Water samples are taken monthly and a range of physical, chemical and biological parameters are analysed.

This is the second report the Environment Protection Authority (EPA) has published on the ambient water quality of the metropolitan coastal waters of Gulf St Vincent. The first report summarised data from February 1995 to December 1996 (EPA 1997a).

Criteria are specified for each parameter, allowing water quality to be described as good, moderate or poor against the desired key environmental values—the protection of ecosystem health, protection of recreational users of water, and protection of aquaculture. Some of the criteria used in the 1997 report to classify water quality have been changed in order to reflect changes in national guidelines, state legislation and our increased understanding of South Australia's marine environment. This has meant that in some cases comparisons drawn between classifications in the two reports may not be appropriate and have therefore been avoided.

The 1997 report concluded that water quality was mostly moderate along the coast, with Brighton, Glenelg, Henley Beach and Grange being the more affected sites. Since that report water quality has remained relatively stable, with no clear trends over the eight years. Generally, the more affected sites from the previous report again potentially compromised ecosystem health, the water quality being better both north and south of this region.

There is evidence of elevated zinc concentrations at all sites across the study region. The cause of these results is uncertain, but it may be a combination of natural origins and urban stormwater runoff. Nutrient enrichment and some elevated nickel concentrations are also evident at the affected sites. Sources are likely to be the Glenelg wastewater treatment plant (WWTP) and the high amount of stormwater runoff entering the marine environment in this region from urban drains, the Torrens River and the Sturt and Brownhill creeks. Generally, microbial concentrations were very low, with only occasional elevated results after periods of heavy rain.

Water quality results indicated that all beaches were safe for recreational users in terms of microbiology; however, there are instances where the turbidity at some beaches may reduce visibility in the water.

Aquaculture protection is possibly being compromised through elevated zinc concentrations at all sites in the study region. High zinc levels may result in bioconcentration of the metal in the tissues of marine organisms, or have toxic effects on these organisms. There are no aquaculture facilities currently located in the study region; however, this information may be used as an assessment tool for any future developments.

Nutrient enrichment can have adverse impacts on the aquatic ecosystem through seagrass loss, increased turbidity and degradation of reef habitats. Elevated concentrations of heavy metals can have impacts on organisms either as acute toxicants or through long-term effects on growth and reproduction.

The main findings of this report are:

- The reference site at Port Hughes was again in relatively good condition.

- Ammonia is elevated at all sites. However, the results show an improvement since the 1997 report. Oxidised nitrogen is elevated at the sites close to the Glenelg WWTP, Torrens River, Patawalonga outlet and stormwater drains. The high oxidised nitrogen and ammonia concentrations are of concern due to the ongoing impacts of nutrient enrichment, including the loss of seagrass and degradation of reef health.
- Chlorophyll *a,* which is a biological indicator of nutrient pollution, was classified as poor at most sites, with potential impacts similar to those observed in other EPA publications, e.g. seagrass loss and subtidal reef degradation.
- Nickel is elevated at the more affected sites and classified as moderate for the protection of aquatic ecosystems. This may have adverse effects on the marine ecosystem and potentially toxic effects on fauna and flora.
- Total zinc was classified as poor at all sites for both ecosystem health and aquaculture protection. This result is of concern due to zinc's ability to bioaccumulate in marine organisms, especially shellfish.
- Turbidity was classified as moderate at five sites and good at three sites. This may play a role in the ongoing loss of seagrass and degradation of reef health already seen in the gulf, especially offshore at Glenelg and Henley Beach.
- The microbiological parameters were classified as good at all metropolitan sites for the protection of recreational users, indicating that all beaches are normally safe for swimming.

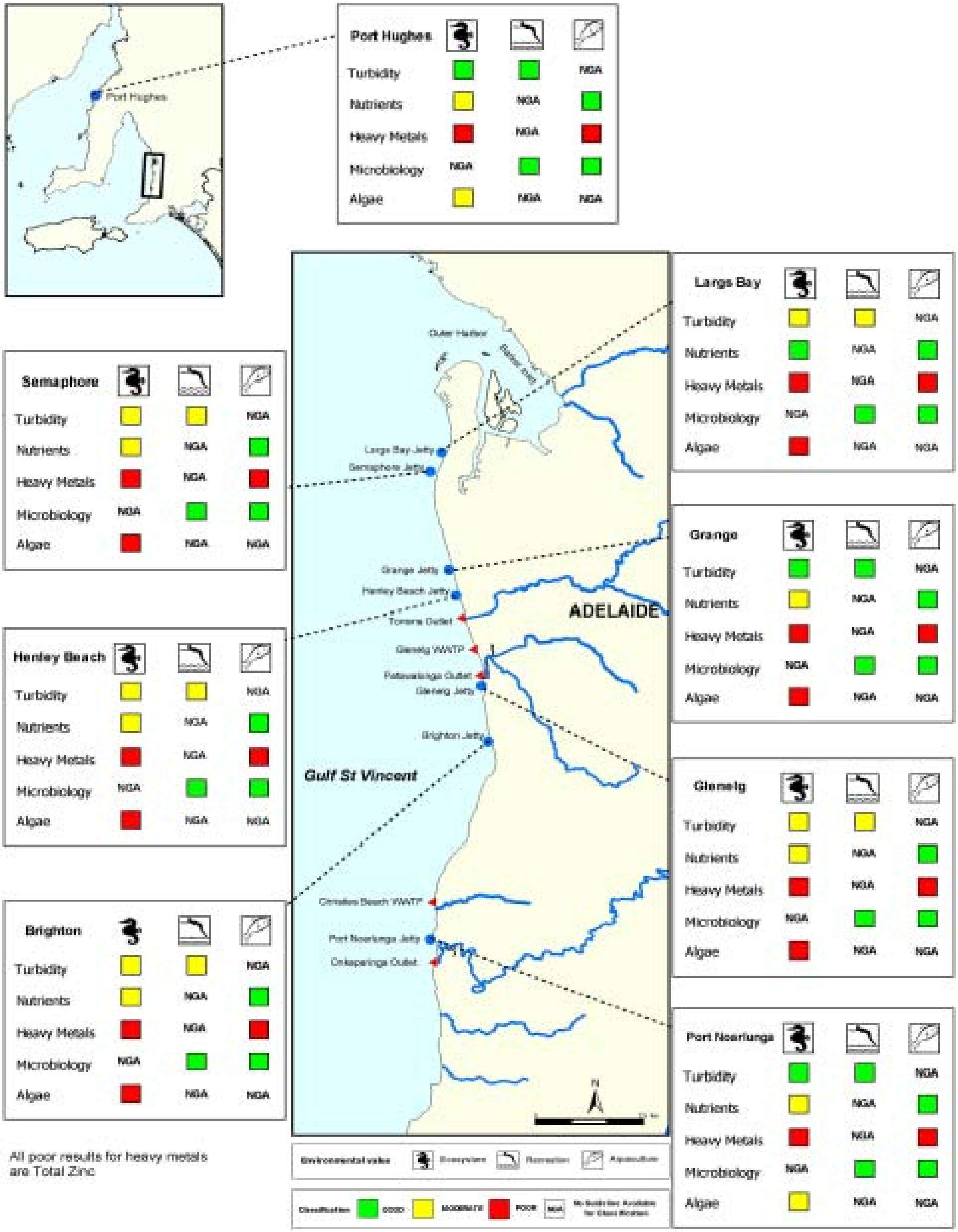
Several developments and strategies are currently being undertaken by government, industry and the community to reduce the pollutant load entering Gulf St Vincent. It is anticipated that the following initiatives will improve water quality over time:

- Industries, including SA Water, that discharge into the gulf and other waterways are implementing Environment Improvement Programs to reduce nutrient loads and turbidity entering the coastal waters.
- The *Environment Protection (Water Quality) Policy 2003* and the catchment water management boards (CWMBs) will promote and implement reductions in diffuse pollution entering the gulf in stormwater from domestic, urban, agricultural and industrial sources.
- Ongoing development and management of wetlands to detain and treat stormwater will reduce the amount of nutrients, metals, bacteria and suspended solids entering the gulf.
- EPA codes of practice for stormwater pollution prevention from the building and construction industry, the community, and local, state and federal governments will restrict stormwater pollution from entering the gulf. Further codes of practice for marinas and wharf handling facilities will be developed in the near future.
- The Adelaide Coastal Waters Study, which is investigating a broad range of water quality issues, will increase knowledge of South Australia's marine environment. It is expected to be completed by June 2006.

It is hoped that the improvement in water quality resulting from these initiatives will result in a slowing of seagrass loss—or even a gradual increase in coverage over a long time period—and the slowing or stopping of degradation of subtidal reefs.

However, it should be noted that we have been polluting Gulf St Vincent for over 160 years. Advancements in water quality management will take many years to improve water quality and promote recovery and regeneration of the marine environment. This would be the case even if we could prevent all discharges to the gulf today.

This report will be updated approximately every five years.



Port Hughes			
Turbidity	🟩	🟩	NGA
Nutrients	🟨	NGA	🟩
Heavy Metals	🟥	NGA	🟥
Microbiology	NGA	🟩	🟩
Algae	🟨	NGA	NGA

Largs Bay			
Turbidity	🟨	🟨	NGA
Nutrients	🟩	NGA	🟩
Heavy Metals	🟥	NGA	🟥
Microbiology	NGA	🟩	🟩
Algae	🟥	NGA	NGA

Semaphore			
Turbidity	🟨	🟨	NGA
Nutrients	🟨	NGA	🟩
Heavy Metals	🟥	NGA	🟥
Microbiology	NGA	🟩	🟩
Algae	🟥	NGA	NGA

Grange			
Turbidity	🟩	🟩	NGA
Nutrients	🟨	NGA	🟩
Heavy Metals	🟥	NGA	🟥
Microbiology	NGA	🟩	🟩
Algae	🟥	NGA	NGA

Henley Beach			
Turbidity	🟨	🟨	NGA
Nutrients	🟨	NGA	🟩
Heavy Metals	🟥	NGA	🟥
Microbiology	NGA	🟩	🟩
Algae	🟥	NGA	NGA

Glenelg			
Turbidity	🟨	🟨	NGA
Nutrients	🟨	NGA	🟩
Heavy Metals	🟥	NGA	🟥
Microbiology	NGA	🟩	🟩
Algae	🟥	NGA	NGA

Brighton			
Turbidity	🟨	🟨	NGA
Nutrients	🟨	NGA	🟩
Heavy Metals	🟥	NGA	🟥
Microbiology	NGA	🟩	🟩
Algae	🟥	NGA	NGA

Port Noarlunga			
Turbidity	🟩	🟩	NGA
Nutrients	🟨	NGA	🟩
Heavy Metals	🟥	NGA	🟥
Microbiology	NGA	🟩	🟩
Algae	🟨	NGA	NGA

All poor results for heavy metals are Total Zinc

Figure 1 Gulf St Vincent monitoring sites and water quality classifications—February 1995–July 2002

1 INTRODUCTION

In February 1995 the Environment Protection Authority (EPA) began an ongoing ambient water quality monitoring program designed to provide a long-term assessment of water quality in the metropolitan coastal waters of Gulf St Vincent. Water samples are collected monthly from eight sites and analysed for a range of physical, chemical and biological parameters.

The sites chosen are predominantly used for primary and secondary contact activities such as swimming and fishing. The key environmental values focused on are human (recreational) health, ecosystem protection and aquaculture protection.

The eight monitoring locations are at each of the seven metropolitan jetties and a reference site at the Port Hughes jetty on Yorke Peninsula. These locations provide the opportunity to examine spatial patterns in water quality along the metropolitan coast, ranging from recently urbanised at Port Noarlunga to historical impacts from urbanisation at locations such as Glenelg and Henley Beach. The reference site at Port Hughes provides a relatively unaffected site with which to compare results from the metropolitan sites. Monthly sampling allows seasonal patterns, annual variation and long-term trends to be examined.

An initial report by the EPA released in November 1997 (EPA 1997a) reported the results from February 1995 to December 1996. This report summarises the first eight years of the program, from February 1995 until July 2002.

1.1 Adelaide’s metropolitan coastal waters

The majority of Gulf St Vincent’s shoreline is relatively sheltered, with shallow gradients creating safe swimming beaches. Adelaide’s metropolitan foreshore is typically characterised by sandy beaches, with subtidal seagrass meadows extending over 5 km out to sea. Focal points at these beaches in summer are the jetties, providing shade on the beach and a base for anglers.

Ecologically, the waters of Gulf St Vincent are quite diverse, with seagrass, sand and reef ecosystems supporting important feeding grounds and nurseries for fish, crustaceans, molluscs and marine mammals. The maintenance of these marine habitats relies heavily on the quality of the water, and jeopardising them may put at risk biodiversity, wild and commercial fish stocks and aquaculture.

Contamination of the marine environment may endanger recreational users of the waters, particularly swimmers, resulting in beach closures for public safety. Pollution may also diminish the aesthetic value of marine waters and can potentially cause algal blooms and fish kills. The integrity of the marine environment as a resource depends on the maintenance of these key environmental values and the preservation of water quality.

Australian Bureau of Statistics (ABS) 2002 data shows that more than 85% of South Australians live within 25 km of the coast. Urban development has meant an enlargement of the total surface area impervious to water, leading to increased stormwater discharges into the marine environment. Typically, these stormwater discharges contain nutrients, hydrocarbons, suspended solids and heavy metals, all of which can be toxic to marine organisms and adversely affect the ecosystems of Gulf St Vincent.

Wastewater treatment plants (WWTP) discharge secondary treated effluent from four locations into Gulf St Vincent: Bolivar, Port Adelaide (via the Port River), Glenelg and Christies Beach. These discharges are high in nutrients and suspended solids and can contain heavy metals such as copper and zinc. Historically, sewage sludge has also been discharged into the gulf through pipelines at Glenelg and Port Adelaide, causing the loss of more than 1200 ha of seagrass along the Adelaide metropolitan coast (Neverauskas 1987). Although the sludge pipes ceased discharging in 1993, nutrient enrichment, turbidity and erosion are still causing seagrass loss at an approximate rate of 100 ha per year between North Haven and Sellicks Beach (Cameron 2003). However, in the ten years since the sludge pipes ceased discharging there has been some seagrass regrowth in previously affected areas (Neverauskas pers. comm.).

Gulf St Vincent is a reverse estuary which has only limited exchange with the Southern Ocean. The tides in the study region flow northwards almost parallel to the shoreline to the northern extremities of the gulf. At the turn of the tide there is a period of relatively slack water, then the flow of water is reversed and heads southwards, again almost parallel to the shore (Grzechnik & Noye 1996). This has ramifications for water quality: the water in the gulf has a longer residence time when compared with the open ocean, and the movement of polluted water from point source discharges can have negative environmental impacts on other regions.

Physical changes to the shoreline may also influence water quality. In 1949 the Outer Harbor breakwater was constructed, significantly affecting the northward movement of sand along the coast. This has resulted in sand accretion south of the breakwaters and potential smothering of seagrasses in the region (EPA 1998). The West Beach boat harbour was built in 1998 with the construction of breakwaters and the dredging of sediment. This has similarly interrupted the flow of sand moving northwards and promoted sand accretion south of the structures. The Barcoo outlet was built in 2001 to divert stormwater from the Patawalonga Basin to the marine environment in all but the largest storms. These activities may have influenced sediment stability, nutrient uptake, bacterial water quality and turbidity. In recent times it has become apparent that human activities have resulted in a loss of over 4000 ha of seagrass and the degradation of rocky reef environments (EPA 1998, 2003).

The beaches of Adelaide are an important natural and economic asset for the State of South Australia and are visited by South Australians as well as tourists from interstate and overseas. Gulf St Vincent is a highly productive and biologically diverse ecosystem. The recreational and commercial fishing industries rely heavily on the protection of its water quality as a resource for aquaculture and a nursery for targeted species of fish and crustaceans (e.g. King George whiting, western king prawn and blue swimmer crab). Water quality was therefore classified as either good, moderate or poor, using national guidelines, and based on the environmental values of the water:

- protection of the aquatic ecosystem
- protection of recreational users of the water
- protection of aquaculture.

1.2 Aims of this ambient water quality monitoring program

Ambient water quality is a representative measure of the overall water quality of a waterbody. It indicates the quality of water when all the impacts that may influence the waterbody are considered as a whole rather than focusing on the effects of particular discharges. The results in this report are indicative of water quality in the metropolitan coastal waters of Gulf St Vincent from February 1995 to July 2002. This monitoring program aimed to:

- determine the quality of Adelaide's metropolitan coastal waters
- categorise water quality as good, moderate or poor, using a classification system based on the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC 2000) (ANZECC guidelines) and the National Health and Medical Research Council (NHMRC) *Australian guidelines for the recreational use of water* (NHMRC 1996)
- examine spatial differences in water quality within the region and compare results with a relatively unaffected site, and discuss what factors might cause variability between sites
- provide data to assess any changes in water quality over time to ensure that the development and use of the waters are ecologically sustainable in the long term.

2 SURVEY METHODOLOGY AND DATA ANALYSIS

2.1 What is monitored

The parameters monitored in the program were generally classified as physical, chemical or biological. The choice of water quality parameters was based on those required to support the designated environmental values listed in section 1.1. Guidelines for these water quality parameters are contained in ANZECC 2000 and NHMRC 1996.

The physical parameter included in this report is water clarity as measured by turbidity. Chemical parameters can be divided into metals (soluble and total aluminium, total chromium, total copper, total lead, total nickel, and soluble and total zinc) and nutrients (ammonia, oxidised nitrogen, total Kjeldahl nitrogen (TKN) and total phosphorus). Biological parameters include an estimate of algal biomass (chlorophyll *a*) and microbiological parameters (faecal coliforms, *Escherichia coli* and enterococci).

2.2 Survey design

In this monitoring program Adelaide's coastal water quality is assessed by taking regular, small and representative samples. It is not possible to sample, and therefore know, the water quality of all points in the gulf at all times. The small subset of samples collected is used to estimate the water quality of the region as a whole. Clearly, this process involves a degree of uncertainty as environmental measurements often show much variability. To interpret data of this nature effectively, a number of simple statistical techniques have been used.

Water samples are taken near the end of each metropolitan jetty. Initially, sampling frequency was monthly; however, with the increasing level of use throughout summer, samples are now collected every two weeks from October until April and monthly at other times. Water samples are collected and analysed by a National Association of Testing Authorities (NATA) accredited laboratory.

2.3 Statistical methods

2.3.1 Descriptive statistics

Water quality measurements from most natural environments are highly variable, so descriptive statistics are used to summarise the data. Detailed descriptions of the statistical methods used are beyond the scope of this report; for further explanation and examples of calculations see the statistical text *Biometry* (Sokal & Rohlf 1995).

Mean (or average)

The mean, often called the average, is the most common measure of central tendency. The sample mean is a good estimate when the distribution of a sample is symmetrical, but if the distribution is skewed the mean should be used with caution. Most of the samples in this study are strongly skewed to the right of the mean, with some very large measurements substantially increasing the mean.

95% confidence interval of the mean

The 95% confidence interval of the mean (95% CIM) enables determination of the certainty of the sample estimate of the population mean. For example, the 95% CIM for turbidity at Largs Bay is 2.2–4.2 nephelometric turbidity units (NTU) and the sample mean is 3.23 NTU. It would be tempting to assume that the population mean is 3.23 but, in reality, there is only a 95% chance that the interval 2.2–4.2 includes the population mean.

Standard deviation

The standard deviation is a calculation of the dispersion or variability of all the measurements in a sample. Generally speaking, it is the average distance of sample points from the sample mean.

Median

Another common estimate of central tendency is the median or 50th percentile. The median is the middle point of a distribution and an equal number of measurements fall below and above it. The median is a more robust estimate of central tendency than the mean as it is not influenced so strongly by skewed distributions or outliers. In most cases in this report the median has been used as the measure of central tendency.

90th percentile

The 90th percentile is a measure that excludes the outermost 10% of the data. This gives a result that is more robust to extreme events which can produce inaccurately high data and skew the mean.

Geometric mean and the 95% confidence interval of the geometric mean

Microbiological data is often highly skewed, with a few high readings combined with many lower values. In distributions such as this the mean and median are substantially different. To overcome this problem, geometric means have been used to describe the data. Unlike the normal 95% CIM, the 95% confidence interval for the geometric mean (95% CIgM) is not symmetrical around the mean, providing a better estimate of the 95% confidence interval in distributions that are skewed. See Sokal and Rohlf (1995) for information on calculating the geometric mean and confidence intervals for the geometric mean.

In this report the geometric mean and 95% CIgM have been used to describe the data but not to classify it. In order to keep within the framework of the NHMRC 1996 guidelines, the median has been used to classify the data.

2.3.2 Differences between sites compared to a reference site

Descriptive statistics allow the data from each site to be summarised; inferential statistics allow differences between sites to be determined. The inferential statistical methods used here allow determination of statistically significant differences between sites at the $p = 0.001$ level. The p value is merely an arbitrary cut-off point (or confidence level) where one data set is different enough from another to say with confidence that they are different for some reason other than chance. A p value of 0.001 means that there is 99.9% confidence that any difference seen is not due to chance.

All results in this report were assessed using p values of 0.05, 0.01, 0.005 and 0.001. Only significant differences at a p value of 0.001 are discussed, due to the higher confidence in the results. Statistical significance at other p values were used when looking at correlations and trends in the data.

Statistically significant differences are the most quantitative way to determine whether a hypothesis can be substantiated. When interpreting 'statistical significance' information in this report, it is advisable to keep the hypotheses (or aims) in mind. They are:

1. *The water quality of Adelaide's metropolitan coastal waters is not different from the water*

quality at Port Hughes.

2. *The water quality at one particular site is not different from any other site tested.*

The results of the statistical tests indicate the levels of confidence in any conclusions drawn. However, while a significant difference may exist in the data, it does not mean that the site is 'polluted' or that there is a significant environmental effect. It is only an indication that there is a difference between sites. There may be several reasons for this difference, or there may be no explanation. The key conclusions are still based on the good/moderate/poor water quality classifications. See Zar (1996) for more details on hypothesis testing.

The parametric tests of analysis of variance, together with a pairwise comparison such as a Tukey's test, are traditionally used to determine differences between samples. However, our data sets are not normally distributed and do not meet many of the assumptions of parametric tests; therefore, non-parametric alternatives were used.

Friedman's test was used to determine whether there were any differences between sites for each parameter. If this test showed that there were statistically significant differences between sites at the $p = 0.001$ level, then a Wilcoxon signed ranks test was used to discover exactly which sites were different from each other. These results are contained in the 'site comparison' column of the data table for each characteristic.

2.4 Water quality classifications

As with previous EPA reports it has been found useful to broadly classify the water quality at each site as good, moderate or poor. However, there are no formal national standards for such classifications. In past reports the EPA has used a system where the 90th and 50th percentiles are compared against a guideline figure from the 1992 ANZECC *Guidelines for Fresh and Marine Waters* (ANZECC 1992). This document has been updated since the last report and the EPA has adopted its replacement *Australian and New Zealand Guidelines for Fresh and Marine Waters*, published by ANZECC in 2000. The object of the ANZECC guidelines is to use the trigger values as concentrations that, if exceeded, would indicate a potential environmental problem and therefore prompt further investigation.

The guidelines state various levels of protection for an ecosystem according to its current water quality and ecological and cultural significance. As a result of past and current impacts, the waters of Gulf St Vincent have been classified through the ANZECC (2000) framework as 'slightly to moderately disturbed'. This classification has implications for determining which water quality expectations and criteria are used to protect habitats in this region. The ANZECC guidelines state that a toxicant water quality trigger value in a slightly to moderately disturbed system is set at a level that will protect 95% of species.

The water quality parameter classifications of good, moderate and poor are generated by the positions of the 90th and 50th percentiles in relation to the trigger values. These percentiles are used to protect organisms from chronic effects of the toxicants. If the 90th percentile is less than the trigger value, the parameter is classified as good. If the 90th percentile is greater than the trigger value but the 50th percentile (median) is less than the trigger value, the parameter is classified as moderate. If the 50th percentile is greater than the trigger value, the water quality parameter is classified as poor—this is a level at which chronic toxicities may be exhibited in some sensitive organisms.

The microbiological parameters are classified by using the median only. If the median is less than or equal to the NHMRC lower guideline value, the water quality is classified as good. If the median is greater than the lower guideline value but less than or equal to the upper value, the water quality is classified as moderate. If the median is greater than the upper guideline value, the water quality is classified as poor.

Turbidity is the only parameter that differs from these classification systems. The previous report (EPA 1997a) used a classification system incorporating a range of values for the protection of recreational users. In this report the upper limit for the protection of recreational users has been modified according to the *Environment Protection (Water Quality) Policy 2003*. Additionally, an ecosystem criterion has been developed that is considerably less than the recreational values. This was seen as important due to the increase in knowledge about the deleterious effects of turbidity on seagrass and subtidal reefs. Using both the 90th percentile and the median, turbidity has been classified as good if the 90th percentile is less than the lower guideline value. If the 90th percentile is greater than, but the 50th percentile is less than, the lower guideline, the turbidity is classified as moderate. If the 50th percentile is greater than the upper guideline, the turbidity is classified as poor.

A more detailed explanation of how the data is classified is given in the introduction to each group of parameters.

3 WATER QUALITY PARAMETERS

3.1 Physical parameters

The physical parameters temperature, pH, total dissolved solids and conductivity (salinity) are measured as part of the determination of the quality of the water along Adelaide's metropolitan coast. They aid in assessing the toxicity of other contaminants, such as metals and nutrients, that may be in the environment, but these parameters have not been specifically addressed in this report.

Turbidity, which is a measure of water clarity, can have direct and indirect impacts on the marine environment and therefore is specifically addressed.

3.1.1 Turbidity

Generally speaking, turbidity is a measure of the transmission of light through water. Specifically, it relates to the amount of scattering of light by particulate and dissolved material in water. Particulate matter such as clay, silt, organic matter and living organisms can all scatter light, as can large dissolved molecules. Turbidity is measured in nephelometric turbidity units (NTU) and is approximately related to visibility as follows:

Turbidity	Visibility depth (m)
2 NTU	10
5 NTU	4
10 NTU	2
25 NTU	0.9
100 NTU	0.2

While turbidity generally increases when the amount of suspended solids in water increases, the correlation between turbidity and suspended matter in natural environments is often poor because the size, shape and composition of different particles influence the amount of light they scatter. Dissolved substances, which are not part of the suspended solid load, can also affect turbidity by changing colour and light transmission through the water column.

Effects

Turbidity has two areas of impact on the marine environment: reduced light penetration and the effect of suspended particles.

Plants and algae require light to carry out photosynthesis. Increased turbidity can reduce the amount of light available, which may result in a reduction in the health of the plants, making them more susceptible to other pressures. It may even result in the total loss of these organisms, leading to a loss of productivity and a reduction in food and habitat for other marine life. A decline in plants such as seagrass may result in a loss of sediment stability, causing increased erosion and sand movement.

Suspended particles can affect the marine environment in several ways. They can smother sessile (fixed to the substratum) organisms such as anemones and corals. Deposition of fine particles can reduce the amount of space available for the attachment of algae and other plants. Filter feeding organisms can be vulnerable to high loads of suspended solids in the water.

Turbidity can also affect the recreational value of the water by making swimming unsafe and reducing its aesthetic value.

For more information on some specific impacts of turbidity on the marine environment, see other EPA publications:

- *Changes to seagrass coverage and links to water quality off the Adelaide metropolitan coastline (1998).*
- *The health of subtidal reefs along the Adelaide metropolitan coastline (2003).*

Sources

Turbidity can originate from both natural and anthropogenic (human related) sources. Discharges from rivers are a source of turbidity through the suspended solids they carry from higher in the catchments. Particles can accumulate on the sea–floor, and wind and wave action can resuspend particles, increasing turbidity.

Stormwater runoff contains particulate and dissolved matter from soil erosion, decaying organic matter and other pollutants such as rubber particles from tyre wear on roads. The Torrens Catchment Water Management Board (TCWMB) estimates that the Torrens catchment discharges over 3000 tonnes (t) of suspended solids each year (TCWMB 2002) and the Patawalonga catchment releases over 2000 t each year (PCWMB 2002). Industries also contribute to the suspended solid load in Gulf St Vincent. The Glenelg wastewater treatment plant (WWTP) discharges approximately 234 t of suspended solids each year.

Dredging can also be a source of localised turbidity. Poorly managed dredging activities can result in large turbidity plumes from the dredge, reducing water clarity and potentially smothering organisms. Due to the northward sand movement along the metropolitan coast, sand builds up on the southern side of many artificial structures such as boat harbours and breakwaters. This can block access to the structure, and dredging is required to clear it.

Turbidity can also result from elevated nutrient levels in the water, due to an increased amount of microscopic algae scattering light through the water column. Nutrient concentrations have been summarised separately from turbidity and will be discussed later in this report.

Results—turbidity

Ecosystem criteria: Good: 90th percentile ≤ 5 NTU
Moderate: 90th percentile > 10 but 50th percentile ≤ 5 NTU
Poor: 50th percentile > 10 NTU.

Of the eight sites sampled five were classified as moderate. These were Largs Bay, Semaphore, Henley Beach, Glenelg and Brighton, with Brighton averaging the highest turbidity with a 90th percentile of 13.5 NTU. Only Grange, Port Noarlunga and Port Hughes were classified as good. Of the 618 measurements taken, 42 were greater than the ecosystem poor guideline of 10 NTU. Port Noarlunga had the clearest water, with 100% of measurements less than the good guideline of 5 NTU. Brighton beach water quality was most compromised by turbidity, with 29% of measurements being greater than the good guideline and 17% greater than the poor guideline.

All sites except Port Noarlunga were significantly different from the reference site ($p < 0.001$).

Recreation criteria: Good: 90th percentile ≤ 5 NTU
Moderate: 90th percentile > 20 but 50th percentile ≤ 5 NTU
Poor: 50th percentile > 20 NTU.

Five sites of the eight measured were considered moderate and the remaining three were good (Grange, Port Noarlunga and Port Hughes). Again, Brighton was the most affected site, with five measurements being greater than or equal to 20 NTU, one of which was 72 NTU, almost four times the upper limit.

Discussion and conclusions

Turbidity is elevated at Henley Beach, Glenelg and Brighton, which may be attributable to the three main inputs along this coast: the Torrens River, the Patawalonga outlet and the Glenelg WWTP.

These discharges and the general northward movement of water along the metropolitan coastline may explain the reason for relatively high turbidity at Henley Beach and Glenelg. Brighton, however, is south of these major discharges; it would be expected to have lower turbidity than Glenelg and Henley Beach but had the highest 90th percentile (13.5 NTU) and the highest mean (5.47 NTU). There are several possible factors that may be causing these unexpectedly high results. Firstly, the Christies Beach WWTP discharges nutrients into the waters south of Brighton, and this water would move northwards and possibly result in increased turbidity and algal growth at Brighton. Secondly, the Edwards Street stormwater drain discharges large volumes of stormwater into this region after periods of heavy rain. Finally, there may be movement of water from the Glenelg WWTP and northern stormwater drains south to Brighton through tidal movements.

The latter theory may be supported by data in Grzechnik and Noye (1996). This study shows that depth averaged velocity vectors for a tidal model of the region around the Port Stanvac oil refinery travel parallel to the coast along the headland at the suburbs of Hallett Cove and Marino. Further north, at approximately Seacliff and Brighton, there is a region of very little water movement when the tide is at full velocity, limiting water exchange. When the tide turns, this region of little movement is flooded with water from north of Brighton.

This region of very little movement may be creating a still area which promotes algal growth and, in turn, increases turbidity. At Brighton the correlation between turbidity and chlorophyll *a* (a measure of algae) was found to be strong (a Spearman rank order correlation coefficient of 0.820). This correlation was not observed to this degree at any other location along the coast.

The moderate turbidity at Largs Bay and Semaphore could possibly be due to the action of a shallower beach and the influence of the North Haven and Outer Harbor breakwaters. The beaches at Largs Bay and Semaphore are subject to lower wave energy than those further south. In combination with long–term sand movement in the area, this has resulted in shallower beaches, possibly amplified by the Outer Harbor and North Haven breakwaters accumulating sand on their southern sides. Shallower beaches are generally made up of finer sediment, which may result in more resuspension of sediment due to wind and wave actions on the beach. As at Brighton, turbidity at Largs Bay may also be influenced by algae. A Spearman rank order correlation coefficient of 0.694 (the second highest after Brighton) shows that a correlation exists between algae (as chlorophyll *a*) and turbidity at Largs Bay. This increase in algae may be due to an influx of nutrient–rich water in the Port River and the restriction of water around the North Haven and Outer Harbor breakwaters.

The results show that there are differences in both the 90th percentiles and medians between the current data and the data in report no. 1 (EPA 1997a). However, this may reflect uncertainties associated with the smaller sample size in the 1997 study and increased statistical power gained from larger sample sizes.

There were no discernible trends in turbidity over the eight-year study period.

Table 1 Statistical summary of turbidity 1995–2002

	Mean (NTU)	Standard deviation (NTU)	95% confidence interval	Median (NTU)	90th percentile (NTU)	Max (NTU)	Number of samples	Water quality classification		Site comparison(a)
								Ecosystem	Recreation	
1 Largs Bay	3.226	4.570	2.2–4.2	1.650	7.24	31	81	Moderate	Moderate	Site 1 > 7,8
2 Semaphore	2.367	2.560	1.8–2.9	1.375	5.43	13	81	Moderate	Moderate	Site 2 > 7
3 Grange	2.858	4.102	1.9–3.8	1.600	4.57	24	79	Good	Good	Site 3 > 7,8
4 Henley Beach	3.725	5.033	2.6–4.9	2.000	9.14	25	79	Moderate	Moderate	Site 4 > 7,8
5 Glenelg	3.613	4.615	2.6–4.7	1.750	8.90	26	78	Moderate	Moderate	Site 5 > 7,8
6 Brighton	5.457	9.758	3.3–7.6	1.658	13.50	72	79	Moderate	Moderate	Site 6 > 7,8
7 Pt Noarlunga	0.879	0.752	0.7–1.0	0.603	1.61	5	81	Good	Good	n.s.
8 Pt Hughes	1.363	2.747	0.7–2.1	0.653	2.20	20	60	Good	Good	n.s.

(a) Friedman probability: $p < 0.001$ statistically significant differences between sites. The > symbol indicates that the measurement at the specified location is significantly greater than at certain other sites. For pairwise site comparisons, 'n.s.' signifies the site is not significantly greater than any other site.

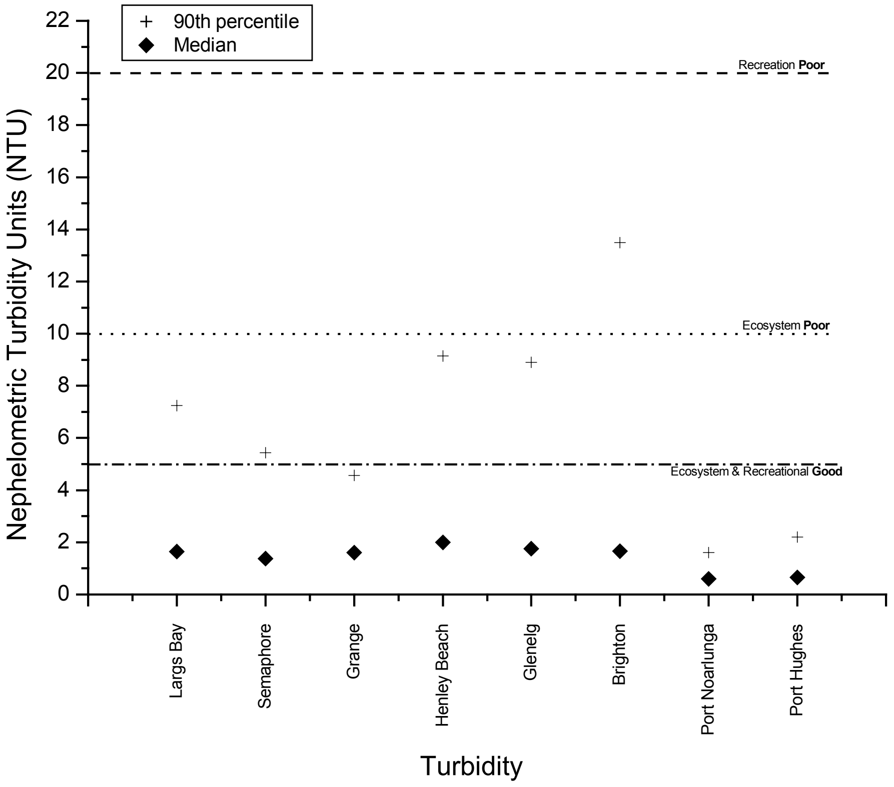


Figure 2 Median and 90th percentile for turbidity 1995–2002

3.2 Chemical parameters

3.2.1 Metals

Metals occur in the environment in mineral deposits and can enter the marine environment naturally through weathering of rocks and ores. Human activities such as ore refining and many industrial processes can also release metals into the environment. Metals entering the metropolitan coastal waters can be linked to two major sources: urban stormwater and industrial sites. Urban stormwater can contain metals deposited on impervious surfaces such as roads from the wearing of vehicle parts (e.g. tyres, brake pads and linings); vehicle, boat and aircraft exhausts; and leaking oil and petrol. Industrial sources include discharges from power stations, port facilities, shipping and vessel maintenance, wastewater treatment plants, and chemical and manufacturing plants.

Metals can be present in a dissolved form but are more often associated with fine particulate matter. When bound to fine particulates, they can settle into the sediments and cause localised contamination which may remain for long periods of time. This has occurred in areas of the Port River where there is localised historical sediment contamination by tribuytltin (an antifoulant) residues. These residues may still have an effect on organisms some time after the pollution occurred. Contaminated sediments could also be resuspended though wind and wave action or through dredging, which is particularly of concern around shipping channels.

The toxicity and water solubility of metals in the environment depend largely on physical and chemical conditions, including pH and salinity. Metals are generally more toxic at lower salinity and pH levels. Factors that affect bioavailability are pH, salinity, temperature and water hardness. Metals in water adsorb onto particles including clay and organic matter, reducing their availability. Turbid waters may therefore have higher metal concentrations but the metals may not be bioavailable. Changes in chemistry, such as lowered pH, can increase the bioavailability of metals in sediments. The parameters measured in this study are total concentrations of metals in the sample but this does not take into account the specific bioavailability of the metals, which may differ according to the environmental conditions at the site.

Metals can affect organisms in a number of ways. They can be acutely (in the short term) toxic, causing mortality, or chronically (in the longer term) toxic, resulting in mortalities or sub-lethal effects such as growth or reproductive abnormalities. Certain chemicals can bioaccumulate in an organism, i.e. where the concentration of a chemical inside the organism’s tissues is greater than the concentration in the environment. Some chemicals can also magnify in concentration up the food chain to have effects in the top predators (e.g. PCBs in dolphins and whales). No heavy metals measured in this report significantly biomagnify through the food chain.

Metal accumulation in fauna and sediments is an important issue; however, it is not covered in this report. (See the EPA publications *Special survey of the Port River: Heavy metals and PCBs in dolphins, sediments and fish* (EPA 2000) and *Sediment quality monitoring of the Port River estuary* (EPA 1997c)).

It can be difficult to measure metals at lower concentrations in saline waters because the salts present may interfere with the analytical equipment. Also, because very low concentrations of some metals can harm the environment, the ANZECC guidelines for metal concentrations are very low and in some instances (e.g. chromium, copper, lead) below or equal to the analytical detection limit. In these cases it is unreasonable to use the relevant ANZECC guidelines as all sites would be classified as poor simply because of limitations in analytical technique. Instead, to classify the sites based on the location of the 90th percentile, the analytical detection limit is used as the guideline for the metal concerned.

Classification of metals

In this report metal concentration classifications differ from previous EPA reports to reflect changes to the ANZECC guidelines and an increased understanding of coastal waters. Water quality classifications are based on two environmental values: the protection of the aquatic ecosystem and the protection of aquaculture. These environmental values have different guideline values as they focus on different aspects of the environment.

The water quality classifications for the protection of the ecosystem use the following guideline values from the ANZECC guidelines. They are based on the position of the 90th and 50th percentiles in relation to the single guideline criterion:

Good:	Water quality is good if the 90th percentile is less than or equal to the criterion value for the protection of 95% of species in the ecosystem (table 3.4.1, ANZECC 2000).
Moderate:	The 90th percentile is greater than, but the 50th percentile is less than or equal to, the criterion value.
Poor:	Water quality is poor if the 50th percentile is greater than the criterion value. Alternatively, 5% of samples are more than ten times the lower limit. This is considered poor water quality as it is likely to cause toxic effects in some aquatic organisms.

The water quality classifications for the protection of aquaculture use the following guideline values from the ANZECC guidelines. They are based on the position of the 90th percentile and median in relation to the single guideline criterion:

Good:	Water quality is good if the 90th percentile is less than or equal to the criterion value.
Moderate:	The 90th percentile is greater than, and the median is less than or equal to, the criterion value.
Poor:	Water quality is poor if the median is greater than the criterion value.

3.2.2 Aluminium

Aluminium's occurrence in natural waters is reliant on pH and the amount of very fine suspended mineral particles. Aluminium is a non-essential element for plants and animals. It is naturally present in marine waters and makes up a large part of the earth's crust (~8%).

The EPA measures aluminium as soluble and as total aluminium. Soluble aluminium is the amount of dissolved aluminium in the water excluding that which is attached to particles and bonded to organic molecules. This is generally the most bioavailable form. Total aluminium is a measure of all the aluminium that may be potentially available to the system, including that which is dissolved, attached to particles and bonded to organic molecules.

Sources

Aluminium is a naturally occurring element and may be present in the marine environment through natural leaching from rock and soil. It may also be present in industrial discharges, WWTP effluents and stormwater runoff.

Effects

Aluminium is thought to be more toxic to fish than to invertebrates; in high concentrations it interferes with reproduction and damages the gills. It has been responsible for fish kills in freshwater lakes where the water is acidic. However, due to the alkaline nature and buffering capabilities of sea water, this is not considered a problem in Gulf St Vincent. Aluminium will bioaccumulate in marine organisms, particularly at lower pH.

Results—soluble aluminium

Ecosystem criteria: Currently there is insufficient data to generate guideline values for aluminium in marine waters.

The availability of aluminium is pH dependent, with lower pH making aluminium more available. Sea water is highly buffered at a pH of approximately 8. This may significantly reduce the toxic effect of aluminium in marine waters. There were no sites significantly different from the reference site of Port Hughes or from each other.

Aquaculture criteria:	Good:	90th percentile ≤ 0.025 mg/L (modified from 0.01 mg/L)
	Moderate:	90th percentile > 0.025 but 50th percentile ≤ 0.025 mg/L
	Poor:	50th percentile > 0.025 mg/L.

Due to analytical difficulties, soluble aluminium was unable to be classified reliably. There are several interferences in the analytical procedure, especially when testing in sea water, which give a higher than normal limit of detection and unreliable results.

Where available the EPA must use laboratory methods with reliable detection limits below the current guideline values in ANZECC (2000). This information will give marine scientists a better understanding of the concentration levels of these trace elements in the marine environment, and will aid in its management.

Results—total aluminium

Ecosystem guideline: There is no guideline for total aluminium.

It is not possible to classify total aluminium as currently there are no criteria for it in sea water. The results for total aluminium were very similar along the coast with the exception of Port Noarlunga, which was significantly less than at all other sites. This is probably linked to the lower turbidity at this site.

Discussion and conclusions

The actual toxic effect of aluminium in sea water would be expected to be less than the aquaculture guideline. This is because higher pH and water hardness reduce toxicity, and aluminium adheres to suspended particles, organic matter and sediment, so it is no longer bioavailable. The sites with the higher total aluminium results were also the sites with the higher turbidity, which supports the above statements.

Changes in pH can release aluminium, which may then have a toxic effect on aquatic organisms. This is sometimes a problem in freshwater systems but the marine environment is heavily buffered to resist changes in pH, which generally means that aluminium is not a problem in marine waters. For this reason it may be appropriate for the EPA to remove this parameter from the monitoring program.

Table 2 Statistical summary of soluble aluminium 1995–2002

	Mean (mg/L)	Standard deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality classification		Site comparison[(a)]
								Ecosystem	Recreation	
1 Largs Bay	0.033	0.012	0.031-0.036	0.025	0.05	0.082	78	n.a.	n.c.	n.s.
2 Semaphore	0.033	0.011	0.030-0.035	0.025	0.048	0.067	78	n.a.	n.c.	n.s.
3 Grange	0.033	0.011	0.030-0.035	0.026	0.047	0.079	78	n.a.	n.c.	n.s.
4 Henley Beach	0.034	0.023	0.029-0.039	0.025	0.045	0.213	78	n.a.	n.c.	n.s.
5 Glenelg	0.034	0.018	0.030-0.038	0.025	0.054	0.152	78	n.a.	n.c.	n.s.
6 Brighton	0.034	0.014	0.030-0.037	0.025	0.046	0.117	78	n.a.	n.c.	n.s.
7 Pt Noarlunga	0.032	0.012	0.029-0.035	0.025	0.046	0.075	78	n.a.	n.c.	n.s.
8 Pt Hughes	0.036	0.015	0.032-0.040	0.027	0.058	0.08	58	n.a.	n.c.	n.s.

(a) For pairwise site comparisons, 'n.s.' signifies the site is not significantly greater than any other site.

n.a. Criterion classification is 'not appropriate'. The ANZECC guidelines state there is insufficient reliable data to define a criterion for this parameter.

n.c. Criterion 'not classifiable'. There is a criterion for this parameter; however, the results were unable to be reliably classified due to inconsistencies in the analytical data.

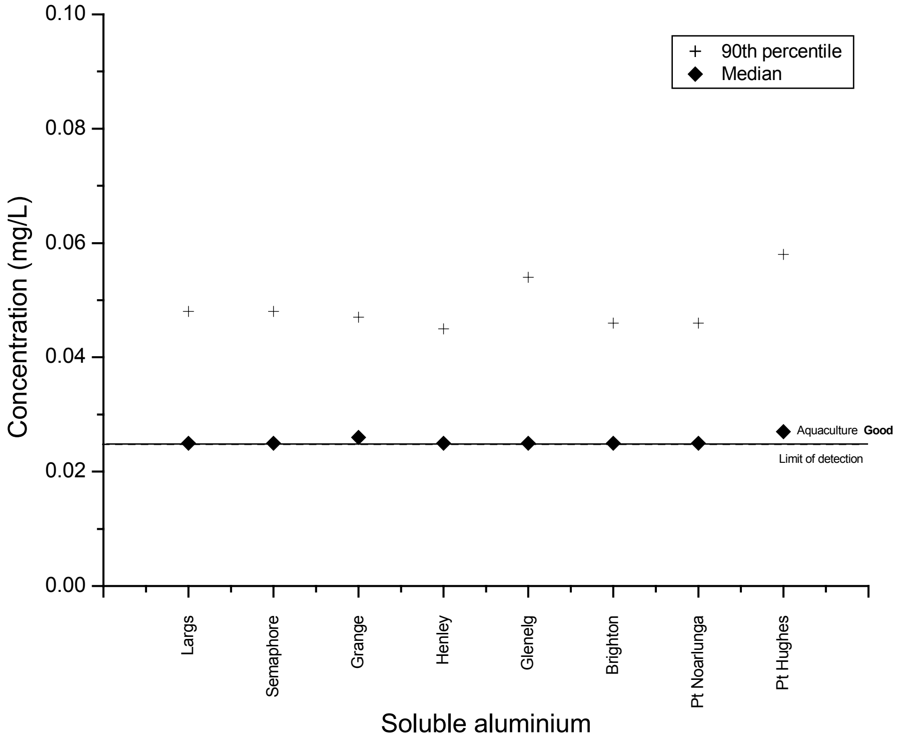


Figure 3 Median and 90th percentile for soluble aluminium 1995–2002

Table 3 Statistical summary of total aluminium 1995–2002

	Mean (mg/L)	Standard Deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality classification		Site comparison[(a)]
								Ecosystem	Aquaculture	
1 Largs Bay	0.084	0.118	0.058–0.111	0.046	0.167	0.706	77	n.a.	n.a.	Site 1 >7
2 Semaphore	0.070	0.077	0.052–0.087	0.040	0.153	0.380	77	n.a.	n.a.	Site 2 >7
3 Grange	0.072	0.100	0.050–0.095	0.047	0.118	0.682	77	n.a.	n.a.	Site 3 > 7
4 Henley Beach	0.094	0.131	0.065–0.124	0.051	0.213	0.862	77	n.a.	n.a.	Site 4 >7
5 Glenelg	0.083	0.098	0.061–0.105	0.051	0.157	0.619	77	n.a.	n.a.	Site 5 >7
6 Brighton	0.098	0.114	0.073–0.124	0.051	0.255	0.757	77	n.a.	n.a.	Site 6 >7
7 Pt Noarlunga	0.046	0.035	0.038–0.054	0.034	0.077	0.176	77	n.a.	n.a.	n.s.
8 Pt Hughes	0.055	0.055	0.040–0.069	0.033	0.111	0.284	59	n.a.	n.a.	Site 8 >7

(a) Friedman probability: $p < 0.001$ statistically significant differences between sites. The > symbol indicates that the measurement at the specified location is significantly greater than at certain other sites. For pairwise site comparisons, 'n.s.' signifies the site is not significantly greater than any other site.

n.a. Criterion classification is 'not appropriate'. The ANZECC guidelines state there is insufficient reliable data to define a criterion for this parameter.

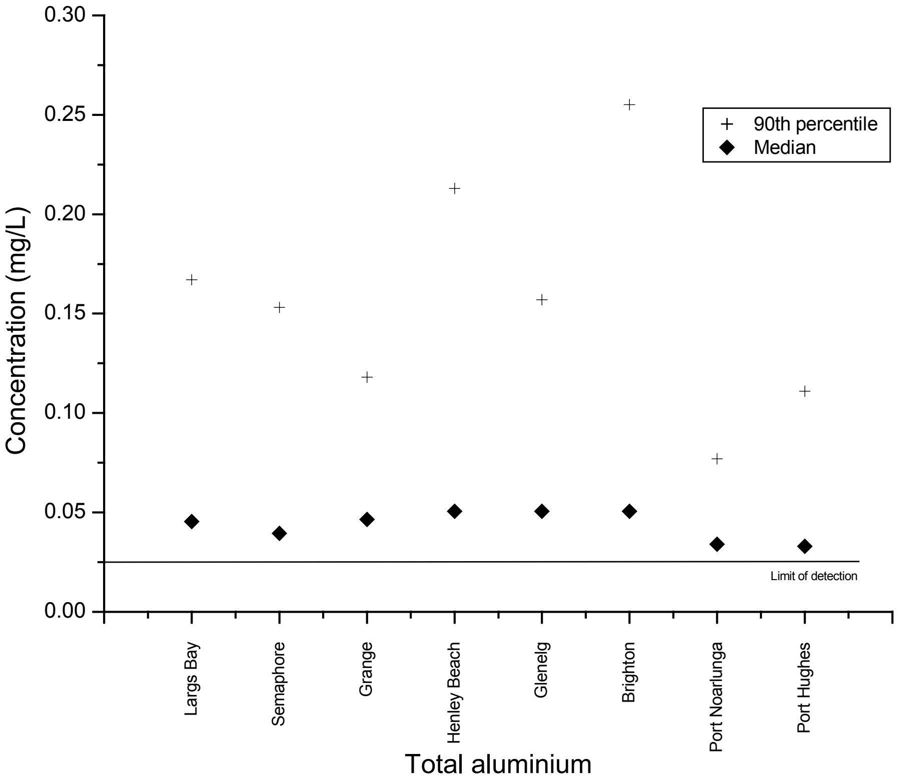


Figure 4 Median and 90th percentile for total aluminium 1995–2002

3.2.3 Chromium

Chromium is usually present naturally in very low concentrations in natural waters in two forms, chromium 3+ (trivalent) and chromium 6+ (hexavalent). Hexavalent chromium is more toxic to organisms than the trivalent form. Chromium is a non-essential element in plants; however, it is essential for carbohydrate metabolism in animals.

The EPA measures total chromium, including both Cr^{3+} and Cr^{6+}. It is assumed that the majority is present as Cr^{6+}, so the more conservative guideline is used to ensure adequate protection of organisms.

Sources

Chromium is used in electroplating and the manufacture of alloys, is also present in pigments, dyes, ceramics and fungicides, and is frequently used for corrosion control in cooling waters. Chromium has also been present historically in WWTP effluents. Bolivar WWTP discharged 1100 kg in the 1999–2000 National Pollutant Inventory (NPI) reporting year, but this amount has been drastically reduced over the last three years through strict trade-waste regulations that restrict chromium from industrial sites entering the sewer system.

Effects

While small concentrations of chromium are essential for some aspects of life, high concentrations can cause an increase in mucus production and gill damage and result in suffocation in fish. Chromium can be carcinogenic and can bioaccumulate in tissues of organisms. Its toxicity is affected by the hardness of the water as it can bind to calcium and magnesium ions and can also strongly bind to suspended solids and sediment.

Results—total chromium

Ecosystem criteria:	Good:	90th percentile ≤ 0.01 mg/L (modified from 0.0044 mg/L)
	Moderate:	90th percentile > 0.01 but 50th percentile ≤ 0.01 mg/L
	Poor:	50th percentile > 0.01 mg/L.

The analytical detection limit for chromium is currently 0.01 mg/L, which is much greater than the ANZECC guideline limit of 0.0044 mg/L. This means that when chromium is detected in a sample its concentration is greater than the guideline level. The classification was based on whether the 90th percentile was greater than or at the analytical detection limit for chromium.

Of the 598 measurements taken there was only four occasions when chromium was detected in a sample. Of these, there were three occasions (two at Henley Beach) when it exceeded the ANZECC guideline by more than ten times. This is likely to have caused toxic effects in some marine organisms. No sites were significantly different from the reference site or from each other.

The result from 29 November 2001 at Henley Beach is of concern due to the likely acute toxicity from a concentration of 0.09 mg/L. Studies have demonstrated toxicity of Cr^{6+} in marine waters at levels as low as 0.0025 mg/L for an annelid worm (*Neanthes* sp.) and 0.0048 mg/L for a dinoflagellate (ANZECC 2000). The result at Henley Beach is more than 20 times the ecosystem criterion of 0.0044 mg/L.

Aquaculture criteria:	Good:	90th percentile ≤ 0.02 mg/L
	Moderate:	90th percentile > 0.02 but 50th percentile ≤ 0.02 mg/L
	Poor:	50th percentile > 0.02 mg/L.

Despite the three occasions outlined above when chromium exceeded the aquaculture guideline of 0.02 mg/L, the water quality classifications still remain good due to the higher guideline figure for aquaculture.

Discussion and conclusions

Where available the EPA must use laboratory methods with reliable detection limits below the current guideline values in ANZECC (2000). This information will give marine scientists a better understanding of the concentration levels of these trace elements in the marine environment, and will aid in its management.

Table 4 Statistical summary of total chromium 1995–2002

	Mean (mg/L)	Standard deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality classification		Site comparison[a]
								Ecosystem	Aquaculture	
1 Largs Bay	0.010	0.002	0.010–0.011	0.01	0.010	0.030	78	Good	Good	n.s.
2 Semaphore	0.010	0	0.010–0.010	0.01	0.010	0.010	77	Good	Good	n.s.
3 Grange	0.010	0	0.010–0.010	0.01	0.010	0.010	77	Good	Good	n.s.
4 Henley Beach	0.011	0.009	0.009–0.013	0.01	0.010	0.090	79	Good	Good	n.s.
5 Glenelg	0.010	0	0.010–0.010	0.01	0.010	0.010	77	Good	Good	n.s.
6 Brighton	0.010	0	0.010–0.010	0.01	0.010	0.010	76	Good	Good	n.s.
7 Pt Noarlunga	0.010	0.001	0.010–0.011	0.01	0.010	0.017	79	Good	Good	n.s.
8 Pt Hughes	0.010	0	0.010–0.010	0.01	0.010	0.010	55	Good	Good	n.s.

(a) For pairwise site comparisons, 'n.s.' signifies the site is not significantly greater than any other site.

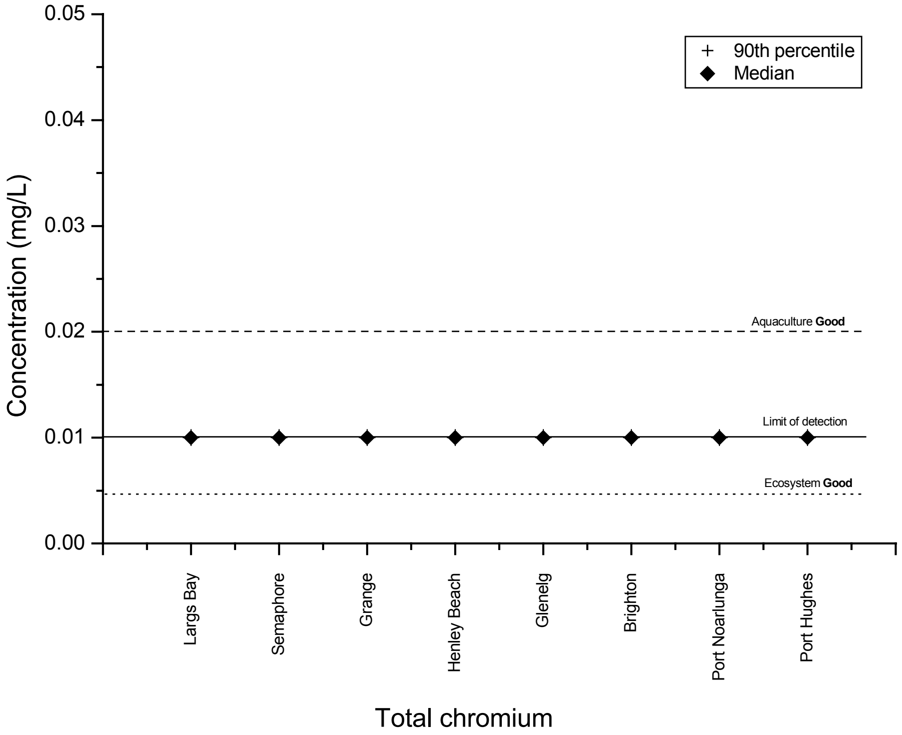


Figure 5 Median and 90th percentile for total chromium 1995–2002. Note that median and 90th percentiles are equal

3.2.4 Copper

Copper occurs naturally in the earth's crust and in waters at very low concentrations, and is an essential element to plants and animals. It will adhere to sediment and suspended solids and is generally not highly bioavailable. High sediment load/suspended solids will therefore reduce the acute toxicity of copper. Sediment contamination can be a problem as historical uses have caused localised contamination which may remain for long periods of time. Resuspension from activities such as dredging and changes in pH can remobilise copper and cause toxicity.

Sources

Copper can occur in the environment naturally through leaching and weathering of rocks and soils. Anthropogenic inputs are from stormwater due to wear in vehicle brake pads, linings and tyres; and from manufacturing and chemical processes. It is also used widely in household pipes, and can leach from antifouling paints on the hulls of boats. Industrial discharges of copper are primarily from WWTP effluents; Bolivar and Glenelg WWTPs discharged 1600 and 780 kg of copper respectively in the 2001–02 NPI recording period (NPI 2003). Copper is used as an algicide in most of the State's drinking water reservoirs to control algal growth. This can affect the marine environment when water is released from the reservoirs and finds its way to the gulf.

Copper is an essential trace element in both plants and animals; however, in high concentrations it can have toxic effects.

Effects

Copper toxicity is dependent on water hardness, and toxicity increases as water hardness decreases. Toxicity also depends on pH, with higher toxicity/bioavailability in more acidic waters. Copper is particularly toxic to fish and can affect organisms through diffusion across the gill membrane and also through ingestion. It has been shown to have reproductive effects at low concentrations. Copper will strongly bioaccumulate in the tissue of organisms and is stored mainly in the liver, brain, heart, kidney and muscles.

Studies have shown that copper is extremely toxic to other marine organisms, with crustaceans, corals and sea anemones being particularly sensitive. Acute toxicities range from 0.11–0.50 mg/L depending on exposure time and species, and sublethal effects are seen at concentrations as low as 0.01 mg/L (Brand & Ahsanullah 1992; Arnott & Ahsanullah 1979).

Results—total copper

Ecosystem criteria: Good: 90th percentile ≤ 0.01 mg/L (modified from 0.0013 mg/L)
Moderate: 90th percentile > 0.01 but 50th percentile ≤ 0.01 mg/L
Poor: 50th percentile > 0.01 mg/L.

The analytical detection limit for copper is currently 0.01 mg/L, which is much greater than the ANZECC guideline limit of 0.0013 mg/L. This means that when copper is detected in a sample its concentration is greater than the guideline level.

The maximum concentration measured was 0.027 mg/L at Port Hughes, which is more than 20 times the good guideline value. It is reasonable to assume that this concentration may have resulted in toxicity to some marine organisms.

No sites were significantly different from the reference site of Port Hughes or from each other.

Aquaculture criteria: Good: 90th percentile ≤ 0.01 mg/L (modified from 0.005 mg/L)
Moderate: 90th percentile > 0.01 but 50th percentile ≤ 0.01 mg/L
Poor: 50th percentile > 0.01 mg/L.

All sites are classified as good with respect to the protection of aquaculture. There were seven occasions when the concentration of copper exceeded the aquaculture guideline, three of these being at Port Hughes.

Discussion and conclusions

Of the 634 samples taken, copper concentration was greater than the detection limit in only 12. However, the analytical detection limit is more than seven times the criterion value of 0.0013 mg/L as set by the ANZECC guidelines. This is alarming due to the occasional high values seen at some locations and the potential for these elevated concentrations to be causing acute or chronic toxicity.

Three out of the 12 occasions when copper exceeded the criterion value occurred at Port Hughes, which suggests that the sources of copper in the marine environment may not be wholly anthropogenic.

Copper may be present in more samples at a level greater than this criterion value but it was not detected. Where available the EPA must use laboratory methods with reliable detection limits below the current guideline values in ANZECC (2000). This information will give marine scientists a better understanding of the concentration levels of these trace elements in the marine environment, and will aid in its management.

Table 5 Statistical summary of total copper 1995–2002

	Mean (mg/L)	Standard deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality Classification		Site comparison[(a)]
								Ecosystem	Aquaculture	
1 Largs Bay	0.010	0	0.01–0.01	0.010	0.010	0.010	80	Good	Good	n.s.
2 Semaphore	0.010	0	0.01–0.01	0.010	0.010	0.010	80	Good	Good	n.s.
3 Grange	0.010	0	0.01–0.01	0.010	0.010	0.010	80	Good	Good	n.s.
4 Henley Beach	0.010	0	0.01–0.01	0.010	0.010	0.013	80	Good	Good	n.s.
5 Glenelg	0.010	0.001	0.01–0.01	0.010	0.010	0.018	80	Good	Good	n.s.
6 Brighton	0.010	0.001	0.01–0.01	0.010	0.010	0.022	80	Good	Good	n.s.
7 Pt Noarlunga	0.010	0.001	0.01–0.01	0.010	0.010	0.016	80	Good	Good	n.s.
8 Pt Hughes	0.010	0.001	0.01–0.01	0.010	0.010	0.019	59	Good	Good	n.s.

(a)For pairwise site comparisons n.s. signifies the site is not significantly greater than any other site.

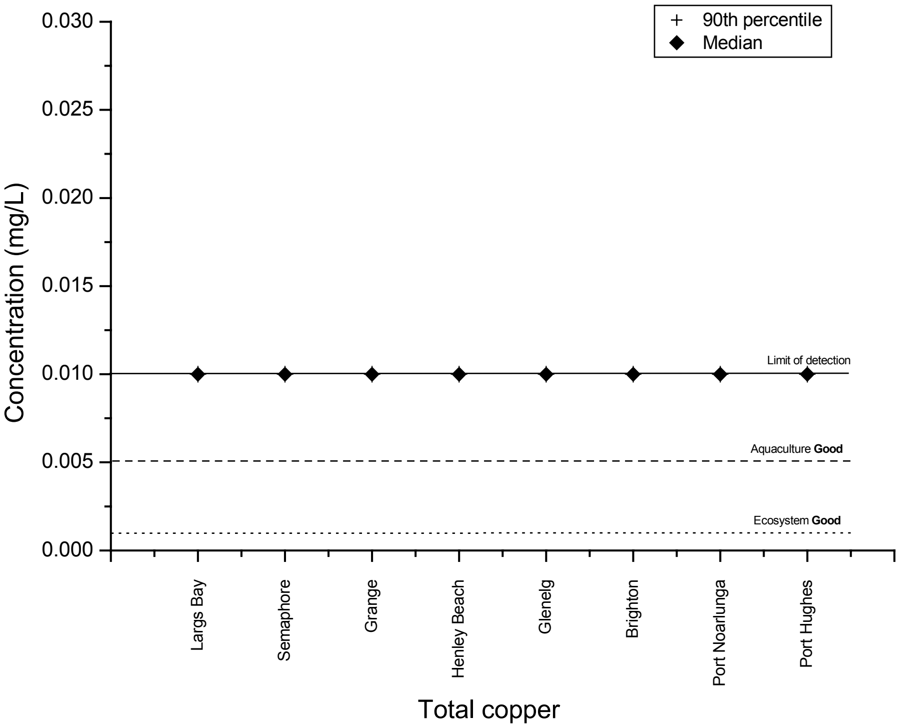


Figure 6 Median and 90th percentile for total copper 1995–2002. Note that median and 90th percentile are equal

3.2.5 Lead

Lead is a non-essential element for both plants and animals. Lead partitions primarily into sediments and is more bioavailable under lower pH, water hardness and the presence of organic matter. Lead can accumulate in sediments and remain there for many years, causing ecological problems in high exposure regions such as those used for duck shooting. This, however, is not likely to be a problem in this study area.

Sources

Lead in the marine environment can come from a wide range of sources—a primary route is through urban stormwater from everyday wear on vehicle brake pads and linings. Spillage and exhaust emissions from the use of lead as an anti-knocking agent in leaded fuel also contribute significantly to the load of lead entering waterways. Lead is used in car batteries, various metal products, ammunition, pipes and solder. Historically, it was also used by farmers in lead–arsenic insecticides and rodenticides. The NPI states that the Bolivar and Glenelg WWTPs discharged 140 and 44 kg of lead respectively into Gulf St Vincent in the 2001–02 reporting year (NPI 2003).

Although most results were undetectable by current analytical techniques, it is considered that the concentration of lead in the environment should fall as a result of the restriction of lead–based petrol and paints. This may be evident in an observed reduction in the concentrations of lead in tissues of marine organisms.

Effects

Lead can be bioconcentrated by organisms from water. However, it does not bioaccumulate due to its relative inability to be absorbed through the intestinal tract. Accordingly, lead concentrations in organisms generally decrease as position in the food chain increases. The majority of causes of lead poisoning in higher animals are a result of consuming paint flakes, fishing sinkers and lead shot.

Lead is a potent neurotoxin and adversely affects algal growth and invertebrate reproduction. In fish it can cause growth and reproduction problems, muscle and nerve degeneration and loss and, in high doses, mortalities. Lead can also cause cancer in animals; however, there is insufficient data on the effect of lead in humans (ANZECC 2000).

Results—total lead

Ecosystem criteria: Good: 90th percentile ≤ 0.005 mg/L (modified from 0.0044 mg/L)
Moderate: 90th percentile > 0.005 but 50th percentile ≤ 0.005 mg/L
Poor: 50th percentile > 0.005 mg/L.

As with both chromium and copper, the analytical detection limit for lead is marginally higher than the guideline limit. The classification system was based on the position of the median and 90th percentiles relative to the detection limit.

All sites were classified as good throughout the study period. All 90th percentiles were at the detection limit. The highest single measurements were recorded on 8 October 1997, with 0.013 mg/L at both Glenelg and Brighton.

Aquaculture criteria: Good: 90th percentile ≤ 0.005 mg/L (modified from 0.0044 mg/L)
Moderate: 90th percentile > 0.005 but 50th percentile ≤ 0.005 mg/L
Poor: 50th percentile > 0.005 mg/L.

All sites were at the detection limit for lead and therefore classified as good. The maximum result was 0.013 mg/L at both Brighton and Glenelg, which is approximately three times the good guideline value.

Discussion and conclusions

The analytical detection limit is slightly greater than the criterion value of 0.0044 mg/L as set by ANZECC 2000. Lead may be present in samples at a level greater than this criterion value but it could not be detected. Where available the EPA must use laboratory methods with reliable detection limits below the current guideline values in ANZECC (2000). This information will give marine scientists a better understanding of the concentration levels of these trace elements in the marine environment, and will aid in their management.

Table 6 Statistical summary of total lead 1995–2002

	Mean (mg/L)	Standard deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality classification		Site comparison[(a)]
								Ecosystem	Aquaculture	
1 Largs Bay	0.005	0.001	0.005–0.005	0.005	0.005	0.01	80	Good	Good	n.s.
2 Semaphore	0.005	0.001	0.005–0.005	0.005	0.005	0.012	80	Good	Good	n.s.
3 Grange	0.005	0.001	0.005–0.005	0.005	0.005	0.009	80	Good	Good	n.s.
4 Henley Beach	0.005	0.001	0.005–0.005	0.005	0.005	0.01	80	Good	Good	n.s.
5 Glenelg	0.005	0.001	0.005–0.005	0.005	0.005	0.013	80	Good	Good	n.s.
6 Brighton	0.005	0.001	0.005–0.005	0.005	0.005	0.013	80	Good	Good	n.s.
7 Pt Noarlunga	0.005	0.001	0.005–0.005	0.005	0.005	0.012	80	Good	Good	n.s.
8 Pt Hughes	0.005	0.001	0.005–0.005	0.005	0.005	0.008	59	Good	Good	n.s.

(a) For pairwise site comparisons n.s. signifies the site is not significantly greater than any other site.

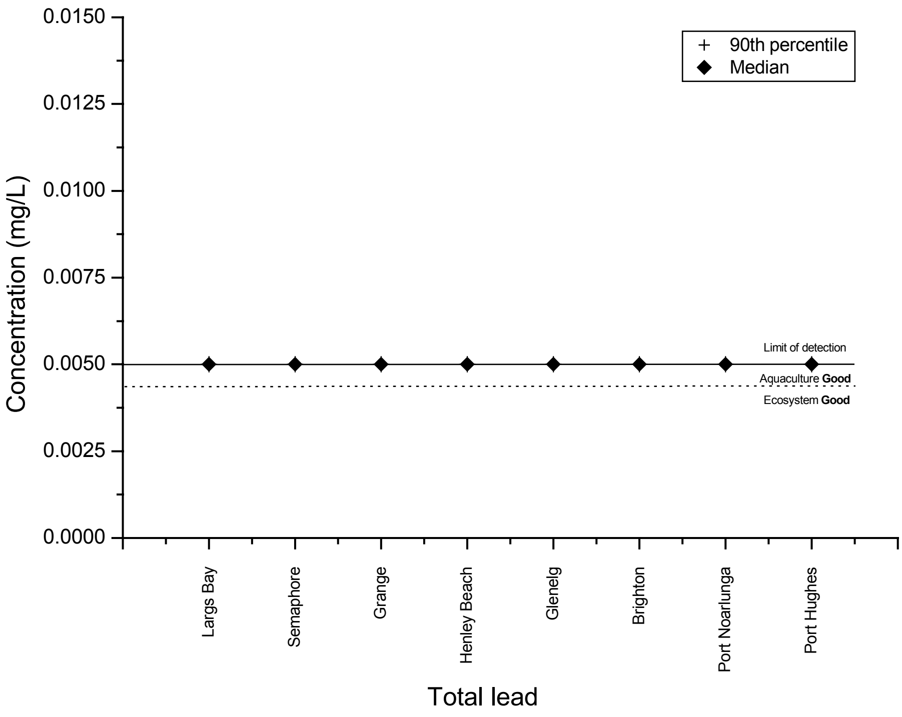


Figure 7 Median and 90th percentile for total lead 1995–2002. Note that median and 90th percentile are equal

3.2.6 Nickel

Nickel occurs naturally in surface waters from the weathering of minerals and rocks. It is primarily associated with abundant iron and manganese particles, which precipitate and absorb free nickel ions. Much of the nickel in the aquatic environment is therefore found in sediments.

Nickel is thought to be an essential element for some plants and animals.

Sources

Nickel is naturally abundant in the environment, and is especially widespread in the seabed. Other natural sources of nickel include geological sources associated with historical volcanic activity. Anthropogenic sources include combustion processes such as the burning of coal and other fossil fuels (e.g. diesel and petrol). Nickel can enter the marine environment in stormwater, which collects it from roads and other impervious surfaces. It is also used in the manufacture of stainless steel, batteries and computer components, and wastes from these processes and products are potential nickel sources.

Effects

Nickel is considered to be both a mutagen (causes mutations) and a carcinogen in animal and human cells (IPCS 1991). In the aquatic environment it has been observed to cause tissue damage and a reduction in growth. Molluscs and crustaceans appear to be more sensitive than other organisms in the marine environment. However, the toxicity of nickel is highly dependent on the hardness of the water, with the highest toxicities being recorded in the softest waters.

Nickel does not appear to bioaccumulate in marine organisms.

Results—total nickel

Ecosystem criteria: Good: 90th percentile ≤ 0.007 mg/L
Moderate: 90th percentile > 0.007 but 50th percentile ≤ 0.007 mg/L
Poor: 50th percentile > 0.007 mg/L.

The nickel concentrations at most sites were classified as good. However, a slight increase around the more densely populated beaches of Glenelg and Brighton, and also at Port Noarlunga, led to these being classified as moderate. The highest single result occurred at Port Noarlunga with 0.075 mg/L, which is more than ten times the good criterion value. Studies have shown that while highly dependent on salinity, nickel can be acutely toxic to marine organisms at concentrations in the range 0.05–1.1 mg/L (ANZECC 2000).

Aquaculture criteria: Good: 90th percentile ≤ 0.1 mg/L
Moderate: 90th percentile > 0.1 but 50th percentile ≤ 0.1 mg/L
Poor: 50th percentile > 0.1 mg/L.

Nickel concentrations were classified as good for aquaculture use at all sites along the metropolitan coast. There were no occasions when the nickel concentration exceeded the aquaculture guideline value.

Discussion and conclusions

The results for nickel show an increase in concentration around the major urban centre of Adelaide when compared with other sites sampled. Although this increase was not statistically significant it was sufficient to change the classification of the sites. A possible explanation for the small increase could be the high prevalence of stormwater drains, river mouths and the Glenelg WWTP in the region. However, this may not be an indicator of urban pollution along the coast. The result for Port Hughes is similar to the results from the more densely populated areas such as Glenelg (0.007 mg/L vs. 0.008 mg/L). This small difference could be attributed to several causes, including sampling and analytical variation.

Table 7 Statistical summary of total nickel 1995–2002

	Mean (mg/L)	Standard deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality classification		Site comparison[(a)]
								Ecosystem	Aquaculture	
1 Largs Bay	0.006	0.002	0.005–0.006	0.005	0.007	0.014	80	Good	Good	n.s.
2 Semaphore	0.006	0.002	0.005–0.006	0.005	0.006	0.021	80	Good	Good	n.s.
3 Grange	0.006	0.002	0.005–0.006	0.005	0.005	0.014	80	Good	Good	n.s.
4 Henley Beach	0.006	0.003	0.005–0.007	0.005	0.007	0.032	80	Good	Good	n.s.
5 Glenelg	0.006	0.002	0.005–0.006	0.005	0.008	0.015	80	Moderate	Good	n.s.
6 Brighton	0.006	0.002	0.005–0.006	0.005	0.008	0.014	80	Moderate	Good	n.s.
7 Pt Noarlunga	0.007	0.008	0.005–0.009	0.005	0.008	0.075	80	Moderate	Good	n.s.
8 Pt Hughes	0.006	0.004	0.005–0.007	0.005	0.007	0.028	59	Good	Good	n.s.

(a) For pairwise site comparisons 'n.s.' signifies the site is not significantly greater than any other site.

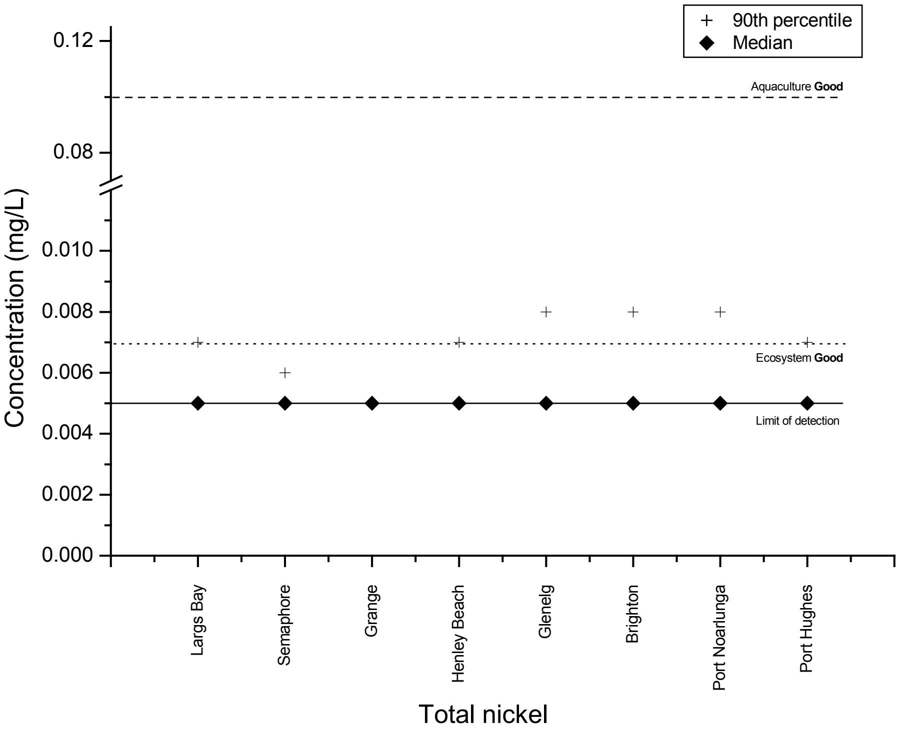


Figure 8 Median and 90th percentile for total nickel 1995–2002

3.2.7 Zinc

Zinc is an essential element for both plants and animals. Either too little or too much zinc can cause health problems in all forms of life. Its ability to pollute is usually closely linked to the presence of cadmium, lead and sometimes copper. Free zinc in the aquatic environment is predominantly in the more bioavailable Zn^{2+} form; however, this is usually in very low concentrations due to its strong tendency to form complexes with organic and inorganic compounds.

The EPA measures zinc as both total and soluble zinc. The measure of soluble zinc gives an indication of the approximate amount that is bioavailable to organisms in the marine environment, while total zinc measures all zinc, whether in soluble form, attached to particles or bonded to organic matter.

Sources

Zinc can enter the marine environment naturally through weathering of minerals and rocks, and through human influence. Zinc is present in urban stormwater from wear on tyres (about 1.5% Zn) and fuel combustion. It is a major constituent of galvanising the steel used in roofing iron—corrosion of the roofs will result in the release of zinc to the environment, as runoff from gutters and drainpipes finds its way into the stormwater. In regions with more acidic rain this may result in rainwater being unsuitable to drink due to high Zn and Cd concentrations; fortunately this is currently not the case in Adelaide. Zinc can also be present in herbicides and fertilisers. In the 2001–02 NPI reporting year the Bolivar WWTP discharged 1700 kg of zinc compounds into the marine environment north of Adelaide (NPI 2003).

Effects

Even though zinc is an essential nutrient for both plants and animals, elevated zinc levels can cause reductions in growth, survival and reproduction in all types of organisms. As with most metals, zinc is predominantly partitioned into sediments rather than existing as free ions or complexes in the water column.

Zinc is readily bioaccumulated in marine organisms, potentially causing problems for higher animals, including humans, from eating contaminated organisms.

Results—total zinc

Ecosystem criteria:	Good:	90th percentile ≤ 0.015 mg/L
	Moderate:	90th percentile > 0.015 but 50th percentile ≤ 0.015 mg/L
	Poor:	50th percentile > 0.015 mg/L.

Total zinc concentrations are sufficiently high to classify water quality as poor for aquatic ecosystems at every site. Largs Bay was the site with the lowest concentration (0.059 mg/L), which is still four times the good criterion value. Port Hughes had the highest concentration with a 90th percentile of 0.108 mg/L, over seven times the criterion value, but all sites were much greater than the ecosystem criterion. There were numerous high results at all sites that exceeded the good criterion value by more than ten times, the highest single result (0.288 m/L) being at Port Hughes, almost 20 times the good criterion value.

No sites were significantly different from the reference site of Port Hughes or from each other.

Aquaculture criteria: Good: 90th percentile ≤ 0.01 mg/L (modified from 0.005 mg/L)
Moderate: 90th percentile > 0.01 but 50th percentile ≤ 0.01 mg/L
Poor: 50th percentile > 0.01 mg/L.

The limit used to classify total zinc for aquaculture use has been altered from the ANZECC guideline figure to reflect the elevated analytical detection limit. The criterion value for aquaculture is less than the ecosystem guideline due to the tendency of zinc to bioaccumulate, especially in shellfish. All sites were classified as poor for the protection of aquaculture. Of the 633 samples taken, 58% exceeded the aquaculture guideline.

Results—soluble zinc

There are no ANZECC guideline criteria for soluble zinc. In order to assess the impacts of soluble zinc specifically, monitoring data has been compared with the total zinc criterion of 0.015 mg/L for good ecosystem health. The intention of this is to investigate the potential for toxicity as the soluble form of zinc is the readily bioavailable form, and the concentrations seen would more directly show the environmental effects.

Measurements at seven out of eight sites were greater than the good criterion value and would have been classified as moderate. Brighton would be classified as poor due to a median of 0.016 mg/L, exceeding the criterion of 0.015 mg/L. The zinc results were highly variable, as seen in the large standard deviations (up to 0.026 mg/L). This variation is due to interferences in the analytical procedure by salts present in the marine waters; the EPA changed analytical procedures in November 2001 in an attempt to rectify this problem. The results from these analyses cannot therefore be compared to the existing results and have been omitted from this report.

Discussion and conclusions

No sites were significantly different from the relatively unaffected site at Port Hughes; however, Largs Bay was significantly different from Brighton. This would infer that the urbanisation of Adelaide and industrial discharges of zinc are not resulting in significantly higher concentrations in metropolitan waters when compared to Port Hughes.

Although the results for zinc show that the concentrations are high in the ambient waters of the gulf, this may not be an indicator of human pollution. Port Hughes, the site with the lowest amount of urban development, had the highest concentrations of both soluble and total zinc. This would seem to indicate that the zinc concentrations in the marine environment are due to natural origins from the weathering of rocks and soils.

Zinc has the ability to bioaccumulate in the tissues of organisms, especially shellfish. The intention of the aquaculture guideline for total zinc, in this instance, is for the protection of aquaculture species (particularly fish) and not for the protection of human consumers of seafood.

The bioavailability of zinc in the marine environment will determine whether the concentrations seen in these results will actually have an impact on marine organisms. Bioavailability depends on factors such as pH, hardness of the water, salinity and temperature. Site specific conditions such as these vary, as do the tolerances of the species exposed to zinc.

Table 8 Statistical summary of total zinc 1995–2002

	Mean (mg/L)	Standard deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality classification		Site comparison(a)
								Ecosystem	Aquaculture	
1 Largs Bay	0.031	0.039	0.022–0.041	0.019	0.059	0.235	67	Poor	Poor	n.s.
2 Semaphore	0.035	0.034	0.027–0.043	0.021	0.085	0.174	67	Poor	Poor	n.s.
3 Grange	0.036	0.041	0.026–0.046	0.023	0.068	0.275	67	Poor	Poor	n.s.
4 Henley Beach	0.037	0.039	0.028–0.047	0.024	0.085	0.228	67	Poor	Poor	n.s.
5 Glenelg	0.033	0.032	0.025–0.040	0.024	0.068	0.182	67	Poor	Poor	n.s.
6 Brighton	0.036	0.04	0.026–0.046	0.024	0.072	0.222	67	Poor	Poor	n.s.
7 Pt Noarlunga	0.032	0.038	0.023–0.041	0.017	0.07	0.187	67	Poor	Poor	n.s.
8 Pt Hughes	0.041	0.052	0.027–0.056	0.021	0.108	0.288	50	Poor	Poor	n.s.

(a) For pairwise site comparisons 'n.s.' signifies the site is not significantly greater than any other site.

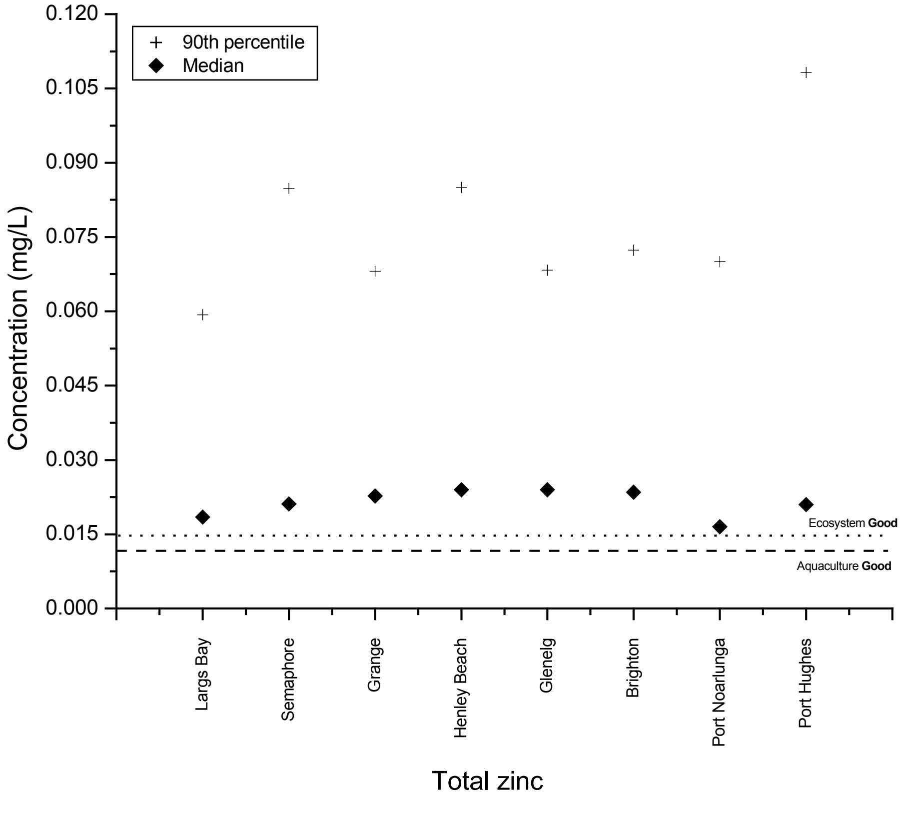


Figure 9 Median and 90th percentile for total zinc 1995–2002

Table 9 Statistical summary of soluble zinc 1995–2002

	Mean (mg/L)	Standard deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality classification		Site comparison[(a)]
								Ecosystem	Aquaculture	
1 Largs Bay	0.018	0.014	0.015–0.022	0.013	0.033	0.083	67	n.a.	n.a.	Site 1 >6
2 Semaphore	0.021	0.022	0.016–0.026	0.011	0.036	0.162	67	n.a.	n.a.	n.s.
3 Grange	0.021	0.016	0.017–0.025	0.013	0.040	0.083	67	n.a.	n.a.	n.s.
4 Henley Beach	0.021	0.015	0.017–0.025	0.014	0.039	0.069	67	n.a.	n.a.	n.s.
5 Glenelg	0.020	0.014	0.017–0.024	0.014	0.040	0.064	67	n.a.	n.a.	n.s.
6 Brighton	0.021	0.017	0.017–0.025	0.016	0.037	0.092	67	n.a.	n.a.	n.s.
7 Pt Noarlunga	0.022	0.024	0.016–0.028	0.011	0.045	0.125	67	n.a.	n.a.	n.s.
8 Pt Hughes	0.026	0.026	0.019–0.034	0.012	0.049	0.113	50	n.a.	n.a.	n.s.

(a) Friedman probability: $p < 0.001$ statistically significant differences between sites. The > symbol indicates that the measurement at the specified location is significantly greater than at certain other sites. For pairwise site comparisons 'n.s.' signifies the site is not significantly greater than any other site.

n.a. Criterion classification is 'not appropriate'. The ANZECC guidelines state there is insufficient reliable data to define a criterion for this parameter.

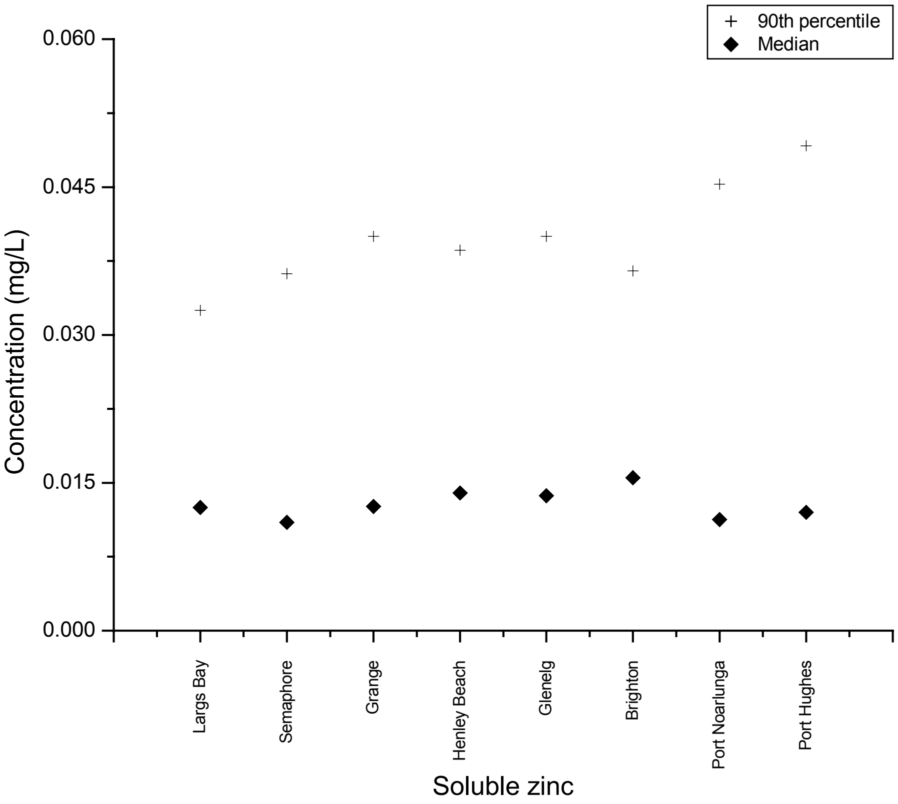


Figure 10 Median and 90th percentile for soluble zinc 1995–2002

3.2.8 Summary of metals

The water quality classifications for the protection of the marine ecosystem show that 73% of samples were good, 7% moderate and 20% poor. While there is no guideline for aluminium in marine waters, these results show soluble aluminium concentrations were generally at or close to the analytical detection limit. However, total aluminium results were relatively high. This may indicate that the aluminium is largely bound to sediment or particulates, resulting in relatively low bioavailablility, and the source may be natural geological deposits. There were occasional high copper concentrations, which is of concern due to the toxicity of copper and its ability to bioaccumulate in marine organisms. Nickel concentrations were moderate around the more urbanised sites (Glenelg and Brighton) but good in the less urbanised regions. This may be a result of inputs from wastewater from the Glenelg WWTP and from stormwater. Total zinc was also poor; however, soluble zinc concentrations were relatively low. Again, this is of concern due to the potential ability of zinc to be bioaccumulated. The difference in concentration between the two is more than likely due to zinc being bound to particulate matter and sediments, thereby reducing bioavailability.

Comparisons of classifications with the 1997 report are not valid due to differences in the criteria used to classify the metals. An additional confounding element is the large variation in the limit of detection reported by the analytical laboratory compared to that in the 1997 report. Several of the classifications used in the report are restrictive due to the detection limit being higher than the criterion value set by ANZECC (2000).

Table 10 Summary of water quality classifications for the protection of ecosystems—metals 1995–2002

	Total chromium	Total copper	Total lead	Total nickel	Total zinc
Largs Bay	Good	Good	Good	Good	Poor
Semaphore	Good	Good	Good	Good	Poor
Grange	Good	Good	Good	Good	Poor
Henley Beach	Good	Good	Good	Good	Poor
Glenelg	Good	Good	Good	Moderate	Poor
Brighton	Good	Good	Good	Moderate	Poor
Pt Noarlunga	Good	Good	Good	Moderate	Poor
Pt Hughes	Good	Good	Good	Good	Poor

Table 11 Summary of water quality classifications for the protection of aquaculture—metals 1995–2002

	Soluble aluminium	Total chromium	Total copper	Total lead	Total nickel	Total zinc
Largs Bay	n.c.	Good	Good	Good	Good	Poor
Semaphore	n.c.	Good	Good	Good	Good	Poor
Grange	n.c.	Good	Good	Good	Good	Poor
Henley Beach	n.c.	Good	Good	Good	Good	Poor
Glenelg	n.c.	Good	Good	Good	Good	Poor
Brighton	n.c.	Good	Good	Good	Good	Poor
Pt Noarlunga	n.c.	Good	Good	Good	Good	Poor
Pt Hughes	n.c.	Good	Good	Good	Good	Poor

The classifications for aquaculture protection show that 80% of samples were classified as good and 20% as poor. Soluble aluminium was unclassifiable due to problems with the analytical procedures. The poor zinc classifications are of concern due to the potential for zinc to be accumulated in tissues of organisms such as shellfish. The guideline value of 0.01 mg/L for zinc on this occasion is designed for the protection of aquaculture species (particularly fish and shellfish) rather than the protection of human health from ingestion of the food.

Three studies investigating the potential metal contamination of fish, molluscs and other invertebrates have shown that marine organisms are generally not at significant risk of bioaccumulating the metals covered in this report from pollution in Gulf St Vincent (EPA 2000; Maher 1986; Olsen 1983).

While the water quality aspects of aquaculture protection are important in themselves, it is also relevant to look at the actual and potential aquaculture growing areas. To date there are no significant commercial projects along the metropolitan coast or in the vicinity of Port Hughes, but the water quality data in this report may be useful in the planning of future aquaculture growing areas in the study region. There are small commercial cockle fishermen in the Port River, but results in another report (EPA 2002) would be more appropriate for the assessment of water quality in this region.

Appendix 1 shows the metal concentrations of all parameters over the eight-year study period. They indicate that there are no significant seasonal or annual trends in any of the measured metals during that time.

3.3 Nutrients

Nutrients are required by aquatic organisms for growth and reproduction. Aquatic plants and algae also need other suitable resources and conditions to grow and reproduce including carbon dioxide, trace elements, sufficient light, an appropriate temperature range and the right hydraulic conditions. If these basic requirements are met, a lack of nitrogen or phosphorus is the most likely factor to limit algal growth, particularly in the naturally nutrient-low coastal waters of South Australia. Nutrients can be present in soluble, particulate, organic and inorganic forms. The bioavailability of different forms varies; transformation from one form to another depends on the physical and chemical conditions present in waters and sediments, and is often mediated by biological processes.

Classification of nutrients

Water quality classifications are based on two environmental values: the protection of the aquatic ecosystem and the protection of aquaculture. The classification of nutrient data for both of these environmental values uses the trigger values in the ANZECC guidelines. The data is classified using the 90th percentile and median (50th percentile) compared to the single trigger value, as follows:

Good:	Water quality is good if the 90th percentile is less than or equal to the trigger value (see table 3.3.8 in ANZECC 2000).
Moderate:	The 90th percentile is greater than, but the 50th percentile is less than or equal to, the trigger value.
Poor:	Water quality is poor if the 50th percentile is greater than the trigger value.

If the results show the water quality measurement is greater than the trigger value, further investigation may be required to ascertain the nature of the high results. There may be several reasons including industrial discharges, urban stormwater or an environmental anomaly such as naturally high concentrations (e.g. an upwelling). In this case a new 'site specific' trigger value may be required to evaluate data in the future.

Sources

In the majority of cases the sources and effects of nutrients are the same for each nutrient. For this reason the sources and effects of nutrients are described at the start of this section instead of under each specific compound.

Land-based discharges such as sewage effluent, urban stormwater runoff, nutrient leaching and fertilisers from agricultural land, and runoff from industries, as well as marine-based aquaculture, can contribute nutrients to the marine environment. By far the majority of the land-based load comes from the three coastal WWTPs. In the 2001–02 NPI reporting year, Glenelg WWTP discharged 520 t of total nitrogen (N) and 150 t of total phosphorus (P) into the marine environment offshore from Glenelg (NPI 2003). Similarly, Christies Beach WWTP discharged 230 t of total N and 72 t of total P into the waters off Christies Beach. Historically, Bolivar WWTP has discharged the highest load of nutrients into the Gulf St Vincent. However, ongoing Environment Improvement Programs (EIP) have reduced the discharge at Bolivar from 1000 t of total N and 150 t of total P in 2000–01 to 480 t of total N and 130 t of total P in 2001–02. While this is more than a 50% reduction in total N load discharged, there is still a significant nutrient load discharged into the gulf.

It is believed that the flow from the Port River has a small but relevant effect on the northern sites in this study. The impacts of these discharges are detailed in other reports (EPA 1997b, 2002) and are therefore not addressed here.

While the WWTPs are significant point sources of nutrients, urban stormwater diffusely contributes more total N than any single WWTP in Adelaide. It is estimated that urban stormwater from Adelaide contributes approximately 550 t of total N each year and 64 t of total P (NPI 2003). This mainly comes from the use of fertiliser on rural and household properties; deposition of oxides of nitrogen emitted from automotive exhausts; and oxidised nitrogen from organic matter in soils, plant and animal material associated with agricultural land uses.

Effects

Generally, nutrients are not directly toxic to organisms, with the exception of ammonia (see later). An increase in nutrients (nitrogen and phosphorus compounds) causes an increase in growth of algae. In a nutrient enriched environment, algae often dominate an ecosystem and can cause an algal bloom, which can result in a loss of habitat and ecosystem degradation through smothering and competition for light and space. Additionally, algal blooms may cause fish kills and other mortalities through stripping the water column of oxygen. An increase in algal growth can also have more subtle effects such as a reduction in the clarity of the water due to higher numbers of algal cells in suspension. This reduces the photosynthetic capability of the seagrass and macroalgae.

Nutrient enrichment of Gulf St Vincent has resulted in an increase in the growth of epiphytic algae, causing smothering of seagrass and a reduction in the amount of light available. This makes the seagrass susceptible to breakage and more vulnerable to other environmental stresses such as erosion and storms (Seddon 2002), and has contributed to the loss of over 4000 ha of seagrass and the degradation of subtidal reefs (EPA 1998, 2003). Sand erosion (called blowouts) can further undermine and erode seagrass beds. Once lost from an area, it may take many years to regenerate.

3.3.1 Total nitrogen (N)

Nitrogen undergoes many transformations in the natural environment through processes involving bacteria and other organisms. Total N is a measure of all the nitrogen available to aquatic plants and animals and takes into account all the different forms of nitrogen in the system. In this report total N is the sum of oxidised nitrogen (nitrate and nitrite) plus total Kjeldahl nitrogen (TKN), but does not include the very small amount of nitrogen present as elemental nitrogen (N_2).

Results—total nitrogen

Ecosystem criteria:	Good:	90th percentile ≤ 1.0 mg/L
	Moderate:	90th percentile > 1.0 but 50th percentile ≤ 1.0 mg/L
	Poor:	50th percentile > 1.0 mg/L.

All sites were classified as good when compared to the ecosystem guideline of 1.0 mg/L.

Henley Beach had the highest median concentration of total N along the coast (0.306 mg/L), which is less than one-third of the ecosystem guideline. Port Noarlunga had the lowest ambient total N concentration of 0.176 mg/L. Port Hughes had the highest variability in total N concentration, with three samples greater than the good guideline value of 1.0 mg/L and a highest single measurement of 2.25 mg/L.

The results for total N show a significant increase in the nitrogen concentration at Grange and Henley Beach when compared to all other sites. Port Noarlunga was significantly less than any other site. Total N was not calculated in the 1997 report; however, 90th percentiles and medians were calculated—compared to current values, it appears that the levels of total N have fallen since December 1997.

Discussion and conclusions

While there is a significant difference in total N at Grange and Henley Beach compared to the other sites, the concentrations are still much less than the ecosystem guideline of 1.0 mg/L. Total N concentrations have fallen over time, as shown in Appendix 1, although this is considered to be probably due to changes in analytical techniques than to reductions in pollution loads.

SA Water is the major contributor of nitrogen to the marine environment through WWTP effluents discharging along the coast.

The high variability at Port Hughes may be due to agricultural runoff entering the marine environment after periods of heavy rain, coastal development and heavy caravan park usage in peak seasons.

Table 12 Statistical summary of total nitrogen 1995–2002

	Mean (mg/L)	Standard deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality classification		Site comparison[(a)]
								Ecosystem	**Aquaculture**	
1 Largs Bay	0.30016	0.1793	0.261–0.340	0.2339	0.59	0.867	82	Good	n.a.	Site 1 > 3, 4, 7
2 Semaphore	0.29412	0.17843	0.255–0.333	0.224	0.506	0.808	82	Good	n.a.	Site 2 > 3, 4, 7
3 Grange	0.34695	0.18707	0.306–0.388	0.282	0.589	0.905	82	Good	n.a.	Site 3 > 6, 7
4 Henley Beach	0.35622	0.19266	0.314–0.399	0.306	0.64	0.974	82	Good	n.a.	Site 4> 6, 7
5 Glenelg	0.31567	0.22053	0.267–0.364	0.25	0.57	1.337	82	Good	n.a.	Site 5 > 7
6 Brighton	0.29138	0.2006	0.247–0.335	0.225	0.577	0.97	82	Good	n.a.	Site 6 > 7
7 Pt Noarlunga	0.25188	0.1813	0.212–0.292	0.1767	0.558	0.813	82	Good	n.a.	n.s.
8 Pt Hughes	0.32736	0.36138	0.235–0.420	0.205	0.698	2.258	61	Good	n.a.	n.s.

(a) Friedman probability: $p < 0.001$ statistically significant differences between sites. The > symbol indicates that the measurement at the specified location is significantly greater than at certain other sites. For pairwise site comparisons 'n.s.' signifies the site is not significantly greater than any other site.

n.a. Criterion classification is 'not appropriate'. The ANZECC guidelines state there is insufficient reliable data to define a criterion for this parameter.

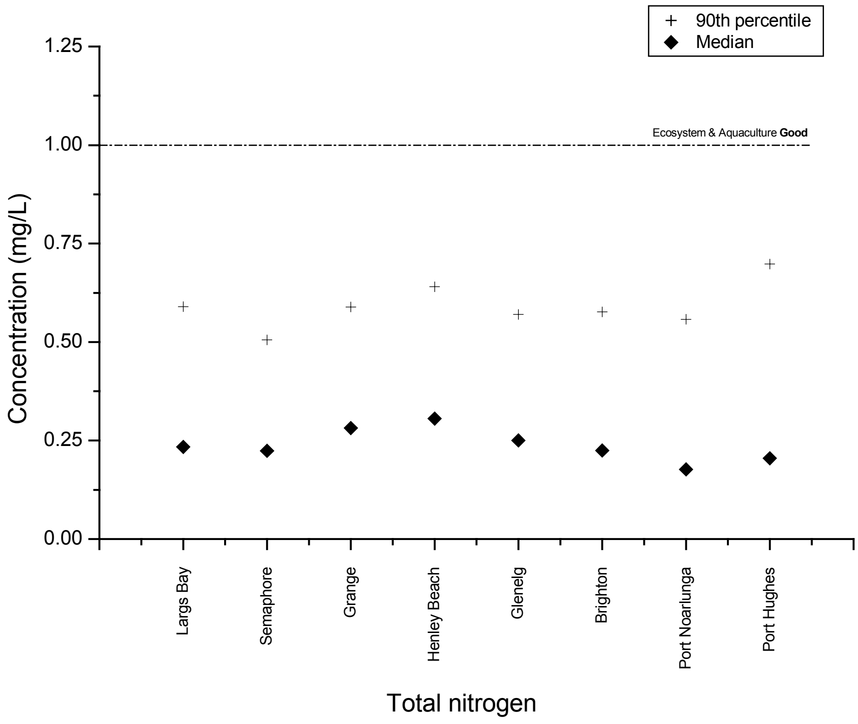


Figure 11 Median and 90th percentile for total nitrogen 1995–2002

3.3.2 Ammonia

Ammonia can act as both a nutrient and a toxicant. It provides a source of nitrogen to plants and animals and can be directly toxic to invertebrates and fish. Ammonia's toxicity is highly dependent on pH, temperature and salinity, and these parameters will also affect its longevity in marine waters. Ammonia can break down to form oxidised compounds of nitrogen such as nitrate and nitrite, which can result in eutrophication of waters. It does not bioaccumulate.

The EPA measures total ammonia, which includes both the ammonia (NH_3) and the ammonium (NH_4^+) forms. Both forms are readily available in the marine environment and the equilibrium between the two is dependent on pH, temperature and salinity. In sea water, at typical marine pH and salinity, the free NH_3 component is moderately toxic to marine organisms.

Sources

Ammonia is naturally present through the mineralisation of organic nitrogen and the reduction of nitrite in the marine environment in very small concentrations. It also represents an intermediate stage in nitrogen fixation—the conversion of atmospheric nitrogen (N_2) to fixed nitrogen and subsequent incorporation into organisms.

Human derived discharges of ammonia are of more concern in the marine environment as they generally far outweigh the natural processes and can cause eutrophication and acute toxicity to organisms. In the 2001–02 NPI reporting year, Christies Beach WWTP discharged 170 t, Glenelg WWTP 140 t and Bolivar WWTP 98 t of ammonia into Gulf St Vincent (NPI 2003). Ammonia in the marine environment can also result from agricultural runoff through the misuse of fertilisers.

Results—ammonia

Ecosystem criteria:	Good:	90th percentile ≤ 0.05 mg/L
	Moderate:	90th percentile > 0.05 but 50th percentile ≤ 0.05 mg/L
	Poor:	50th percentile > 0.05 mg/L.

Of the eight sites sampled, seven were classified as moderate, with only Largs Bay being classified as good. Grange was the most affected site with a median concentration of 0.034 mg/L. The 90th percentile at Glenelg was very close to the poor criterion value of 0.05 mg/L. The site with the lowest concentration of ammonia was Semaphore with a median concentration of 0.02 mg/L, which is the analytical detection limit for ammonia. However, the 90th percentile was greater than the good criterion value and it was thus classified as moderate.

Ammonia concentrations at Largs Bay, Semaphore, Brighton and Port Noarlunga were statistically significantly different from those at Grange, Henley Beach and Glenelg.

Aquaculture criteria:	Good:	90th percentile ≤ 0.1 mg/L
	Moderate:	90th percentile > 0.1 but 50th percentile ≤ 0.1 mg/L
	Poor:	50th percentile > 0.1 mg/L.

The ANZECC guidelines for the protection of aquaculture provide a good criterion for ammonia as 0.1 mg/L. All sites are classified as good for the protection of aquaculture. The difference between the guidelines for the protection of the ecosystem and those for aquaculture is due to the dual nature of ammonia: the ecosystem guideline is based on the action of ammonia as a nutrient, while for the protection of aquaculture the toxicity is of paramount concern.

Discussion and conclusions

The elevated concentrations measured at Glenelg, Henley Beach and Grange are not surprising, considering the amount of ammonia that is discharged via the Glenelg WWTP and the generally northward flow of water along the metropolitan coast. A possible explanation for the relatively low level at Brighton is that the Christies Beach WWTP ammonia discharge is located at a point along the coast that is sufficiently distant to allow ammonia to be taken up by algae and other aquatic organisms. Additionally, the northward trend in water reduces the likelihood of the ammonia reaching Port Noarlunga. However, the ammonia may be oxidising into other forms of nitrogen and contributing to nutrient enrichment and to impacts on seagrass and subtidal reefs in this region.

Table 13 Statistical summary of ammonia 1995–2002

	Mean (mg/L)	Standard deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality classification		Site comparison[(a)]
								Ecosystem	Aquaculture	
1 Largs Bay	0.032	0.028	0.026–0.038	0.024	0.050	0.202	81	Good	Good	Site 1 > 3, 4
2 Semaphore	0.028	0.025	0.022–0.034	0.020	0.055	0.163	81	Moderate	Good	Site 2 > 3, 4, 5
3 Grange	0.044	0.035	0.036–0.052	0.034	0.080	0.192	81	Moderate	Good	Site 3 > 6, 7
4 Henley Beach	0.042	0.031	0.035–0.048	0.030	0.080	0.188	81	Moderate	Good	Site 4 > 6, 7
5 Glenelg	0.041	0.038	0.033–0.050	0.025	0.096	0.185	81	Moderate	Good	Site 5 > 6
6 Brighton	0.027	0.025	0.021–0.032	0.020	0.056	0.170	81	Moderate	Good	n.s.
7 Pt Noarlunga	0.029	0.023	0.024–0.034	0.023	0.054	0.170	81	Moderate	Good	n.s.
8 Pt Hughes	0.033	0.042	0.022–0.044	0.020	0.067	0.275	59	Moderate	Good	n.s.

(a) Friedman probability: $p < 0.001$ statistically significant differences between sites. The > symbol indicates that the measurement at the specified location is significantly greater than at certain other sites. For pairwise site comparisons 'n.s.' signifies the site is not significantly greater than any other site.

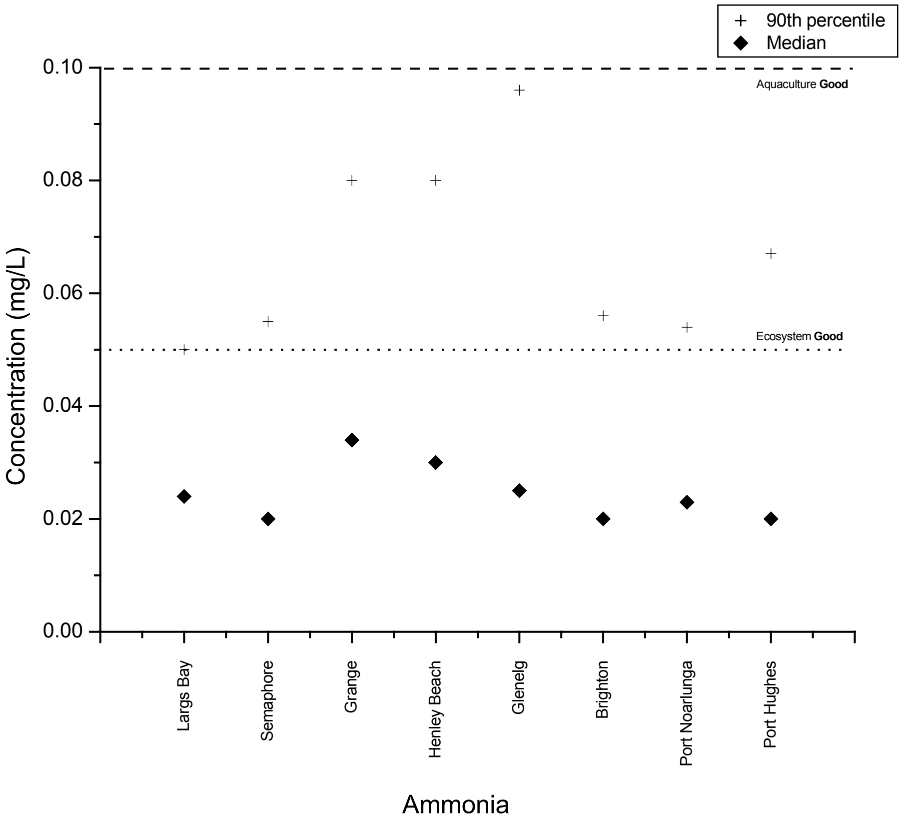


Figure 12 Median and 90th percentile for total ammonia 1995–2002

3.3.3 Oxidised nitrogen

Oxidised nitrogen is a measure of the compounds nitrate (NO_3^-) and nitrite (NO_2^-). Both are highly bioavailable to plants, nitrate being the more widespread form and nitrite often being oxidised further to nitrate under anaerobic conditions. Nitrate concentrations can be an order of magnitude higher than nitrite in the marine environment.

Results—oxidised nitrogen

Ecosystem criteria:	Good:	90th percentile ≤ 0.05 mg/L
	Moderate:	90th percentile > 0.05 but 50th percentile ≤ 0.05 mg/L
	Poor:	50th percentile > 0.05 mg/L.

Oxidised nitrogen concentrations at Glenelg, Henley Beach and Grange were elevated and classified as moderate. The remaining sites were classified as good. Henley Beach had the highest concentrations with a median of 0.03 mg/L and 28% of samples greater than the good criterion value. Port Hughes had the lowest median concentration of 0.005 mg/L, which is the analytical detection limit.

The oxidised nitrogen concentrations at all other sites, both to the north and south and the reference site of Port Hughes, were significantly ($p < 0.001$) less than at Grange, Henley Beach and Glenelg. This indicates that the discharges in this region are increasing the nutrient concentrations at these sites, which may be contributing to the loss of seagrass and the degradation of reef habitats.

Discussion and conclusions

The results seen at Grange, Henley Beach and Glenelg are not surprising, considering the amount of total nitrogen discharged into the gulf from the Glenelg WWTP and stormwater from the Torrens and Patawalonga rivers, and the general northward movement of water along the metropolitan coast.

Table 14 Statistical summary of oxidised nitrogen 1995–2002

	Mean (mg/L)	Standard deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality classification		Site comparison[(a)]
								Ecosystem	Aquaculture	
1 Largs Bay	0.013	0.013	0.010–0.016	0.006	0.0308	0.078	82	Good	n.a.	Site 1 > 3, 4, 5
2 Semaphore	0.013	0.016	0.009–0.017	0.006	0.030	0.110	82	Good	n.a.	Site 2 > 3, 4, 5
3 Grange	0.034	0.037	0.026–0.042	0.018	0.082	0.184	82	Moderate	n.a.	Site 3 > 7, 8
4 Henley Beach	0.037	0.035	0.030–0.045	0.030	0.074	0.164	82	Moderate	n.a.	Site 4 > 6, 7, 8
5 Glenelg	0.029	0.032	0.022–0.036	0.013	0.081	0.140	82	Moderate	n.a.	Site 5 > 6, 7
6 Brighton	0.019	0.022	0.014–0.024	0.007	0.049	0.110	82	Good	n.a.	n.s.
7 Pt Noarlunga	0.018	0.039	0.009–0.026	0.010	0.028	0.349	82	Good	n.a.	n.s.
8 Pt Hughes	0.015	0.043	0.004–0.026	0.005	0.015	0.306	60	Good	n.a.	n.s.

(a) Friedman probability: $p < 0.001$ statistically significant differences between sites. The > symbol indicates that the measurement at the specified location is significantly greater than at certain other sites. For pairwise site comparisons 'n.s.' signifies the site is not significantly greater than any other site.

n.a. Criterion classification is 'not appropriate'. The ANZECC guidelines state there is insufficient reliable data to define a criterion for this parameter.

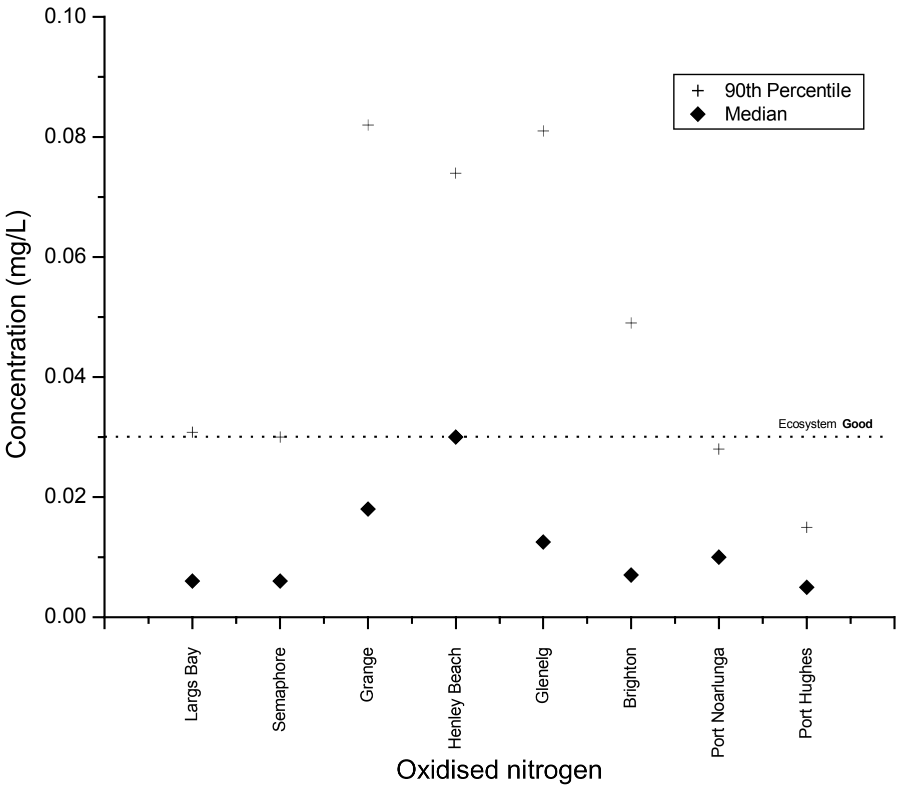


Figure 13 Median and 90th percentile for oxidised nitrogen 1995–2002

3.3.4 Phosphorus

Phosphorus is an essential element in both plants and animals, and is often a limiting nutrient for algal growth in aquatic systems, especially when there is plentiful nitrogen (however, this is generally not the case in Gulf St Vincent). Phosphorus is readily bioavailable to organisms in the phosphate form. However, this ion readily adsorbs to particulate matter and phosphorus is therefore often bound in sediments.

The sources of phosphorus in the marine environment are similar to the sources of nitrogen outlined earlier, i.e. primarily stormwater and WWTP effluent.

Results—total phosphorus

Ecosystem criteria: Good: 90th percentile ≤ 0.1 mg/L
Moderate: 90th percentile > 0.1 but 50th percentile ≤ 0.1 mg/L
Poor: 50th percentile > 0.1 mg/L.

All sites were classified as good. However, there were slight increases in total phosphorus concentration around Grange, Henley Beach and Glenelg. There were occasional high results seen at Port Hughes, resulting in a relatively high standard deviation for this site.

Discussion and conclusions

While the results were not statistically significant, measurements at Glenelg, Henley Beach and Grange were elevated when compared to other sites. This is consistent with the results of other nutrient parameters and could be linked to the Glenelg WWTP and major stormwater discharges in the region.

The high variability seen at Port Hughes may be due to occasional agricultural runoff entering the marine environment after periods of heavy rainfall, and a seasonal influx of people to caravan parks during peak seasons.

Table 15 Statistical summary of total phosphorus 1995–2002

	Mean (mg/L)	Standard deviation (mg/L)	95% confidence interval	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Water quality classification		Site comparison[(a)]
								Ecosystem	Aquaculture	
1 Largs Bay	0.039	0.040	0.030–0.048	0.03	0.058	0.32	82	Good	n.a.	n.s.
2 Semaphore	0.034	0.021	0.029–0.038	0.029	0.054	0.14	82	Good	n.a.	n.s.
3 Grange	0.051	0.073	0.035–0.067	0.04	0.077	0.68	82	Good	n.a.	n.s.
4 Henley Beach	0.044	0.018	0.040–0.048	0.04	0.072	0.091	82	Good	n.a.	n.s.
5 Glenelg	0.038	0.021	0.034–0.043	0.035	0.065	0.115	81	Good	n.a.	n.s.
6 Brighton	0.032	0.017	0.028–0.035	0.026	0.057	0.09	82	Good	n.a.	n.s.
7 Pt Noarlunga	0.025	0.012	0.022–0.028	0.02	0.035	0.095	82	Good	n.a.	n.s.
8 Pt Hughes	0.064	0.156	0.023–0.051	0.021	0.058	0.271	55	Good	n.a.	n.s.

(a) For pairwise site comparisons 'n.s.' signifies the site is not significantly greater than any other site.

n.a. Criterion classification is 'not appropriate'. The ANZECC guidelines state there is insufficient reliable data to define a criterion for this parameter.

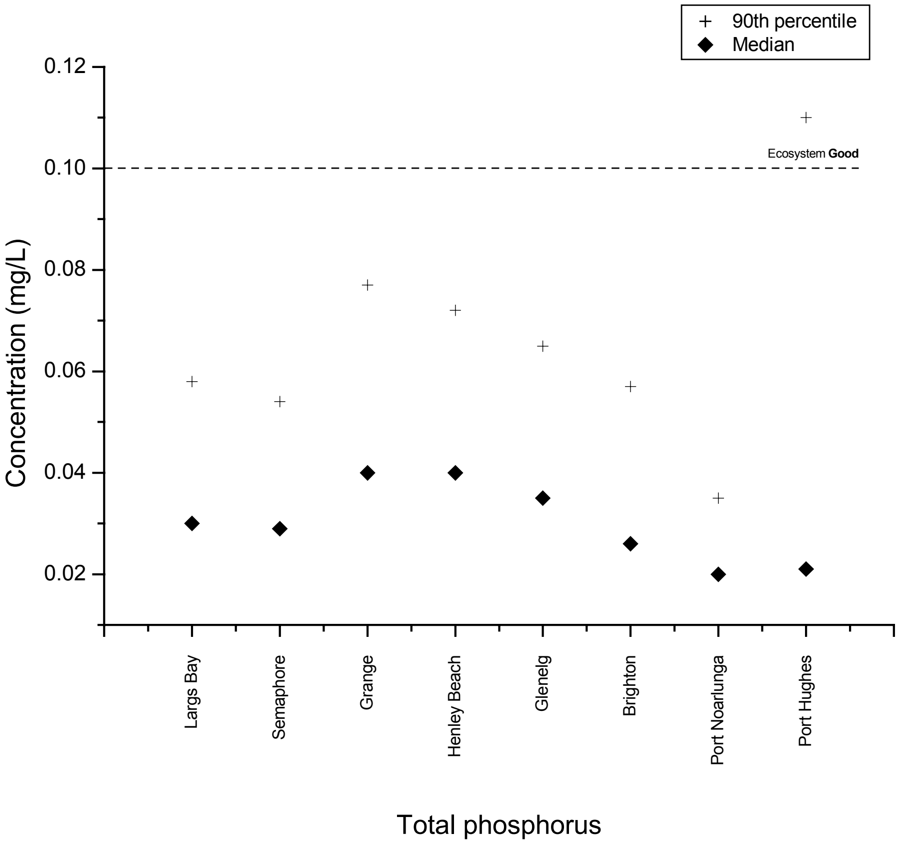


Figure 14 Median and 90th percentile for total phosphorus 1995–2002

3.3.5 Summary of nutrients

For the protection of ecosystems 65% of the nutrient water quality parameters were classified as good, while 35% were classified as moderate. Ammonia, which is both a toxicant and a nutrient, was the parameter of most concern, with seven out of eight sites classified as moderate and only Largs Bay classified as good.

Table 16 Summary of water quality classifications for the protection of ecosystems—nutrients 1995–2002

	Ammonia	Oxidised nitrogen	Total nitrogen	Total phosphorus
Largs Bay	Good	Good	Good	Good
Semaphore	Moderate	Good	Good	Good
Grange	Moderate	Moderate	Good	Good
Henley Beach	Moderate	Moderate	Good	Good
Glenelg	Moderate	Moderate	Good	Good
Brighton	Moderate	Good	Good	Good
Port Noarlunga	Moderate	Good	Good	Good
Port Hughes	Moderate	Good	Good	Good

Table 17 Summary of water quality classifications for the protection of aquaculture—nutrients 1995–2002

	Ammonia	Nitrate*	Nitrite*
Largs Bay	Good	Good	Good
Semaphore	Good	Good	Good
Grange	Good	Good	Good
Henley Beach	Good	Good	Good
Glenelg	Good	Good	Good
Brighton	Good	Good	Good
Port Noarlunga	Good	Good	Good
Port Hughes	Good	Good	Good

* Nitrate and nitrite were not specifically commented on in this report because they are incorporated into the oxidised nitrogen calculation and reporting on them individually would be repetitive. However, the individual results were taken into account and incorporated into results and statistical analyses.

The major nutrient input into Gulf St Vincent is from the three coastal WWTPs (Glenelg, Bolivar and Christies Beach), which cumulatively discharged 408 t of ammonia, 1,230 t of total nitrogen and 352 t of phosphorus in the 2001–02 NPI reporting year (NPI 2003). Each WWTP has an EIP, which is a program to reduce the amount of pollutants in the WWTP discharge. Over the last two reporting years Bolivar WWTP has reduced its discharge by 52%, which represents a reduction of 520 t of total nitrogen compounds entering the gulf from this plant. Continued compliance with EPA policies and EIPs will further reduce the discharges from all WWTPs in the State.

The second major nutrient input into Gulf St Vincent is urban stormwater, which contributes 550 t of nitrogen and 64 t of phosphorus into the marine environment each year. This discharge is much harder to control due to the diffuse nature of the pollution sources. Continuing work by the Catchment Water Management Boards and implementation of the EPA's *Environment Protection (Water Quality) Policy 2003* will reduce the pollution going down the drains and into the gulf waters.

The discharge of nutrients into marine waters can increase algal growth. Excessive algae can smother organisms and out-compete natural species for light and space. Nutrient enrichment has been blamed for the continuing loss of seagrass along the metropolitan coastline, where over 4000 ha of seagrass has been lost since the 1950s (EPA 1998). This loss is ongoing, with an estimated 100 ha of seagrass lost each year between North Haven and Sellicks Beach since 1996 (Cameron 2003). Nutrient enrichment has also been implicated in the degradation of Adelaide's subtidal reefs, especially in the northern region around Glenelg and Semaphore (EPA 2003), which are also the more affected sites in terms of water quality.

Appendix 1 shows the nutrient concentrations of all parameters over the 8-year study period. They indicate that there are no significant seasonal or annual trends in any of the measured nutrients during that time.

3.4 Biological parameters

3.4.1 Algae

Algae are a fundamental part of aquatic systems and form the base of the food chain that marine ecosystems need to function. They use photosynthesis to produce organic matter from inorganic matter. Despite the importance of algae, they can be a problem if they occur in high numbers and form algal blooms. Their growth can be increased by human impacts such as increases in nutrient loads and thermal pollution. Some species produce toxins that can bioaccumulate in shellfish, leading to restrictions on the harvesting of marine animals. Algae can reduce water clarity, thus degrading aesthetic values and recreational safety. Reduced water clarity can also have effects on seagrass and subtidal reefs through shading, reducing the photosynthetic capacity of the plants and organisms. Algal blooms flourish when there are sufficient nutrients, calm, stratified conditions, and optimal water temperature and salinity.

Biological indicators of water pollution are often considered to be the best indicators of impacts on aquatic environments. Biological communities are constantly exposed to the chemicals that are introduced into their local environment and will respond to any change in the bioavailability of the chemicals. Representative biological communities also help to reduce the uncertainty inherent in the occasional repeated sampling methods of chemical monitoring.

3.4.2 Chlorophyll *a*

Algal abundance can be estimated using a number of methods including cell counts and pigment analysis. The relationship between chlorophyll *a* and algal biomass is not perfect, but chlorophyll *a* is the major photosynthetic pigment in algae and therefore provides a good indicator of the amount of algae in the water.

Water quality classifications for chlorophyll *a* were determined by comparing the 90th percentile and median (50th percentile) with the trigger value in the ANZECC guidelines. This system is the same as that used to classify water quality results for nutrients.

Results—chlorophyll a

Ecosystem criteria:	Good:	90th percentile ≤ 1.0 µg/L
	Moderate:	90th percentile > 1.0 but 50th percentile ≤ 1.0 µg/L
	Poor:	50th percentile > 1.0 µg/L.

Chlorophyll *a* concentrations were classified as moderate at Port Noarlunga and Port Hughes, while results showed poor concentrations at all other locations. Henley Beach had the highest median concentration of 3.46 µg/L, while Grange recorded 3.4 µg/L. Port Hughes had the lowest concentration of chlorophyll *a* with 0.56 µg/L, and Port Noarlunga was also low with a median concentration of 0.88 µg/L. Throughout all the sites, approximately 70% of samples were greater than the good criterion value of 1.0 µg/L and 3% were greater than 10 µg/L, which is ten times the trigger value. The highest chlorophyll *a* concentration was recorded at Henley Beach on 7 May 1996 with 24.95 µg/L, nearly 25 times the good criterion value. It is surprising that concentrations at Glenelg were less than at Largs Bay and Semaphore. This may be the result of longer range effects of the Glenelg WWTP and warmer/shallower water promoting the growth of algae.

All sites were significantly different ($p < 0.001$) from the reference site of Port Hughes and from Port Noarlunga. Henley Beach and Grange were also significantly different from Glenelg.

Discussion and conclusions

The results clearly show an increase in chlorophyll *a* concentration in the regions northwards of Glenelg. It is not surprising that Henley and Grange have the highest concentrations as these are the locations likely to be most affected by the nutrients from the Glenelg WWTP outfall.

Aside from seasonal variation (likely to be due to warmer water temperatures and increased sunlight), there is no clear temporal trend in the data over the eight years of sampling.

While nutrient classifications were predominantly good to moderate across all sites, chlorophyll *a* was seen to be mostly poor. As stated above, biological indicators of water quality can be more sensitive than analytical techniques and are more representative of the water quality, especially over longer timeframes. Poor water quality classifications along the metropolitan coast are consistent with the responses of other biological systems, such as the loss of seagrasses and degradation of subtidal reefs in the regions around Glenelg and Henley Beach.

Table 18 Statistical summary of chlorophyll *a* 1995–2002

	Mean (µg/L)	Standard deviation (µg/L)	95% confidence interval	Median (µg/L)	90th percentile (µg/L)	Max (µg/L)	Number of samples	Water quality classification		Site comparison[(a)]
								Ecosystem	Aquaculture	
1 Largs Bay	3.34	2.54	2.74–3.93	2.55	6.63	11.19	72	Poor	n.a.	Site 1 > 7, 8
2 Semaphore	2.78	2.00	2.31–3.25	2.24	4.40	11.40	72	Poor	n.a.	Site 2 > 7, 8
3 Grange	4.36	3.24	3.60–5.12	3.40	7.28	16.92	72	Poor	n.a.	Site 3 > 5, 7, 8
4 Henley Beach	4.54	4.28	3.53–5.54	3.46	8.32	24.95	72	Poor	n.a.	Site 4 > 5, 6, 7, 8
5 Glenelg	2.55	2.14	2.04–3.05	1.92	5.22	9.60	72	Poor	n.a.	Site 5 > 7, 8
6 Brighton	2.77	3.41	1.97–3.57	1.31	7.45	18.61	72	Poor	n.a.	Site 6 > 7, 8
7 Pt Noarlunga	1.15	0.92	0.94–1.37	0.88	2.23	6.13	72	Moderate	n.a.	n.s.
8 Pt Hughes	0.80	0.94	0.55–1.04	0.56	1.20	5.57	60	Moderate	n.a.	n.s.

(a) Friedman probability: $p < 0.001$ statistically significant differences between sites. The > symbol indicates that the measurement at the specified location is significantly greater than at certain other sites. For pairwise site comparisons 'n.s.' signifies the site is not significantly greater than any other site.

n.a. Criterion classification is 'not appropriate'. The ANZECC guidelines state there is insufficient reliable data to define a criterion for this parameter.

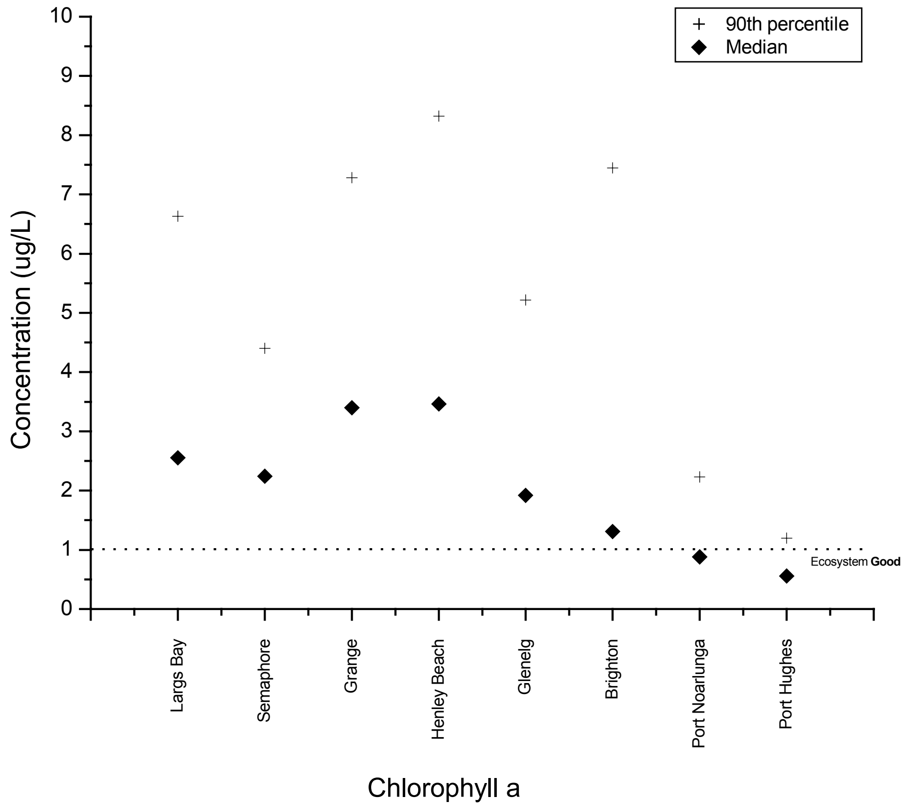


Figure 15 Median and 90th percentile for chlorophyll *a* 1995–2002

3.4.3 Microbiology

'Environmental' micro-organisms are ubiquitous and can occur in very high numbers. Many of these organisms play essential roles in the cycling of nutrients, energy and carbon in healthy aquatic ecosystems, and many higher animals use them as a food source. However, some micro-organisms may compromise environmental values, particularly the recreational use of water. Some bacteria, viruses and protozoans are disease causing (pathogenic). Unfortunately, it is difficult to isolate, culture and identify many of these pathogens so indicator microbes are used to assess microbiological water quality. Faecal coliforms, *Escherichia coli* (*E. coli*), faecal streptococci and enterococci all occur in the digestive tracts of warm-blooded animals and are good indicators of the risk of more dangerous pathogens.

Classification of microbiology

The results from the metropolitan coastal waters have been compared against NHMRC guidelines (NHMRC 1996), which are designed to protect people during direct contact with water through activities such as swimming, bathing and diving.

Good:	Water quality is good if the median is less than or equal to the lower NHMRC guideline.
Moderate:	The median is between the lower guideline and the upper guideline.
Poor:	Water quality is poor if the median is greater than the upper guideline.

Sources

The original source of these organisms is generally faecal contamination from humans or other mammals and birds. Wastewater and sewage outfalls, stormwater from creeks and drains, septic tank leaks and boats can all transfer this contamination to natural waters. Discharges from the WWTPs are chlorinated but this does not eliminate all bacteria. The majority of micro-organism contamination along Adelaide's coastline occurs after periods of heavy rain, when accumulated faecal material is washed into waterways and ultimately ends up in the gulf waters.

Effects

These micro-organisms generally have little impact on marine ecosystem health; however, they are indicators of the possible presence of human pathogens that commonly cause gastrointestinal, eye, ear, nose and throat infections. Examples of these pathogens include viruses, bacteria such as *Salmonella* and *Hepatitis,* and protozoa such as *Cryptosporidium* and *Giardia.* They can be taken up by humans through primary contact activities via ingestion, inhalation or breaks in the skin.

3.4.4 Faecal coliforms

Faecal coliforms are found in large numbers in the intestinal tracts of humans and other warm-blooded animals. While some may be of environmental origin, they are a good indicator of recent faecal contamination. They die off more rapidly in marine waters than some other micro-organisms such as viruses and protozoa.

Results—faecal coliforms

Recreation criteria: Good: Median ≤ 150 cells per 100 mL
Moderate: Median > 150 but ≤ 600 cells per 100 mL
Poor: Median > 600 cells per 100 mL.

All water quality classifications were good and there were no occasions when the results were greater than the poor guideline value. However, the results for faecal coliforms show that there is a slight increase in concentration in the Glenelg, Brighton, Henley Beach and Grange region compared with other sites. Port Hughes had the highest results with a 90th percentile of 21 cells per 100 mL and a highest count of 510 cells per 100 mL, although this was not greater than the poor guideline value of 600 cells per 100 mL.

Discussion and conclusions

Water quality classifications have not changed since the last EPA report in 1997; however, results show a decrease in faecal coliform concentrations along the coast, with several sites having large reductions in the medians and 90th percentiles. In 1997 the average of the 90th percentiles was 17 cells per 100 mL, while in 2002 the average was 7 cells per 100 mL. This may be due to reduction through pollution management by various parties, but it may also be due to a larger sample size reducing the variability in the results. Small numbers of micro-organisms in marine waters are normal, reflecting a range of environmental sources, and are not considered a threat to human health.

The occasional high results at Port Hughes are of concern. The sources of microbial contamination are likely to be overflow from septic tanks, agricultural runoff, or animal in origin, e.g. birds at the sampling location.

Table 19 Statistical summary of faecal coliforms 1995–2002

	Geometric Mean (mg/L)	95% confidence interval (GM_L–GM_U)	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Samples Exceeding 600 cells (per 100 mL)	Water quality classification –recreation	Site comparison[(a)]
1 Largs Bay	0.998	0.571–1.542	0	8	100	82	0	Good	n.s.
2 Semaphore	0.495	0.271–0.760	0	5	24	82	0	Good	Site 2 > 4, 5, 6
3 Grange	1.164	0.697–1.761	0	6	310	81	0	Good	n.s.
4 Henley Beach	1.449	0.949–2.077	1	8	110	81	0	Good	n.s.
5 Glenelg	2.125	1.454–2.979	1	14	140	81	0	Good	Site 5 > 7
6 Brighton	1.683	1.153–2.343	1	12	60	81	0	Good	n.s.
7 Pt Noarlunga	0.916	0.625–1.259	1	4	16	82	0	Good	n.s.
8 Pt Hughes	0.805	0.351–1.411	0	21	510	60	0	Good	n.s.

(a) Friedman probability: $p < 0.001$ statistically significant differences between sites. The > symbol indicates that the measurement at the specified location is significantly greater than at certain other sites. For pairwise site comparisons 'n.s.' signifies the site is not significantly greater than any other site.

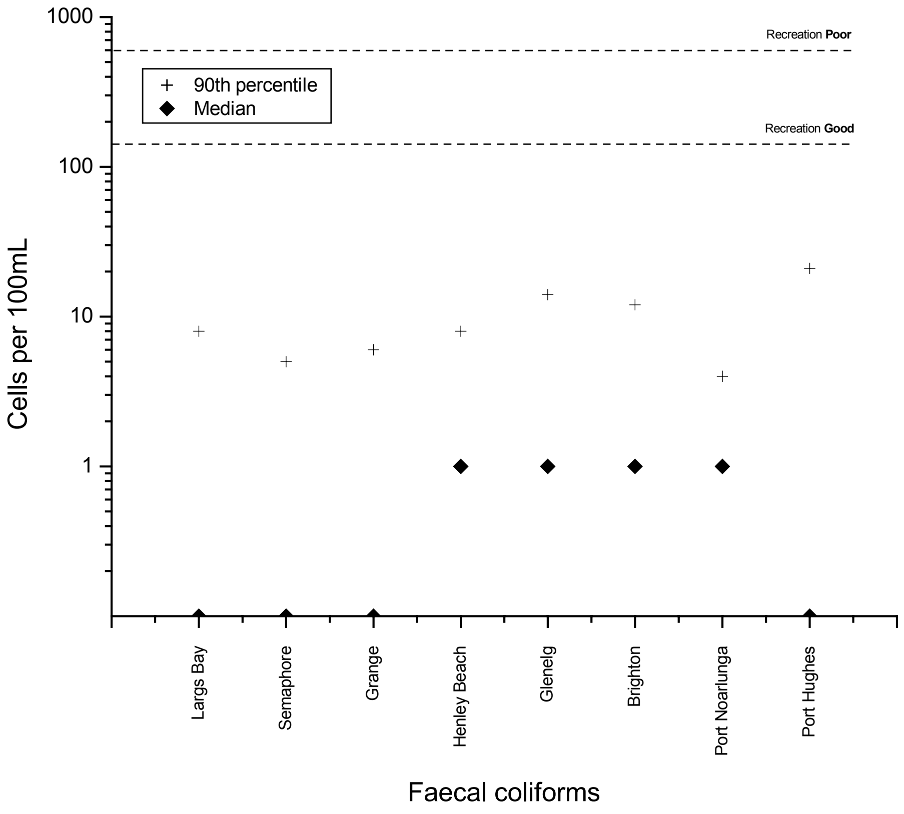


Figure 16 Median and 90th percentile for faecal coliforms 1995–2002

3.4.5 *Escherichia coli (E. coli)*

E. coli is a major subset of faecal coliforms, making up about 97% of all faecal coliform bacteria in human faecal matter. It can originate from any warm-blooded animal including humans, horses, cows and birds. *E. coli* commonly enters waterways in runoff after heavy rains and, as a subset of faecal coliforms, does not thrive in marine waters and usually dies off quickly.

Results—Escherichia coli

Recreation criteria: Good: Median ≤ 150 cells per 100 mL
Moderate: Median > 150 but ≤ 600 cells per 100 mL
Poor: Median > 600 cells per 100 mL.

All sites were classified as good when compared to the NHMRC guidelines. There were no samples that were greater than the poor guideline value of 600 cells per 100 mL. Statistically, no sites were significantly different from the reference site or from each other. Glenelg had the highest concentrations of *E. coli* along the coast, with a 90th percentile of 9.2 cells per 100 mL and a geometric mean of 1.71 cells per 100 mL, but this is much less than the guideline value for safe primary contact activities. Port Hughes had the highest 90th percentile with nearly 20 cells per 100 mL, but the site also had a low geometric mean, indicating that it was subject to large variation.

Discussion and conclusions

The results for *E. coli* show that the water quality along Adelaide's metropolitan coast is good and there are very few risks from primary contact activities. The occasional high results seen at Port Hughes are probably due to runoff from agricultural regions, animals such as birds on the jetty, or septic tank overflows.

The EPA did not report specifically on *E. coli* in the 1997 report.

Table 20 Statistical summary of Escherichia coli 1995–2002

	Geometric mean (mg/L)	95% confidence interval (GML-GMU)	Median (mg/L)	90th percentile (mg/L)	Max (mg/L)	Number of samples	Samples exceeding 600 cells (per 100 mL)	Water quality classification –recreation	Site classification[(a)]
1 Largs Bay	0.60	0.30–0.97	0.00	3.40	80	40	0	Good	n.s.
2 Semaphore	0.37	0.17–0.61	0.00	2.30	24	40	0	Good	n.s.
3 Grange	0.65	0.35–1.00	0.00	4.40	63	39	0	Good	n.s.
4 Henley Beach	0.69	0.40–1.02	0.00	4.40	40	39	0	Good	n.s.
5 Glenelg	1.71	1.21–2.32	1.00	9.20	36	39	0	Good	n.s.
6 Brighton	1.00	0.68–1.38	1.00	4.00	20	39	0	Good	n.s.
7 Pt Noarlunga	1.05	0.75–1.41	1.00	3.20	13	40	0	Good	n.s.
8 Pt Hughes	0.85	0.39–1.46	0.00	19.80	120	32	0	Good	n.s.

(a) For pairwise site comparisons 'n.s.' signifies the site is not significantly greater than any other site.

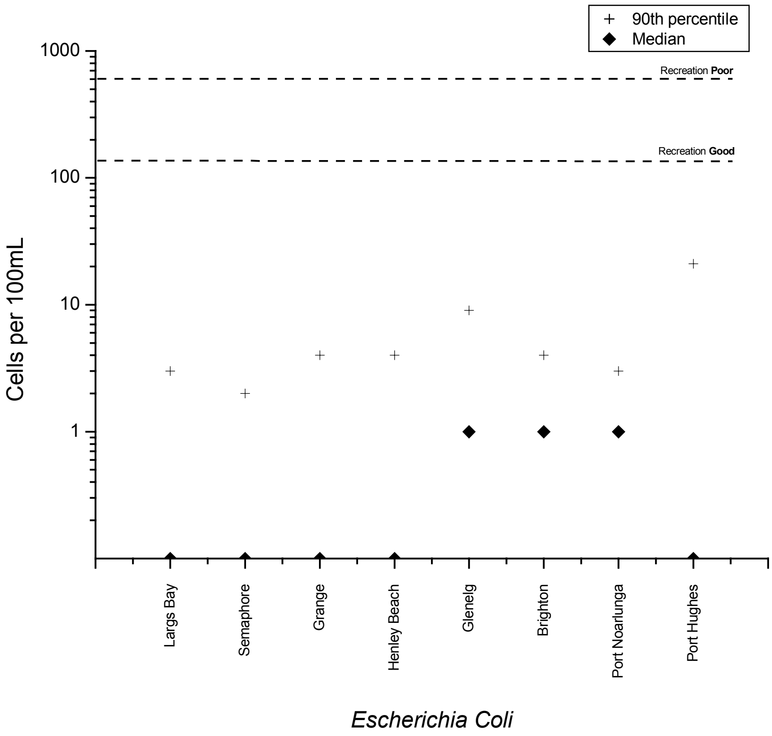


Figure 17 Median and 90th percentile for *Escherichia coli* 1995–2002 [AD1]

3.4.6 Enterococci

Faecal streptococci and enterococci are measured separately in the laboratory because enterococci are a subset of faecal streptococci. In this report nearly all the faecal streptococci were actually enterococci so the two parameters have been counted as one and referred to as enterococci. Enterococci occur in the faeces of humans and other animals; they are less abundant than faecal coliforms in humans but in other animals this may be reversed. Enterococci are more persistent in marine waters than faecal coliforms, so they are a better indicator of the presence of pathogens.

Results—enterococci

Ecosystem criteria: Good: Median ≤ 33 cells per 100 mL
Moderate: Median > 33 but ≤ 60 cells per 100 mL
Poor: Median > 60 cells per 100 mL.

The water quality classifications for enterococci indicate that the coastal waters are generally in good condition. Only 1% of the measurements were greater than the poor guideline value of 60 cells per 100 mL, while 2% were greater than the good guideline value. Brighton and Henley Beach had the highest concentrations of enterococci along the coast, with 90th percentiles of 14 and 16 cells per 100 mL respectively. Port Noarlunga had the lowest concentration with a 90th percentile of 4 cells per 100 mL.

Discussion and conclusions

As with faecal coliforms there has been a reduction in numbers of enterococci since the 1997 EPA report. In 1997 the 90th percentiles for the eight sites averaged 23 cells per 100 mL, while in 2002 this average was 10 cells per 100 mL. Again, this may relate to an actual reduction in numbers of micro-organisms in the waters or it may be a result of less variation in the results due to a larger sample size (19 in 1997 compared with 82 in 2002).

The sites with the highest concentrations are Henley Beach, Glenelg and Brighton, which is consistent with the location of major rivers and stormwater drains in the region. The Patawalonga (Barcoo) outlet, the Torrens River and the Edwards Street stormwater drain could be affecting these sites, especially during rainfall events.

Table 21 Statistical summary of enterococci 1995–2002

	Geometric mean (cells/ 100 mL)	95% confidence interval ($GM_L - GM_U$)	Median (cells/ 100 mL)	90th percentile (cells/ 100 mL)	Max (cells/ 100 mL)	Number of samples	Samples more than 60 cells/ 100 mL	Water quality classification –recreation	Site comparison[(a)]
1 Largs Bay	1.709	1.11–2.47	1	9.9	92	82	2	Good	n.s.
2 Semaphore	0.917	0.54–1.39	0	5.9	160	82	1	Good	n.s.
3 Grange	1.418	0.91–2.05	1	11	42	81	0	Good	n.s.
4 Henley Beach	1.597	1.03–2.32	1	16	74	81	1	Good	n.s.
5 Glenelg	1.752	1.22–2.42	1	10	49	81	0	Good	Site 5 > 7
6 Brighton	2.188	1.50–3.06	2	14	68	82	2	Good	Site 6 > 7
7 Pt Noarlunga	0.886	0.60–1.22	1	4	25	82	0	Good	n.s.
8 Pt Hughes	1.063	0.61–1.64	0	8	75	60	2	Good	n.s.

(a) Friedman probability: $p < 0.001$ statistically significant differences between sites. The > symbol indicates that the measurement at the specified location is significantly greater than at certain other sites. For pairwise site comparisons 'n.s.' signifies the site is not significantly greater than any other site.

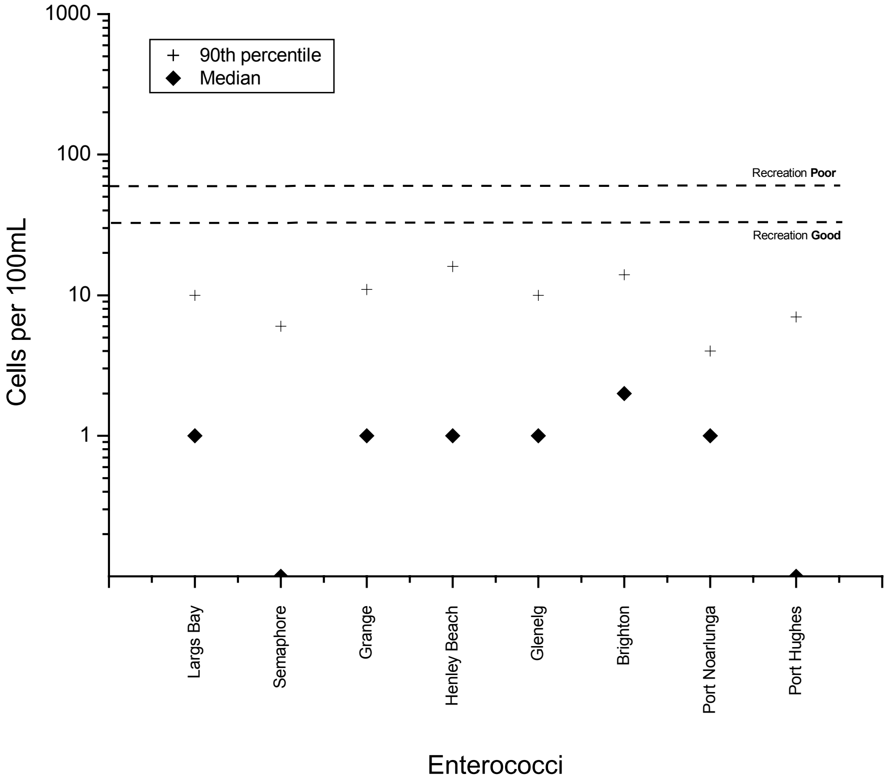


Figure 18 Median and 90th percentile for enterococci 1995–2002

3.4.7 Summary of biological parameters

The biological parameters generally showed that the Adelaide coastal waters are in good condition and the water quality is safe for swimming. The microbiological parameters were classified as good 100% of the time for the protection of recreational users. However, there were occasions when there were slightly elevated cell counts, which may be due to factors including contamination from birds and other mammals, agricultural runoff, and leaking or overflowing septic tank systems.

Chlorophyll *a* concentrations were elevated at all sites across the study. Only Port Noarlunga and Port Hughes were moderate while all other sites were classified as poor. This may be due to the long-term effects of increased nutrient levels from urban stormwater runoff, industrial discharges from the three metropolitan WWTPs and a longer residence time of the water in a reverse estuary such as Gulf St Vincent.

Table 22 Summary of water quality classifications for recreational use—biological parameters 1995–2002

	Chlorophyll *a* (protection of ecosystem)	**Faecal coliforms**	***Escherichia coli***	**Enterococci**
Largs Bay	Poor	Good	Good	Good
Semaphore	Poor	Good	Good	Good
Grange	Poor	Good	Good	Good
Henley Beach	Poor	Good	Good	Good
Glenelg	Poor	Good	Good	Good
Brighton	Poor	Good	Good	Good
Port Noarlunga	Moderate	Good	Good	Good
Port Hughes	Moderate	Good	Good	Good

The median and 90th percentiles for all biological parameters have dropped considerably since the publishing of the last metropolitan waters report (EPA 1997a). The 1997 data was highly variable, with relatively high medians and 90th percentiles. The reduction in these figures in this data may be a function of larger sample sizes and a reduction in variability rather than an actual reduction of micro-organisms at the beaches. However, the pattern of low geometric means with occasional high results indicates that the pollution is probably a short-term response to events such as heavy rainfall rather than ongoing inputs.

4 SUMMARY OF FINDINGS

4.1 Protection of the ecosystem

In general, across all sites, the water quality of the metropolitan coastal waters was good to moderate for protection of the ecosystem (Figure 19). There is a trend of decreasing water quality evident in the vicinity of the large stormwater drains, wastewater treatment plant outfalls and river mouths. The most affected site was Glenelg, with 46% of parameters classified as good and 18% poor. This is consistent with the numerous discharges in this region. Largs Bay, the northernmost site, was in the best condition of the test sites, with 73% of parameters being classified as good.

In this study Port Hughes has been used as a reference site with which to compare the results at the metropolitan sites. Figure 19 shows that, with 73% of water quality classifications being good, Port Hughes is an acceptable indicator of good marine ecosystem health for the majority of the time.

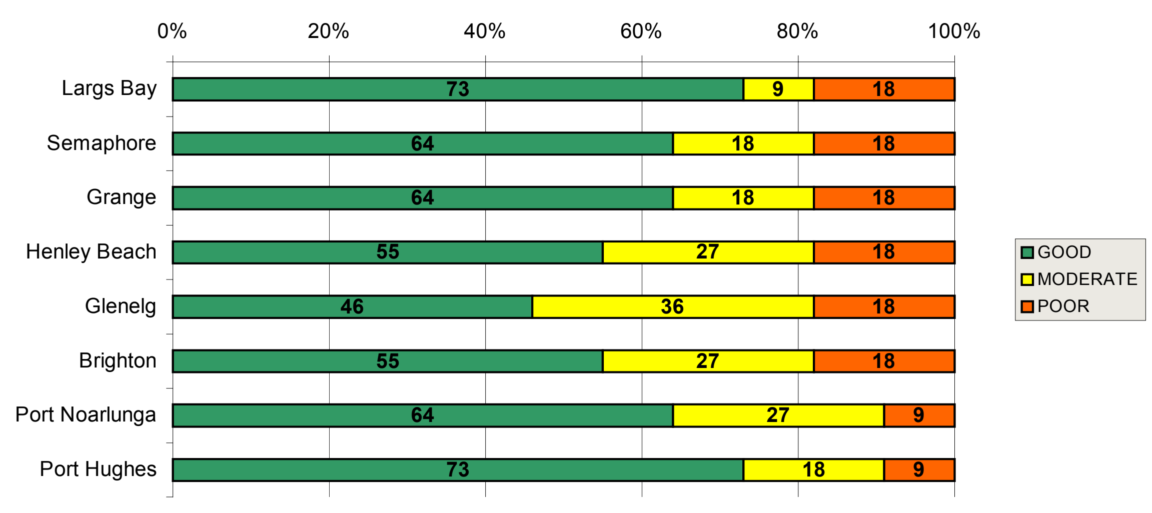


Figure 19 Distribution of water quality classifications for the protection of the ecosystem by site 1995–2002

4.2 Protection of recreational users

The water quality was good for protection of recreational users, with all sites having 75% or more good classifications (Figure 20). There was an increase in turbidity around Brighton, Glenelg and Henley Beach, which is probably due to the combined impacts of discharge from the Glenelg WWTP and stormwater from the Patawalonga outlet and the Torrens River. There was also an increase in turbidity at Largs Bay and Semaphore, which could be a result of sand accretion due to the breakwaters at North Haven and Outer Harbor. Shallower beach gradients may also have an effect in increasing turbidity along the coast, with fine sediments being easily resuspended by wind and wave action.

Again, Port Hughes showed that it was a good reference site with good water quality classifications for all parameters.

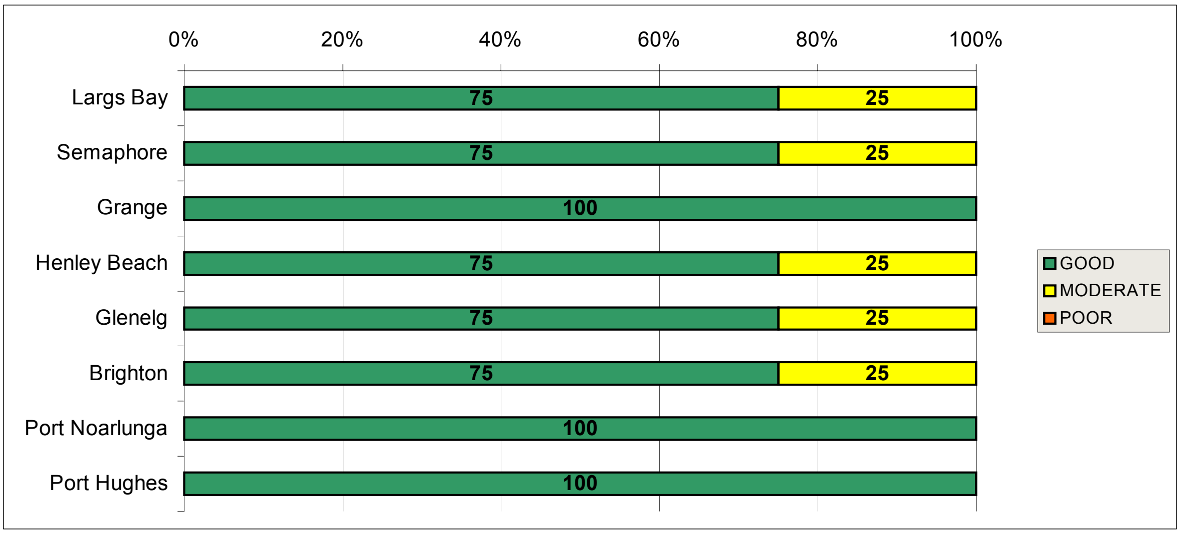


Figure 20 Distribution of water quality classifications for the protection of recreational users by site 1995–2002

4.3 Protection of aquaculture

The water quality for the protection of aquaculture was generally good, with all sites having 88% of parameters classified as good (Figure 21). However, all sites were classified as poor for total zinc. This classification is based on the potential for zinc to bioaccumulate in the flesh of shellfish and, in very high concentrations, to be toxic to marine life. This is not a classification based on any risk to human health from eating shellfish in these areas. As stated earlier, there are currently no aquaculture growing areas in the study region or Port Hughes; however, this data may be used as an assessment tool for any proposed aquaculture developments.

Figure 21 Distribution of water quality classifications for the protection of aquaculture by site 1995–2002

5 CONCLUSIONS

5.1 Protection of the ecosystem

Key conclusions from results for the protection of the ecosystem are:

- Ammonia levels are elevated at all sites, including Port Hughes. The metropolitan sites have remained stable since the 1997 report but Port Hughes has changed from good to moderate. This change is probably due to an increase in sample size from 3 in 1997 to 59 in this report. These moderate classifications may be of concern due to the directly toxic nature of ammonia and its indirect action as a nutrient.
- Oxidised nitrogen levels are elevated at Glenelg, Henley Beach and Grange. This may be due to large nitrogen loads from urban stormwater and the Glenelg WWTP.
- Turbidity results were moderate at Brighton, Glenelg and Henley Beach and also at Largs Bay and Semaphore. It is likely that the input of water from the Glenelg WWTP and urban stormwater is having an effect at Brighton, Glenelg and Henley Beach; while shallower beaches at Largs Bay and Semaphore and sand accretion at the North Haven and Outer Harbor breakwaters may be having an effect on turbidity.
- Chlorophyll *a* is elevated at all sites. This may be an indicator of long-term nutrient pollution, especially as the highest results were from the major nutrient discharge sites of Glenelg, Henley Beach and Grange.
- Total zinc is poor at all sites. Having the potential to bioaccumulate, especially in shellfish, it represents a long-term risk to the environment. However, it may be possible that the elevated zinc concentrations are from natural origins and not human induced.
- Nickel concentrations at Glenelg, Brighton and Port Noarlunga are considered moderate. This is likely to be due to runoff from the Patawalonga outlet, Torrens and Onkaparinga rivers, and the Glenelg and Christies Beach WWTPs.

5.2 Protection of recreational users

Key conclusions from results for the protection of recreational users are:

- All microbiological parameters were classified as good at all sites. There were occasional high cell counts which are likely to be due to animal faecal contamination in runoff after periods of heavy rain.
- Turbidity was considered moderate at Brighton, Glenelg, Henley Beach, Semaphore and Largs Bay (see section 5.1). High turbidity can reduce visibility in the water and create a safety hazard for swimmers.

5.3 Protection of aquaculture

Key conclusions from results for the protection of aquaculture are:

- All sites were predominantly classified as good. However, as stated earlier, where available the EPA must use laboratory methods with reliable detection limits below the current guideline values in ANZECC (2000). This information will give marine scientists a better understanding of the concentrations of these trace elements in the marine environment, and will aid in their management.

- Total zinc was classified as poor at all sites. This may have commercial implications as zinc may bioaccumulate in the tissues of fish and shellfish. As stated above, it is likely that the elevated zinc concentrations originate from natural sources because there were similar concentrations recorded at Port Hughes without anthropogenic inputs such as high volumes of stormwater.

These results show that there are some water quality issues for the beaches of Adelaide's metropolitan coast and some deficiencies in our knowledge of the marine environment—for example, the reasons for the high ammonia and high zinc concentrations in the State's coastal waters. Answers to these and further questions raised by other scientists, environmentalists and the general public should be provided with the completion of the Adelaide Coastal Waters Study (see section 6). Information in this report will aid in the allocation of resources and funding to conduct further research into the marine environment in Gulf St Vincent, resulting in an improvement in water quality and protection of marine biodiversity for the benefit of the environment and all users of Adelaide's coastal regions.

6 WHAT IS BEING DONE?

The metropolitan coastal waters have been affected by pollution from Adelaide's urban development for over 160 years. This pollution has caused an obvious decline in seagrass, reef health and physical/chemical parameters along the coast, and the waters of Gulf St Vincent can not be considered pristine. Many of these effects were identified over 30 years ago, when actions were first initiated to address the decline in coastal water quality. However, there is no easy fix to more than a century of cumulative pollution impacts, and the restoration of these waters will take a significant amount of time.

Key initiatives that are being undertaken to help reduce the level of environmental impact on Gulf St Vincent are:

- implementation of Environment Improvement Programs (EIPs) by industries discharging into the gulf and other waterways of the State. For example, SA Water has invested approximately $280 million to improve metropolitan WWTP discharges and reduce pollution due to nutrient loads and turbidity entering the gulf.
- implementation of EIPs by industries emitting air discharges containing pollutants that settle out in coastal waters
- promotion, according to the *Environment Protection (Water Quality) Policy 2003*, of reductions in diffuse pollution entering the gulf through improvements in stormwater and wastewater discharges from domestic, urban, agricultural and industrial sources
- ongoing development and management of wetlands by CWMBs and councils to detain and treat stormwater, reducing the amount of nutrients, metals, bacteria and suspended solids entering the gulf
- continued catchment management work by the CWMBs to reduce diffuse pollution entering the gulf
- increase in the knowledge of South Australia's marine environment through the Adelaide Coastal Waters Study, a $4 million initiative to investigate a broad range of water quality issues including pollution impacts. This study is expected to be completed by June 2005.
- development by the EPA of codes of practice for marinas and materials handling on wharfs, and preparation of a handbook on pollution avoidance for the building and construction industry
- promotion of several education and community monitoring programs such as CoastCare, Reef Watch, WaterCare and Waterwatch, which educate school and community groups about monitoring biological systems and reducing pollution inputs into the marine environment
- development of a Living Coast strategy to better manage marine, coastal and estuarine issues
- development of Marine Management Plans for the management of sensitive marine areas.

These initiatives will reduce the flow of polluted water and the pollution load entering Gulf St Vincent.

It is accepted that with human development there is some degree of pollution. It is unreasonable to expect the environment to be pristine as it would have been prior to human settlement. However, it is not unreasonable to reduce pollution to a point where water quality is not restricting the health of seagrass or subtidal reefs and the maintenance of biodiversity in the marine environment. To do this, every person in South Australia must take responsibility for their actions and actively reduce pollution entering the marine environment. Over time, this should encourage the return of vast seagrass meadows, healthy reef systems and vibrant marine life throughout the gulf.

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APPENDIX 1: TIME SERIES PLOTS OF WATER QUALITY PARAMETERS

Physical parameters

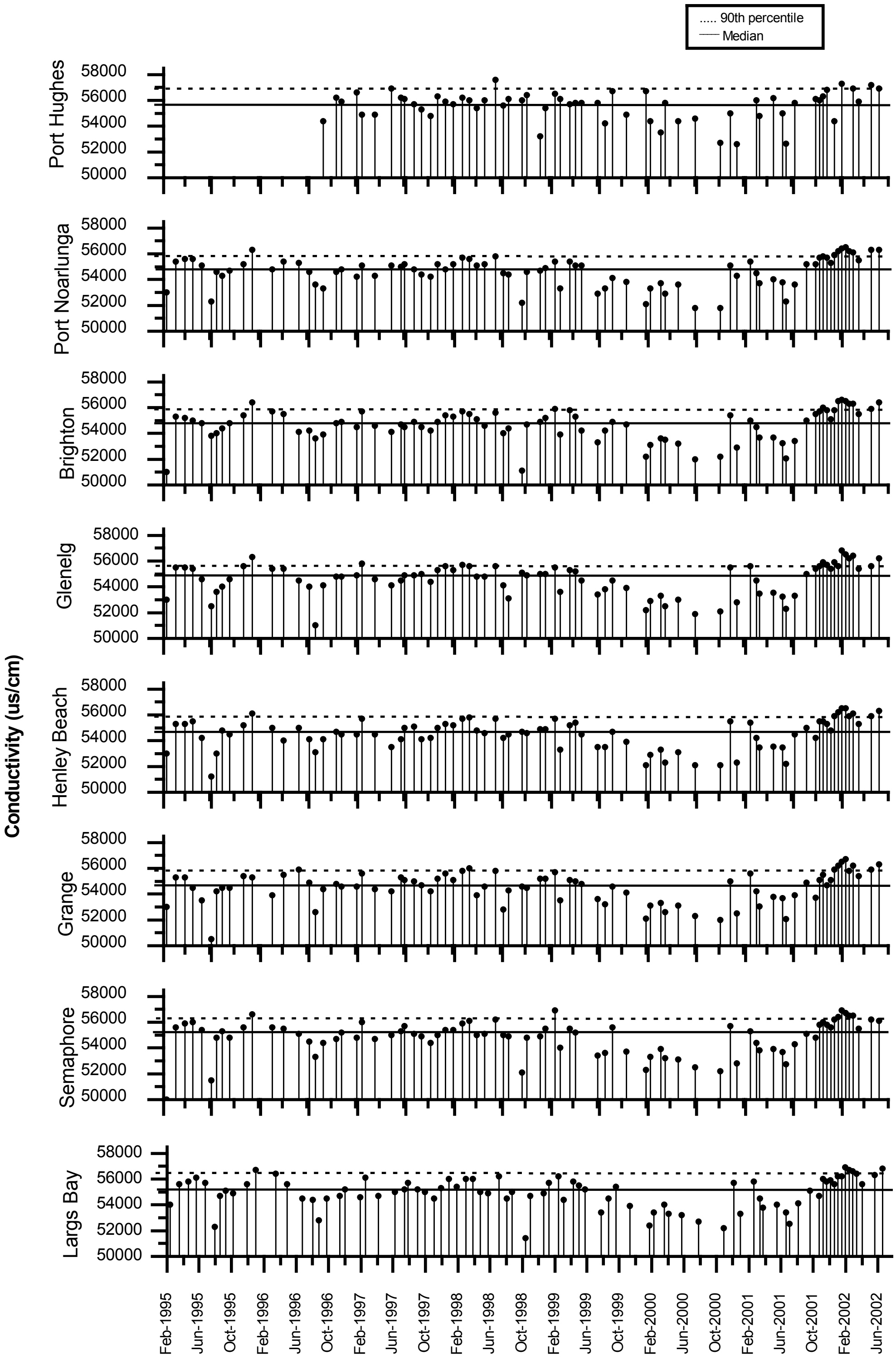

Figure 22 Time series plot for conductivity 1995–2002

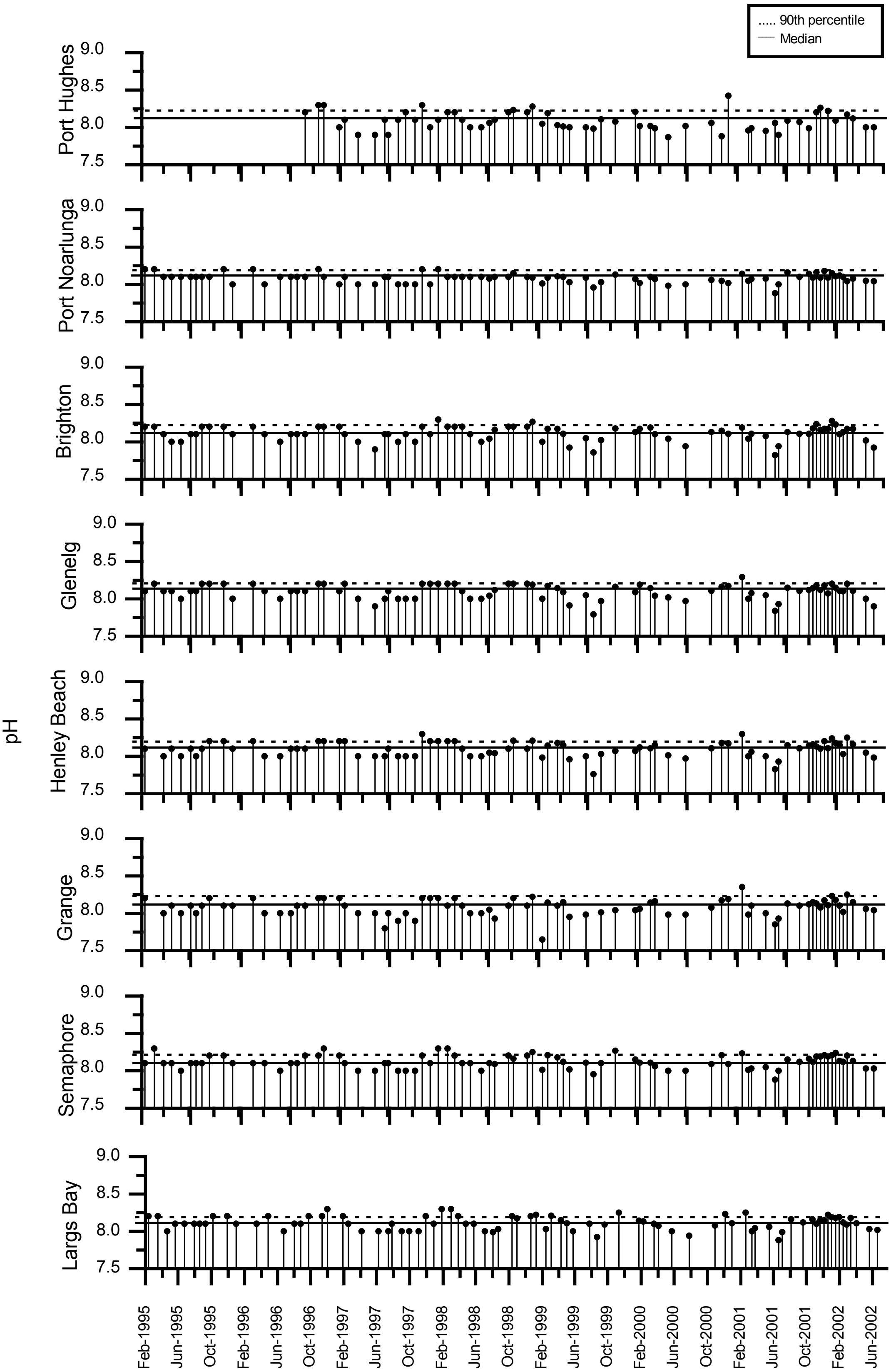

Figure 23 Time series plot for pH 1995–2002

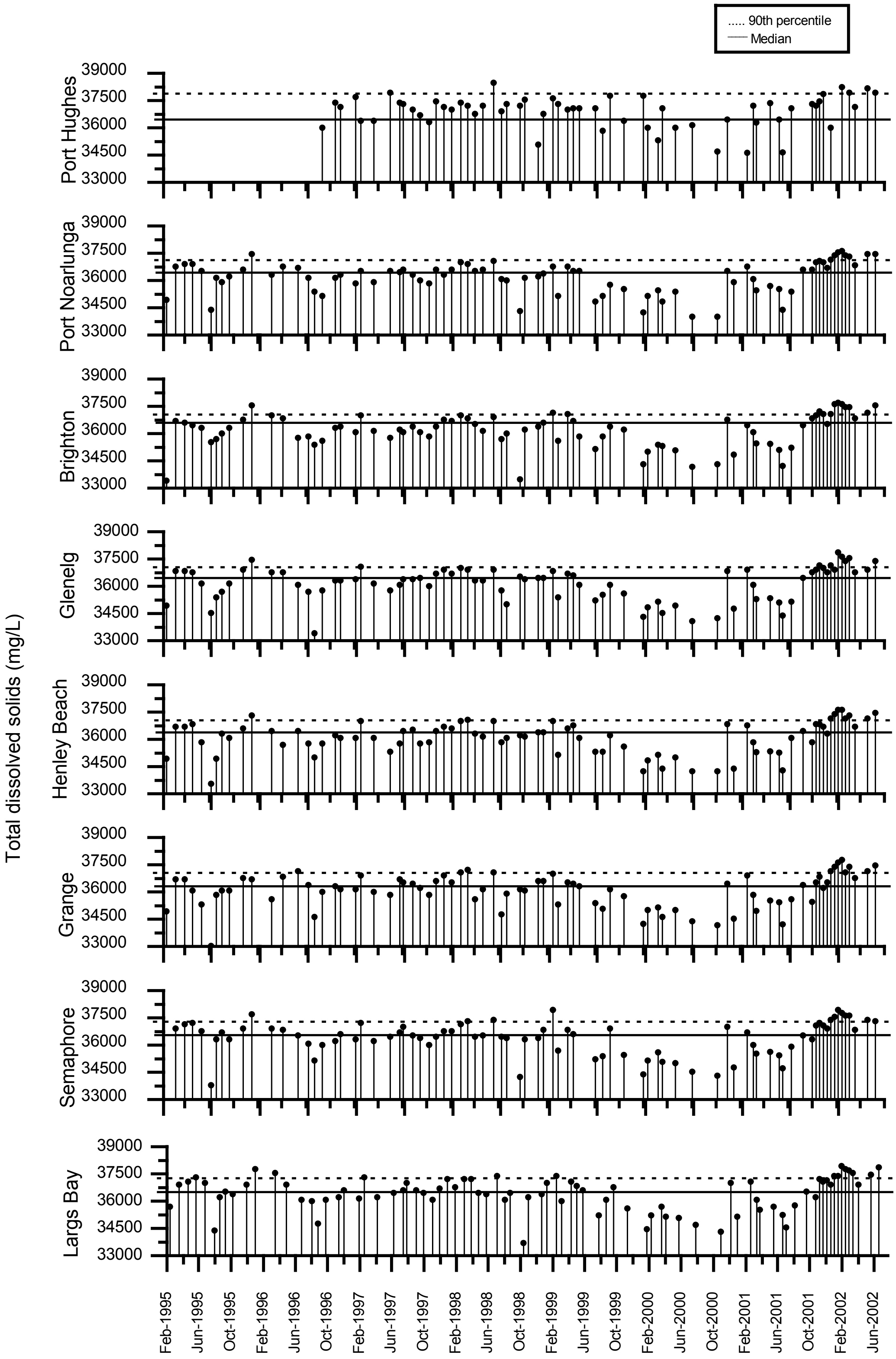

Figure 24 Time series plot for total dissolved solids 1995–2002

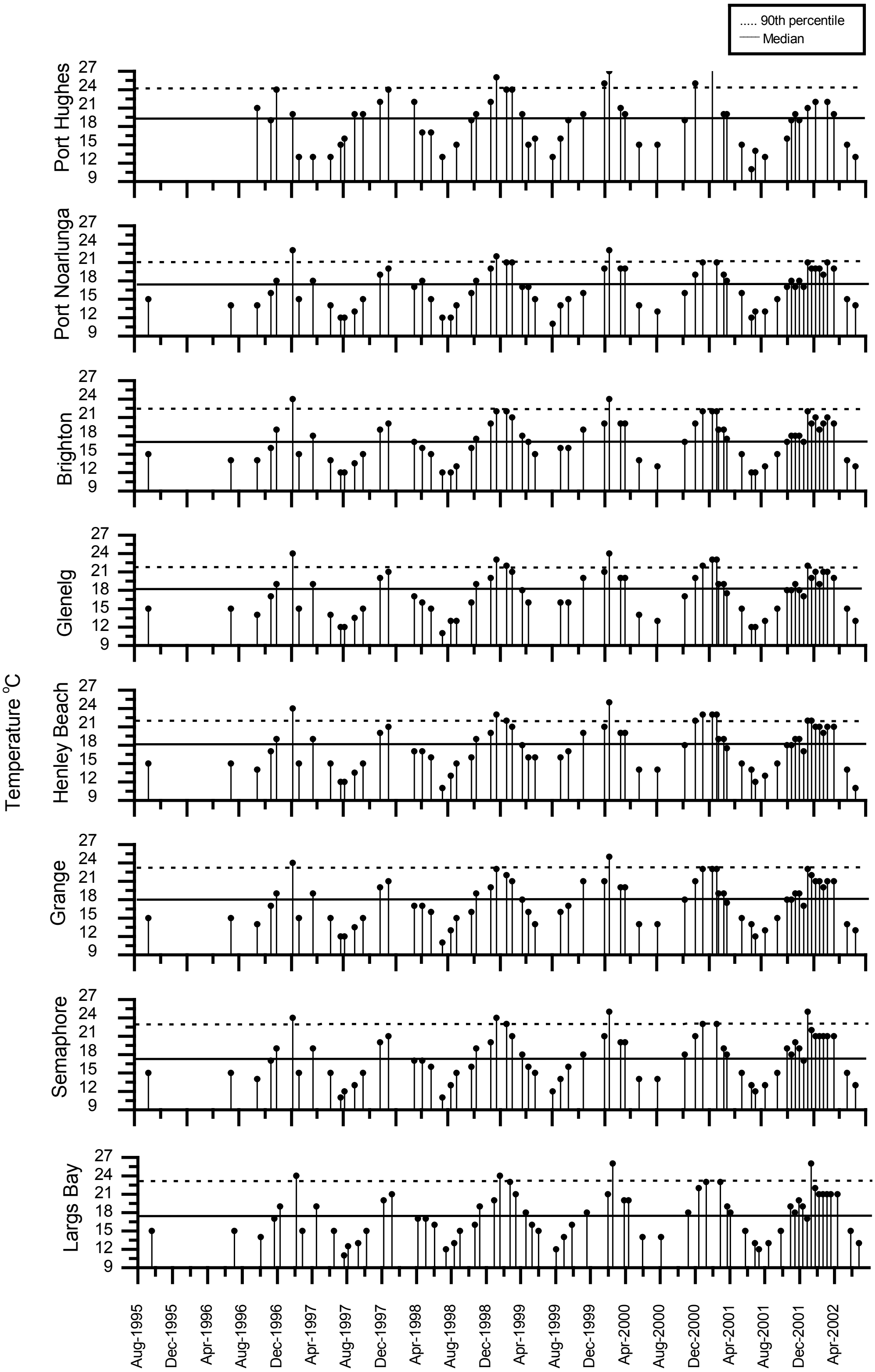

Figure 25 Time series plot for temperature 1995–2002

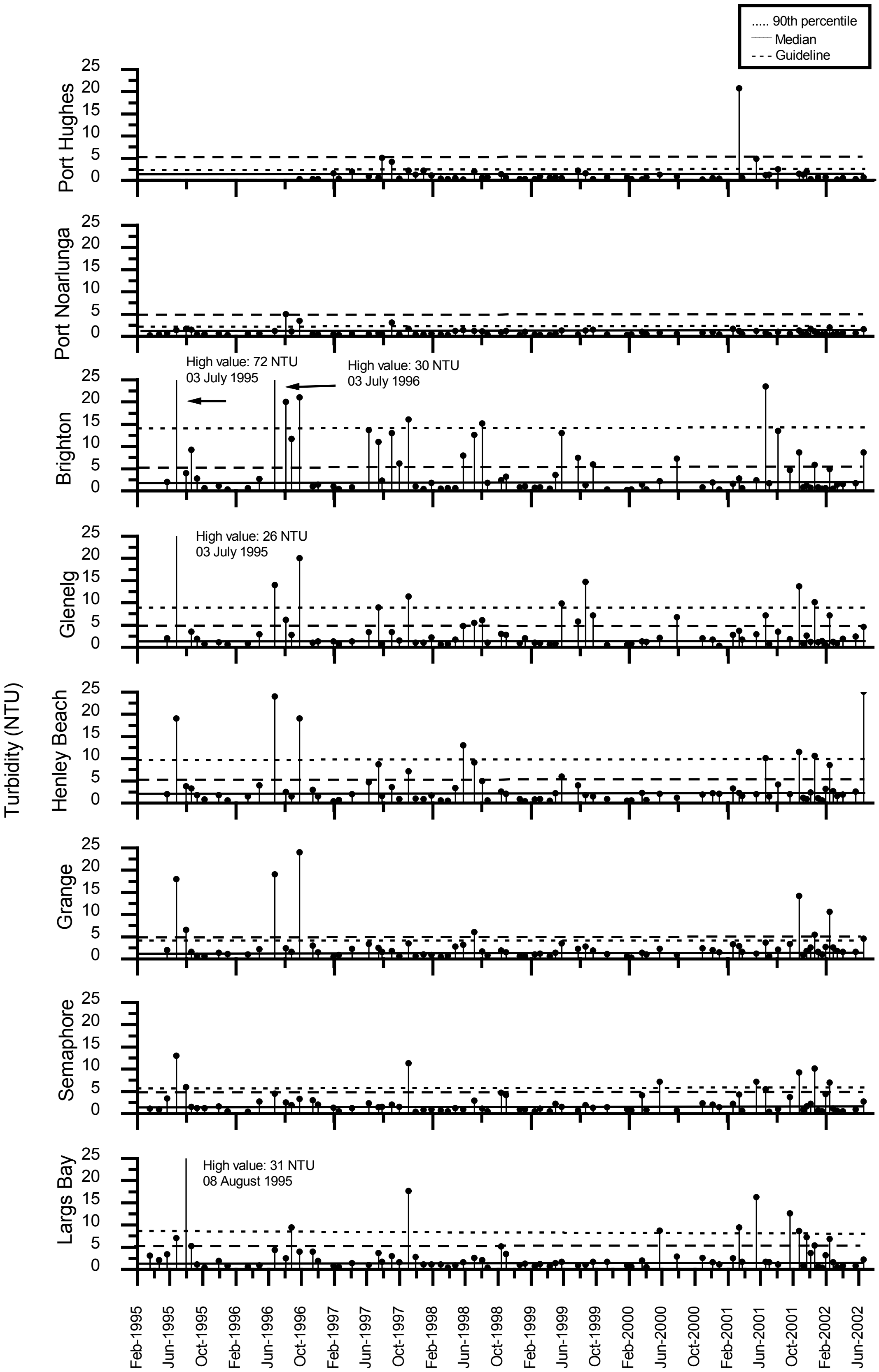

Figure 26 Time series plot for turbidity 1995–2002

Metals

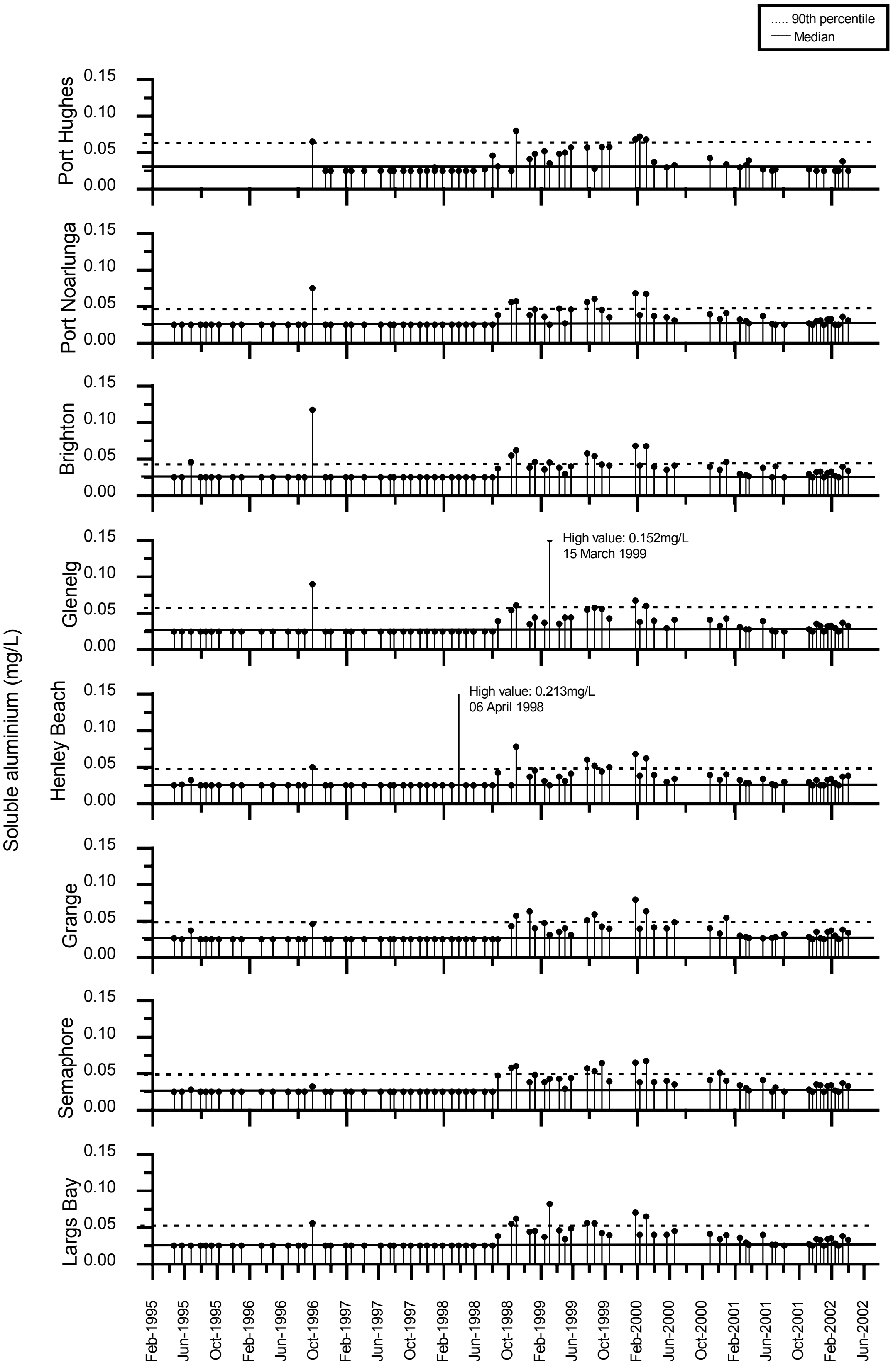

Figure 27 Time series plot for soluble aluminium 1995–2002

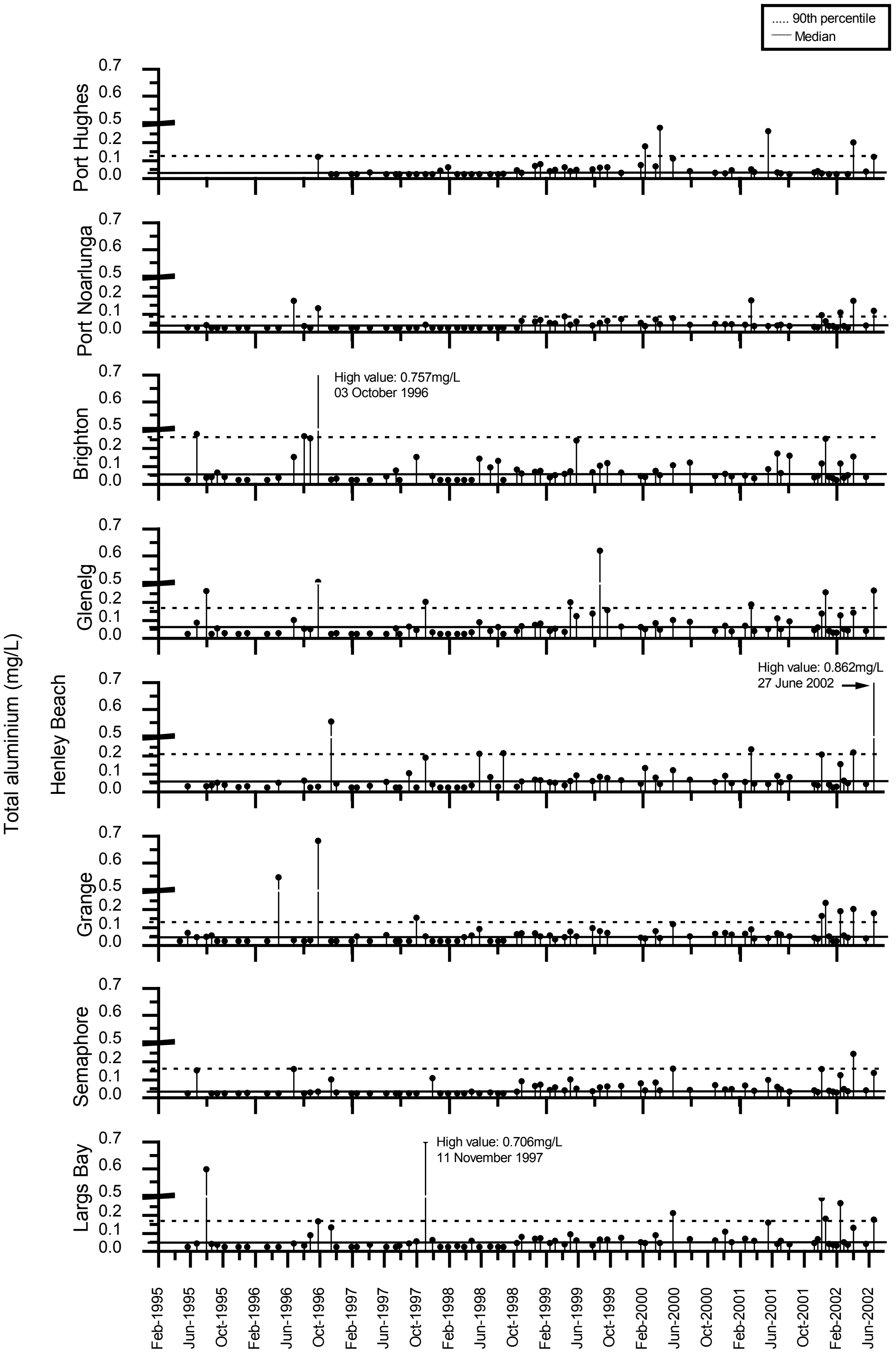

Figure 28 Time series plot for total aluminium 1995–2002

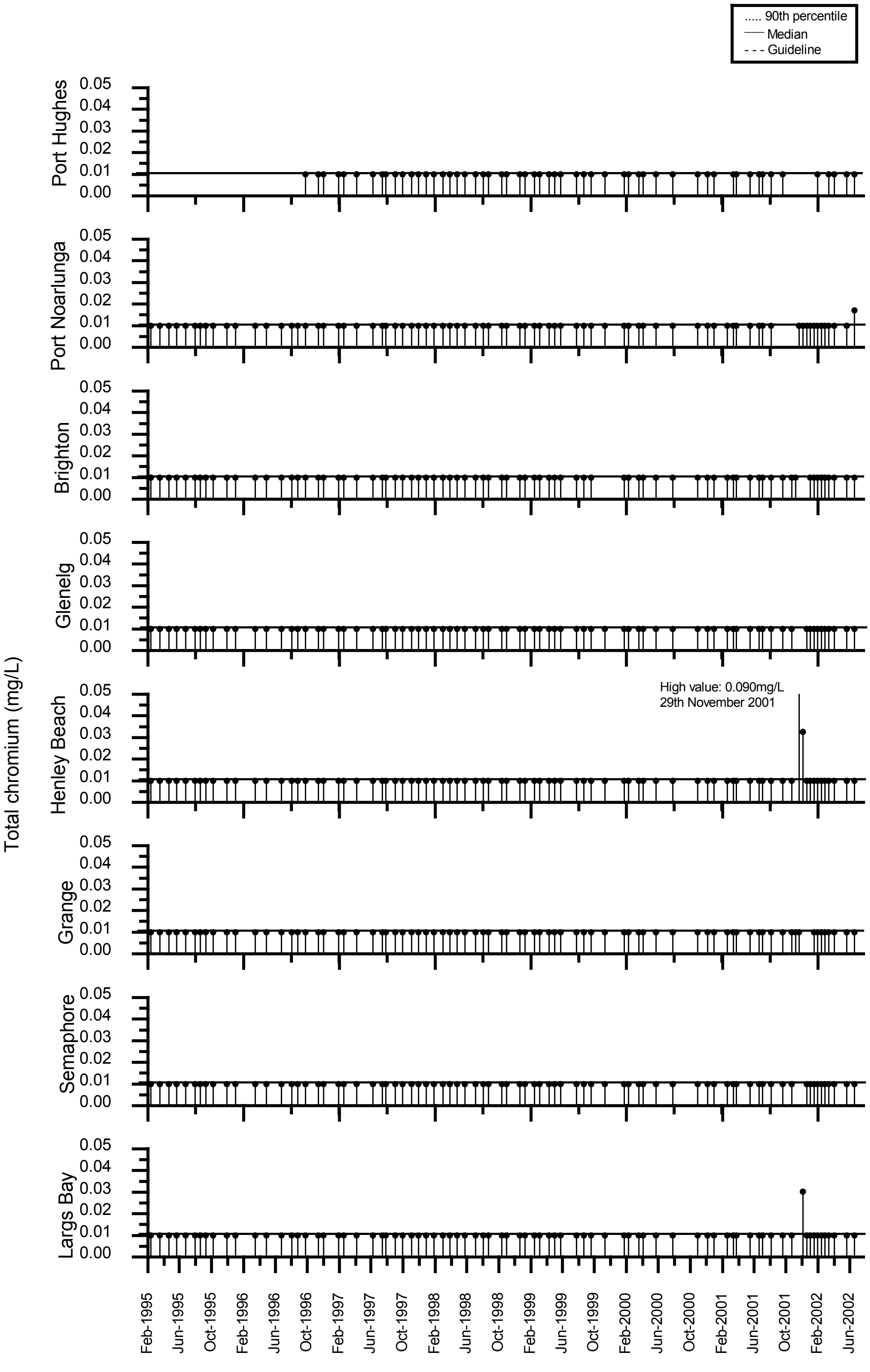

Figure 29 Time series plot for total chromium 1995–2002

Note that median and 90th percentile are both equal to the limit of detection. The limit of detection is higher than the ANZECC guideline of 0.0044 mg/L

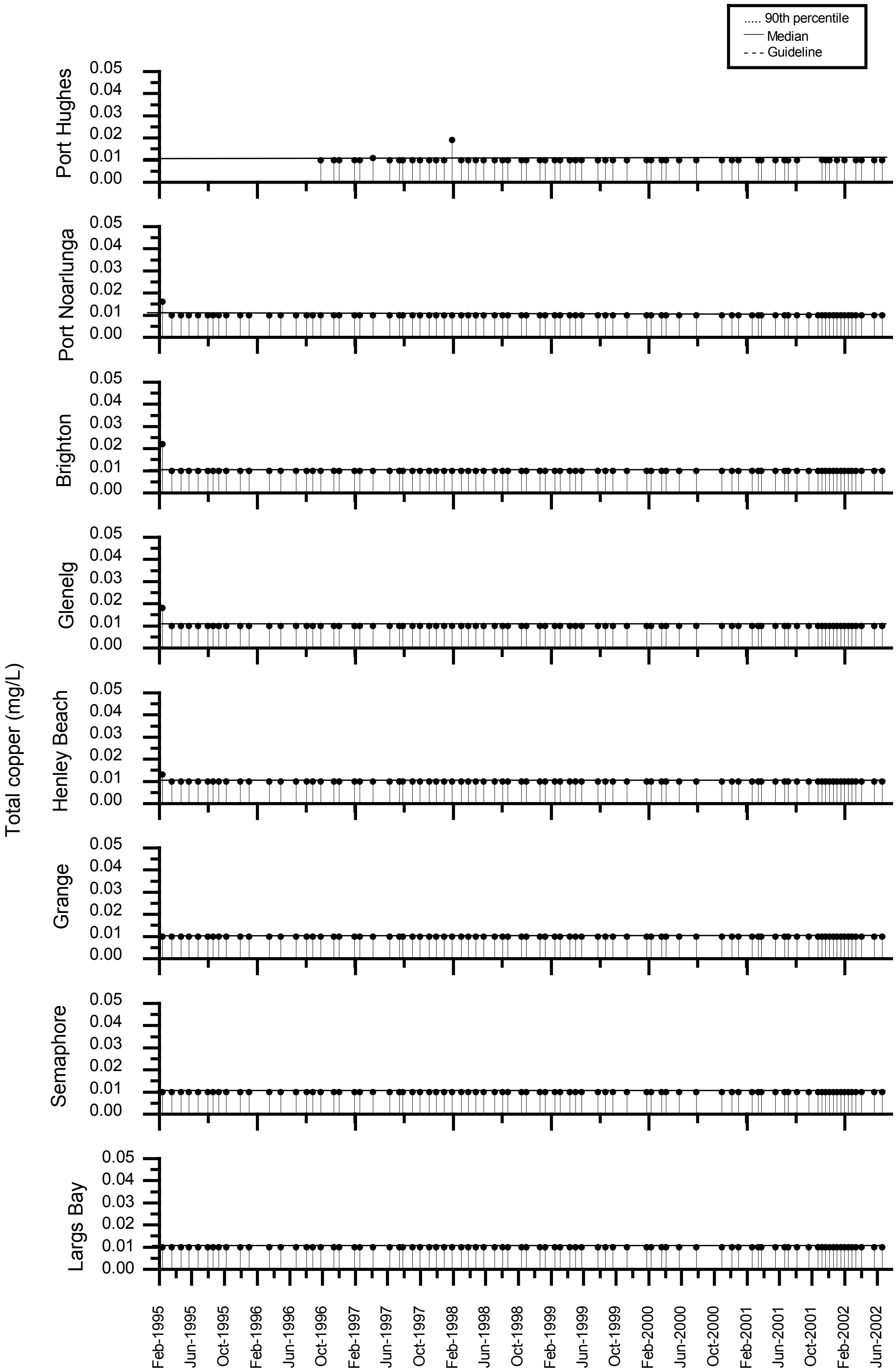

Figure 30 Time series plot for total copper 1995–2002
Note that median and 90th percentile are both equal to the limit of detection. The limit of detection is higher than the ANZECC guideline of 0.0013 mg/L

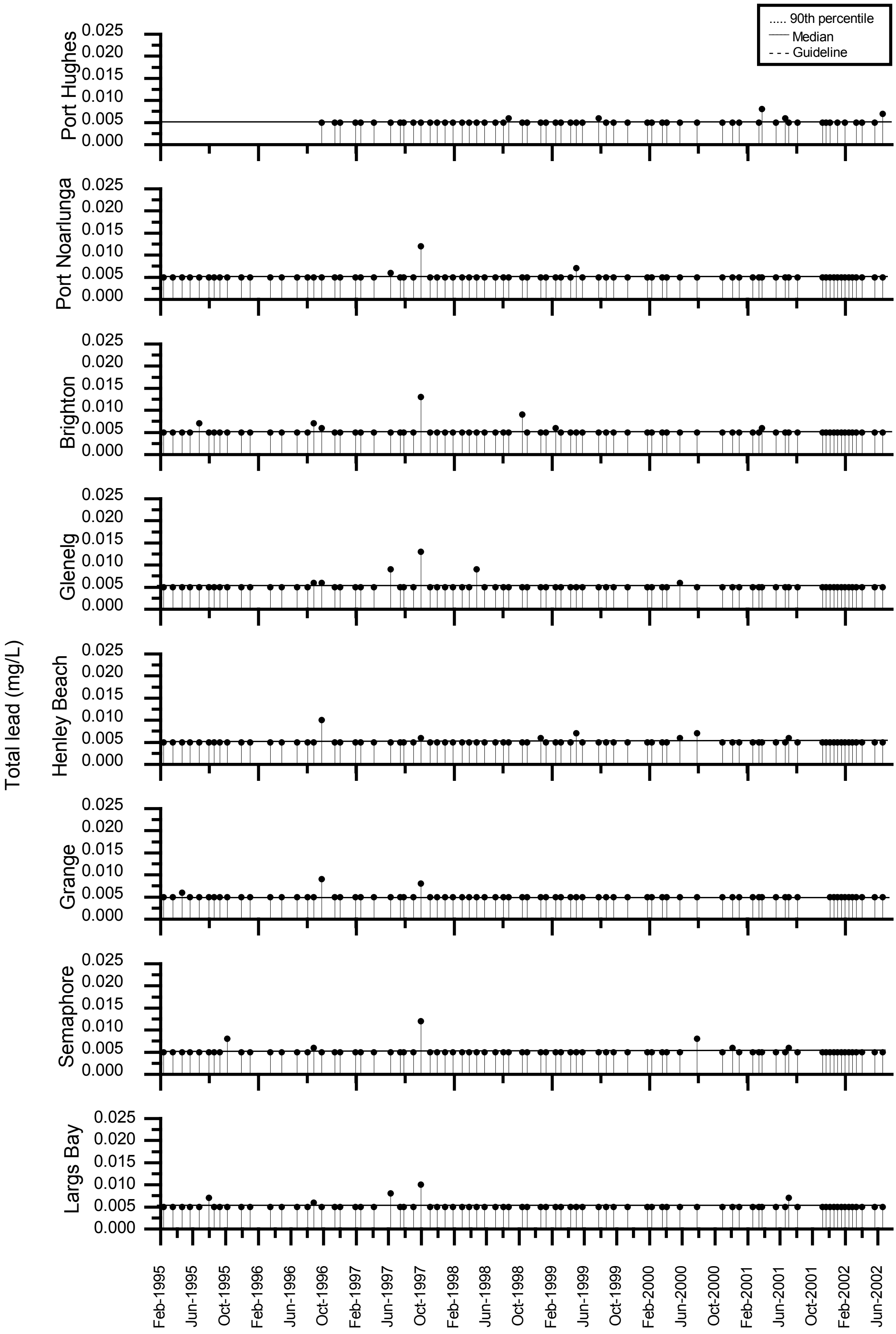

Figure 31 Time series plot for total lead 1995–2002
Note that median and 90th percentile are both equal to the limit of detection. The limit of detection is higher than the ANZECC guideline of 0.0044 mg/L

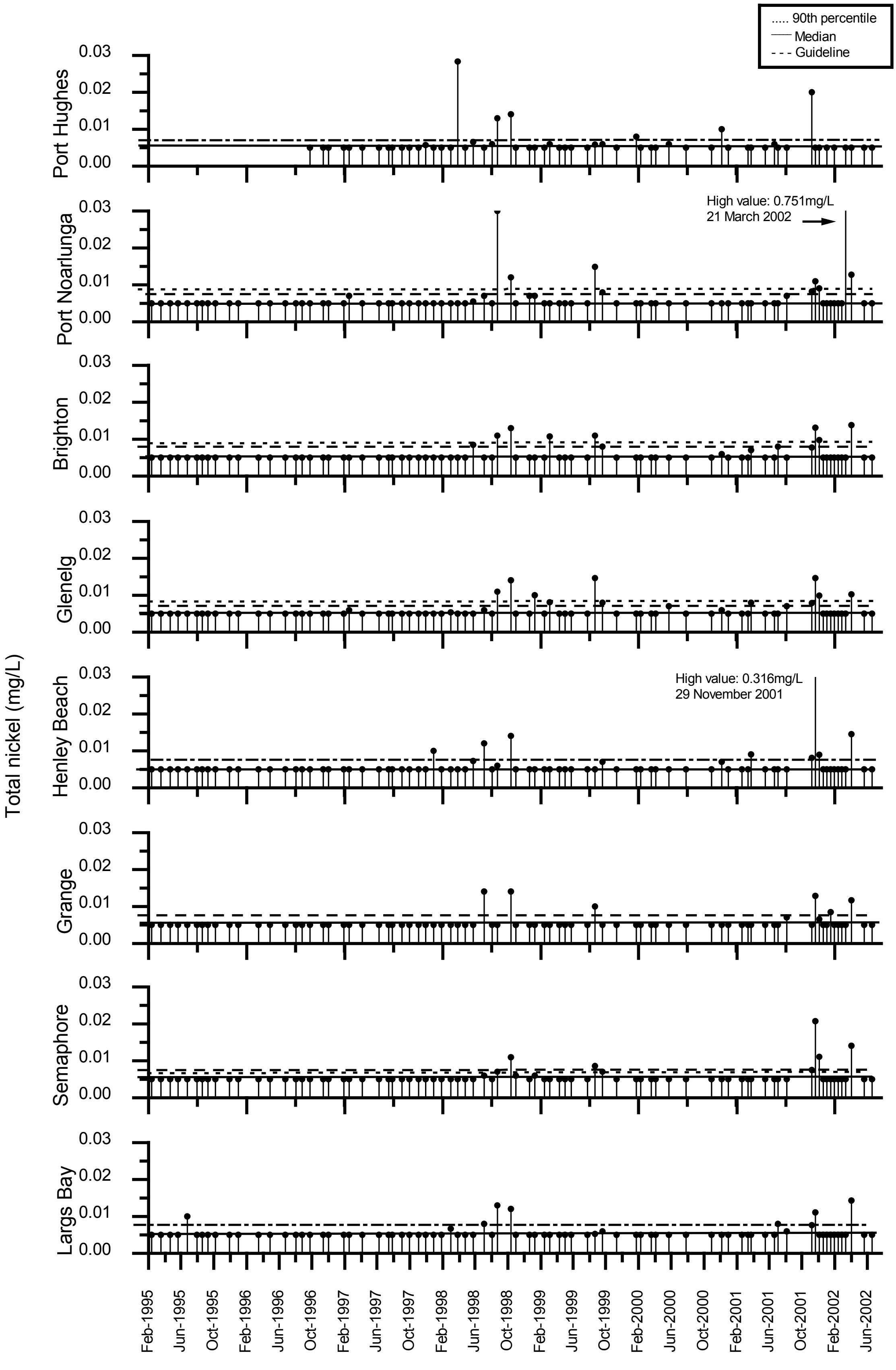

Figure 32 Time series plot for total nickel 1995–2002

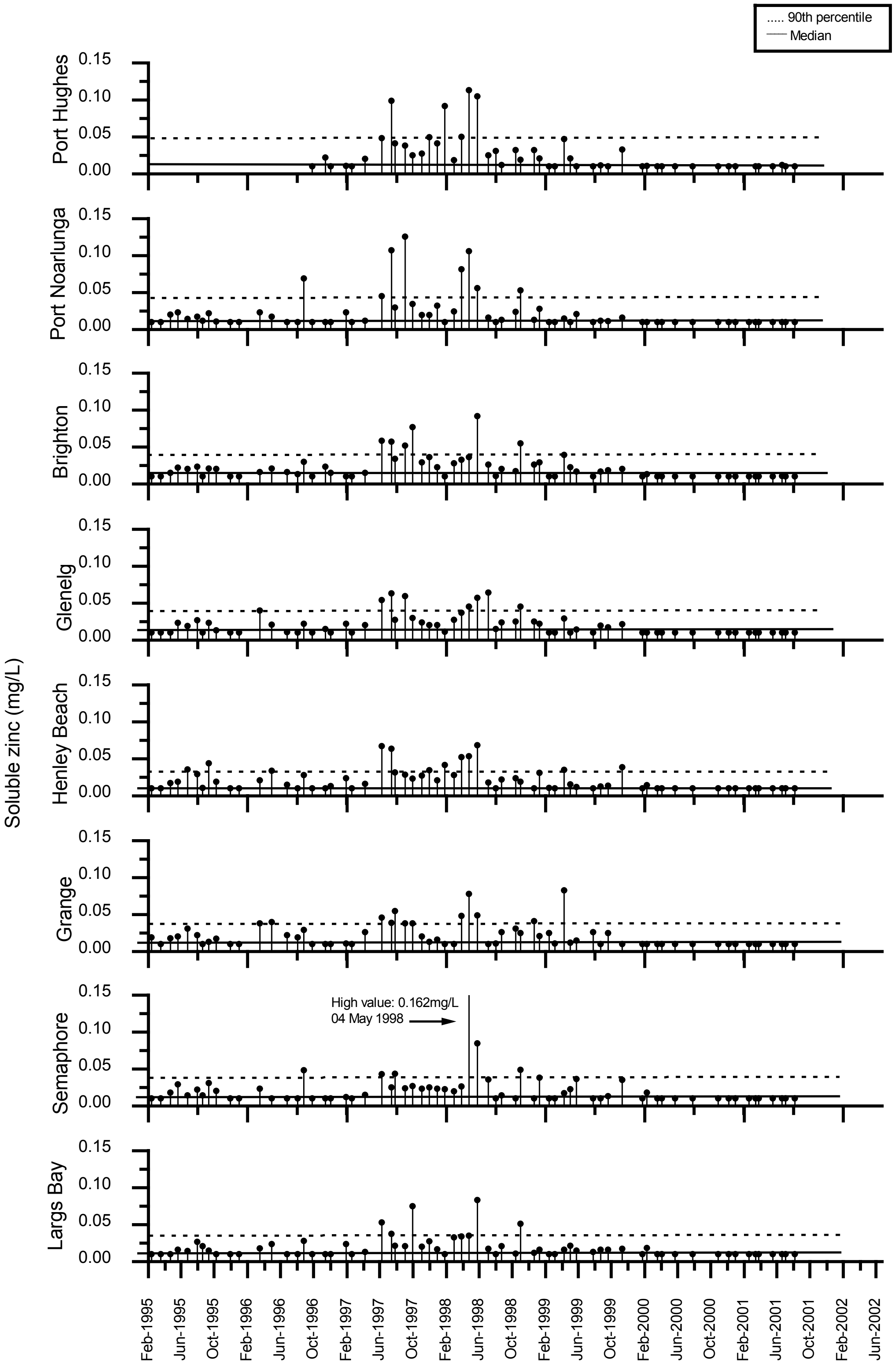

Figure 33 Time series plot for soluble zinc 1995–2002

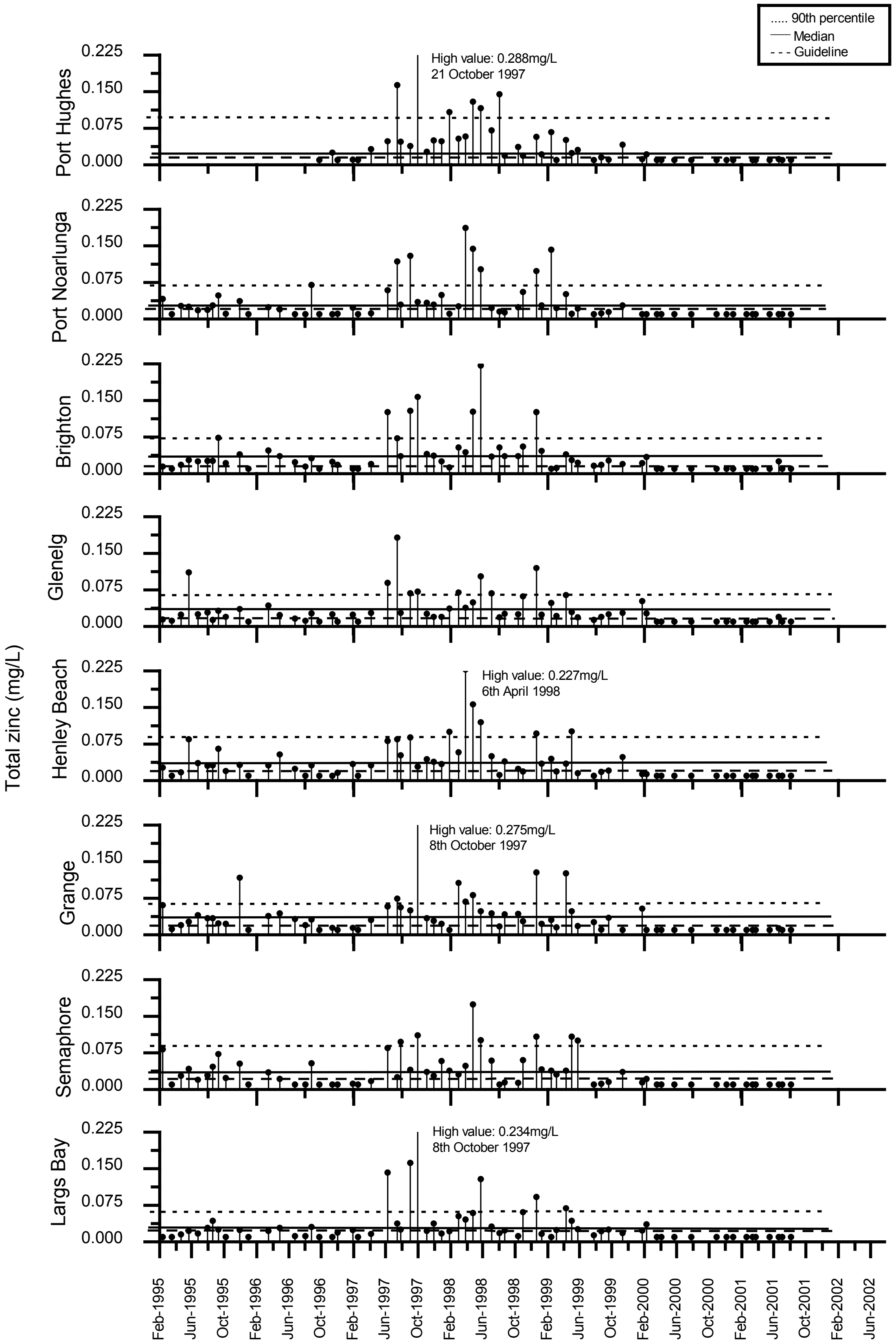

Figure 34 Time series plot for total zinc 1995–2002

Nutrients

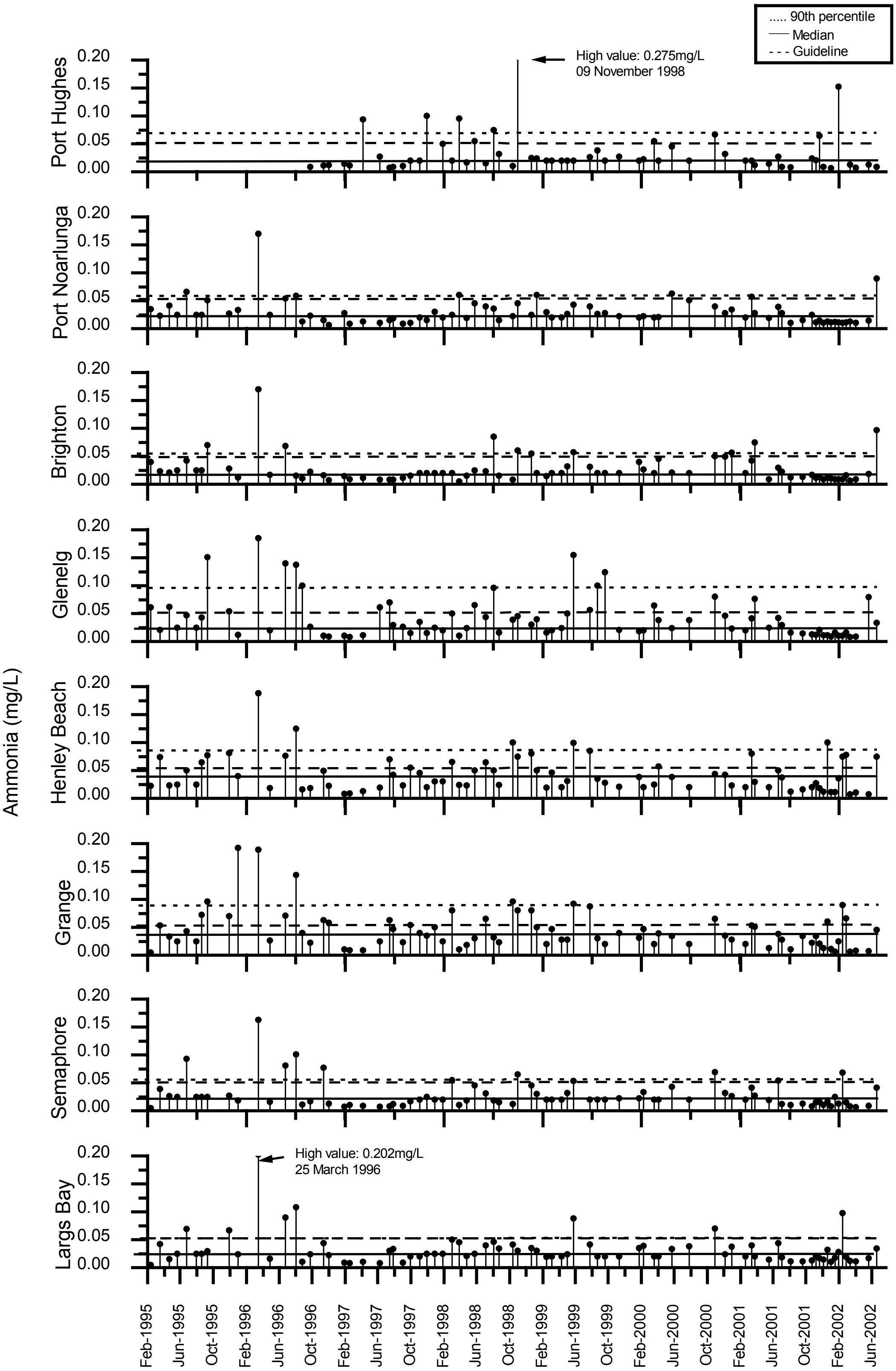

Figure 35 Time series plot for total ammonia 1995–2002

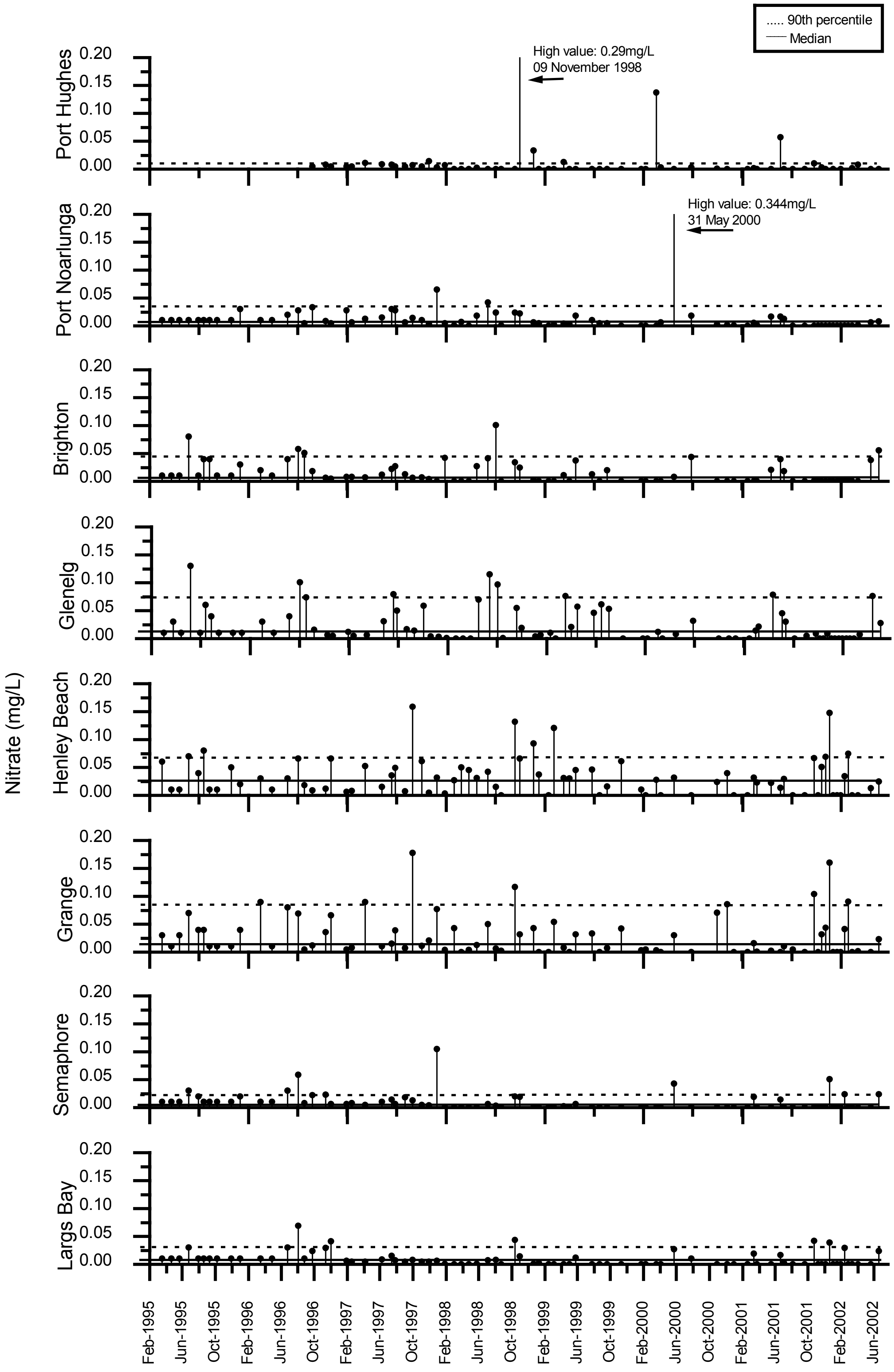

Figure 36 Time series plot for nitrate 1995–2002

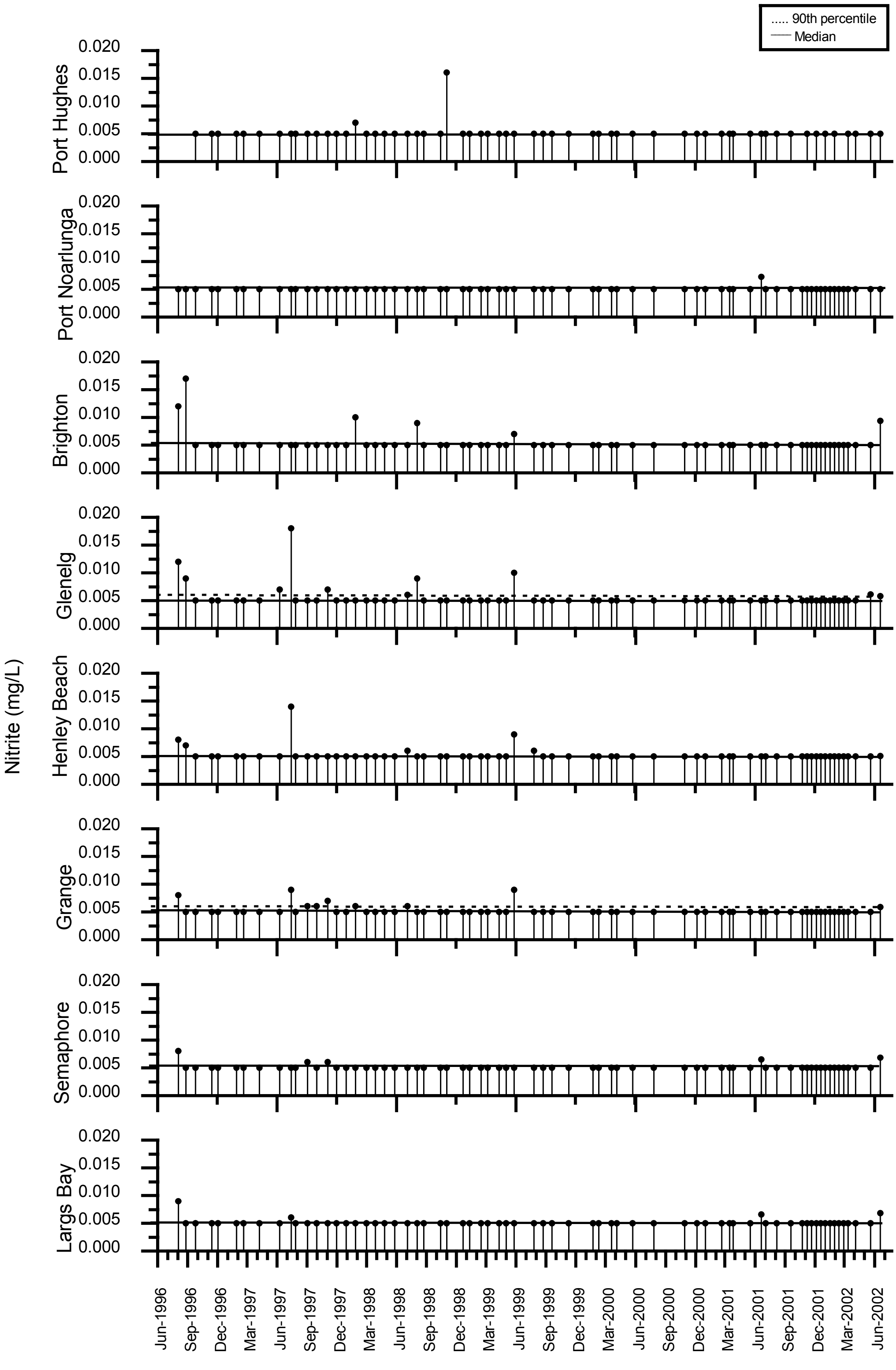

Figure 37 Time series plot for nitrite 1995–2002
Note that median and 90th percentile are both equal to the limit of detection

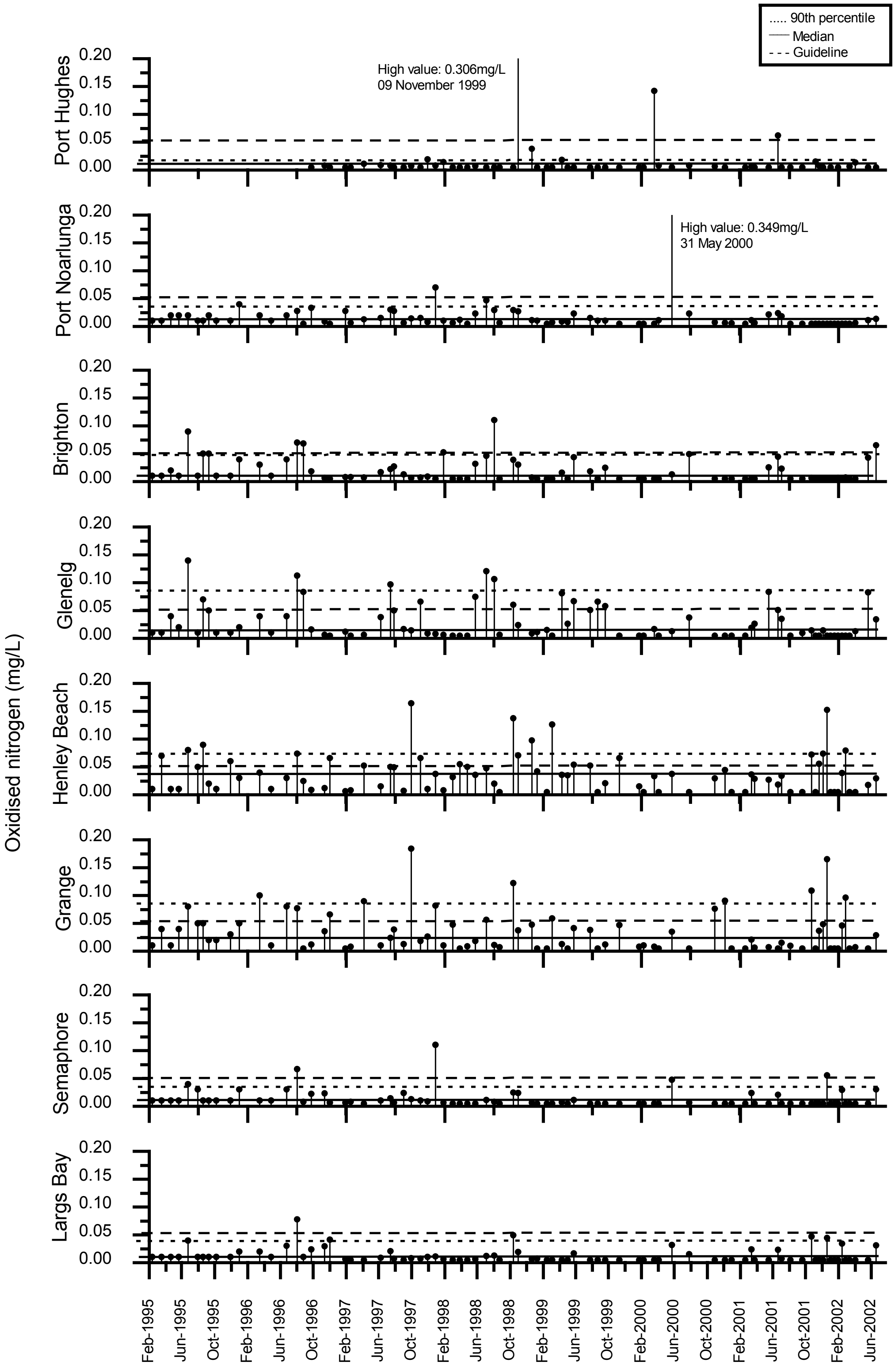

Figure 38 Time series plot for oxidised nitrogen 1995–2002

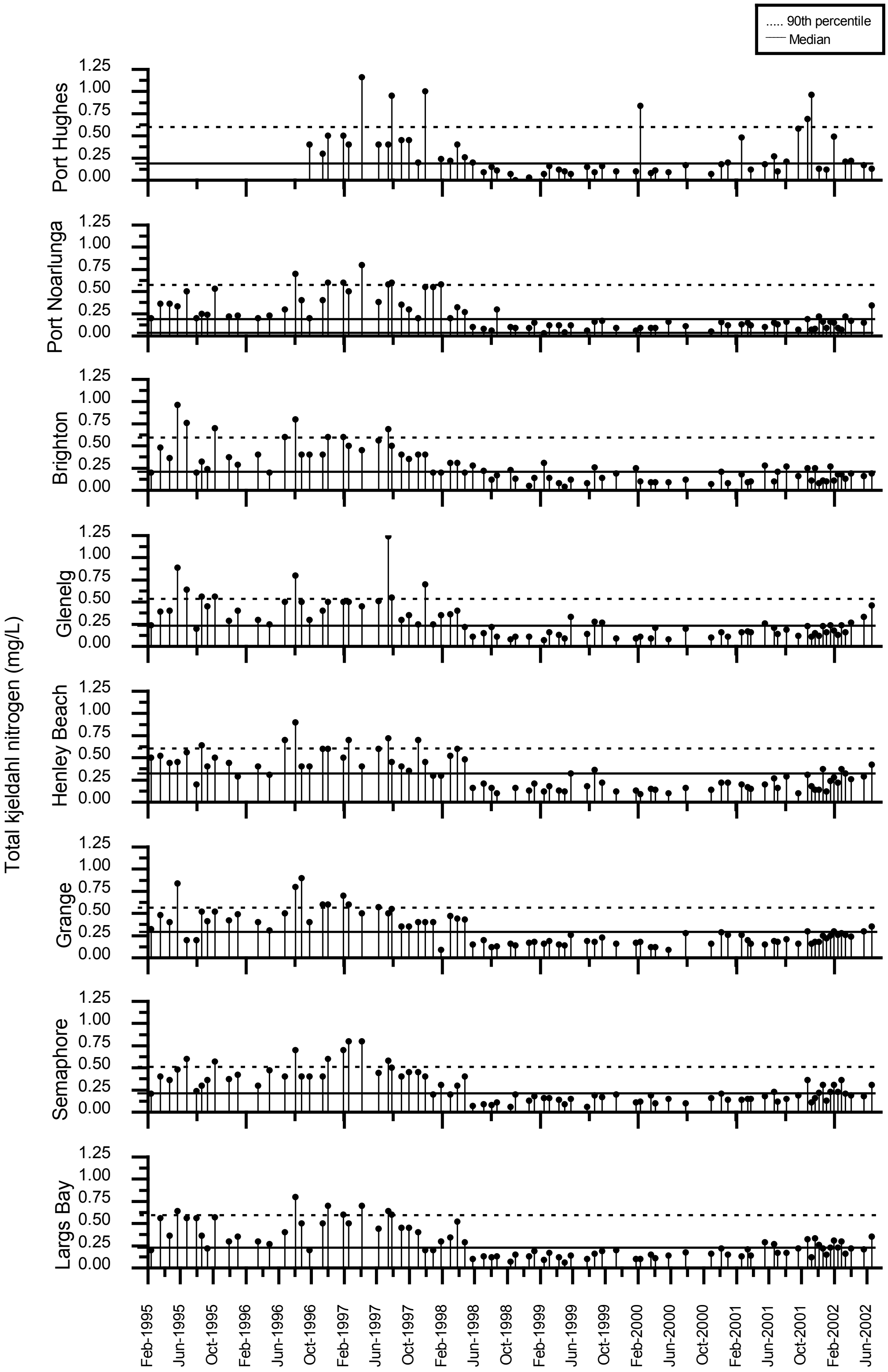

Figure 39 Time series plot for total Kjeldahl nitrogen (TKN) 1995–2002

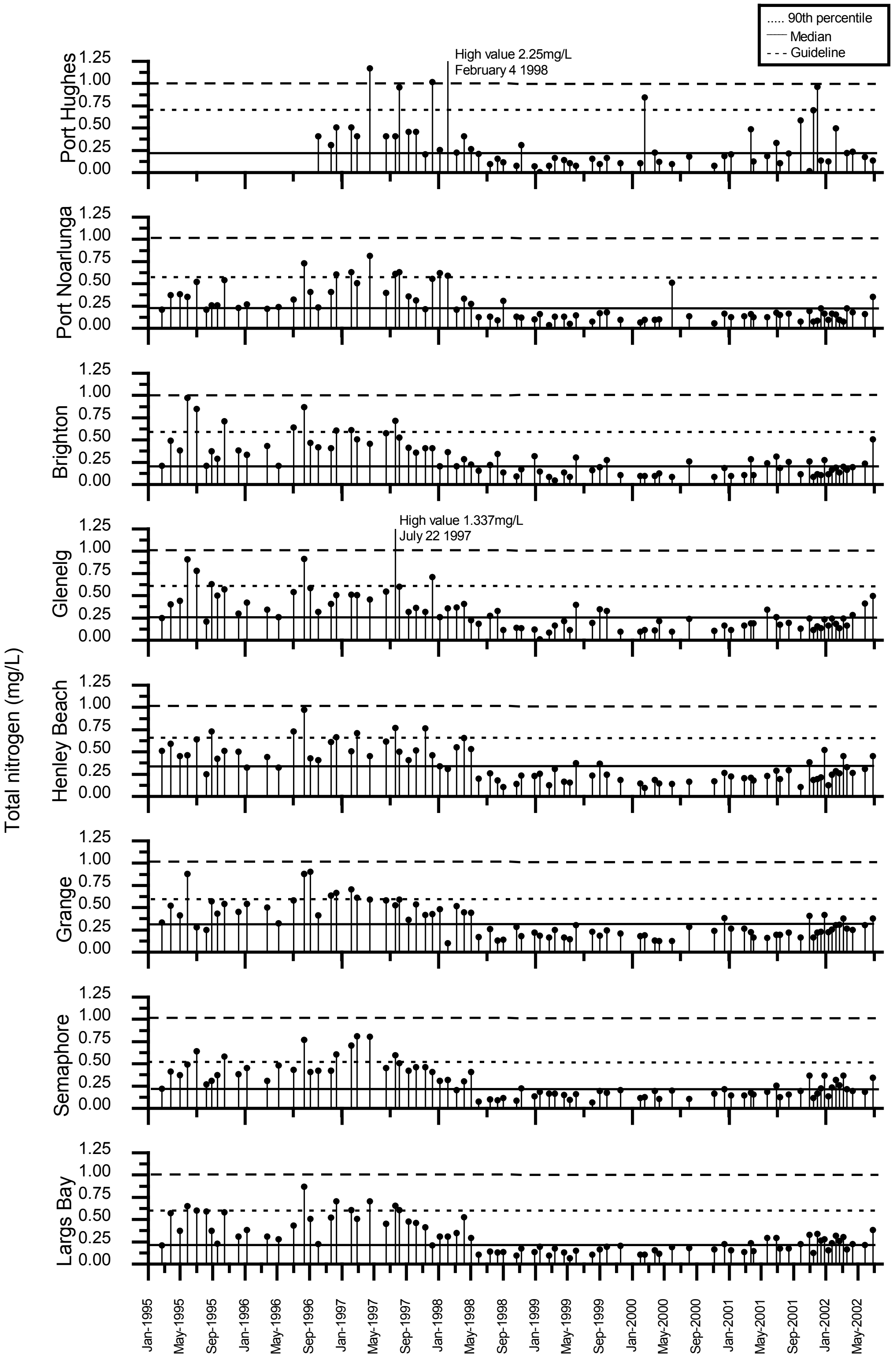

Figure 40 Time series plot for total nitrogen 1995–2002

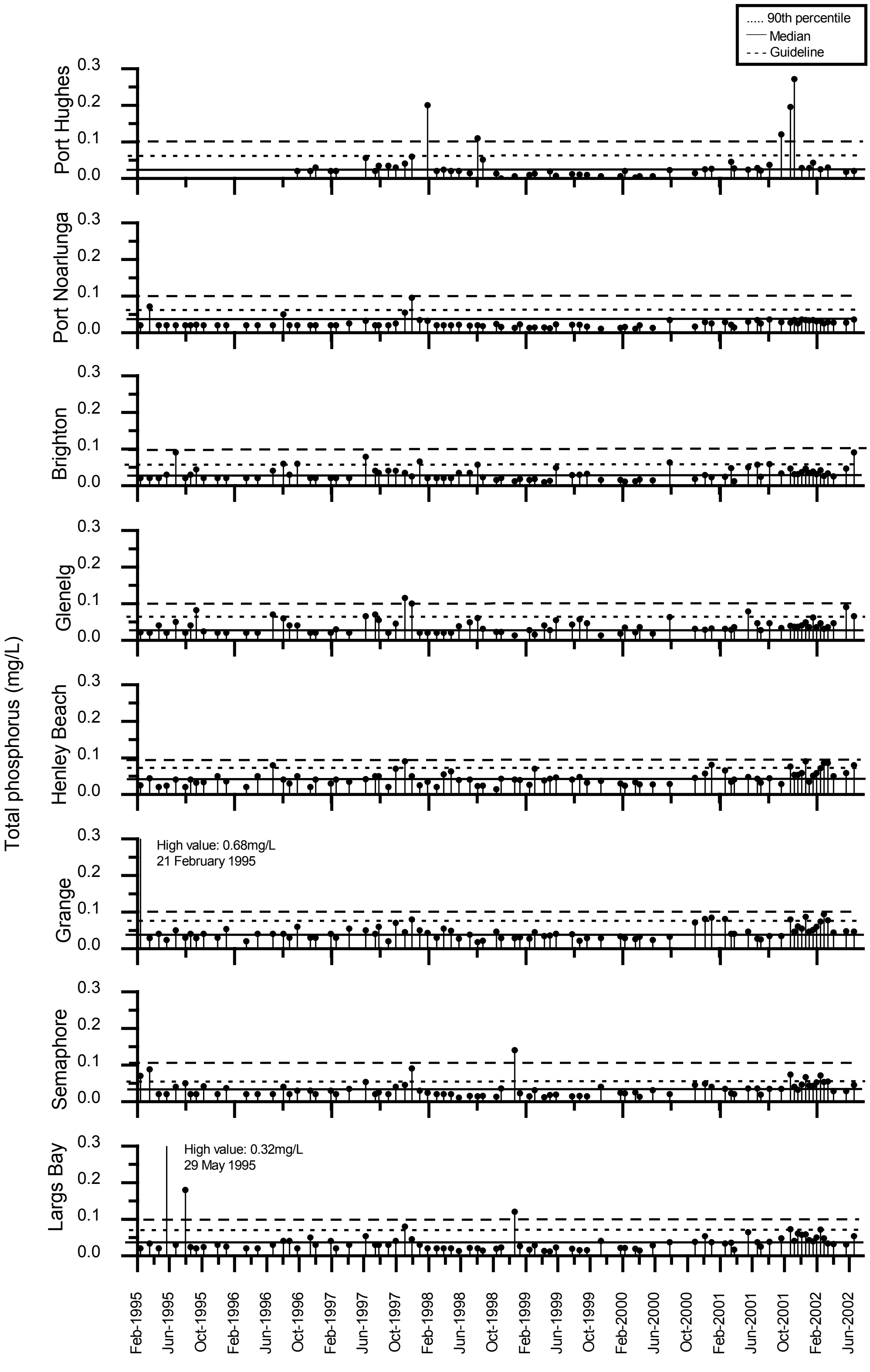

Figure 41 Time series plot for total phosphorus 1995–2002

Algae

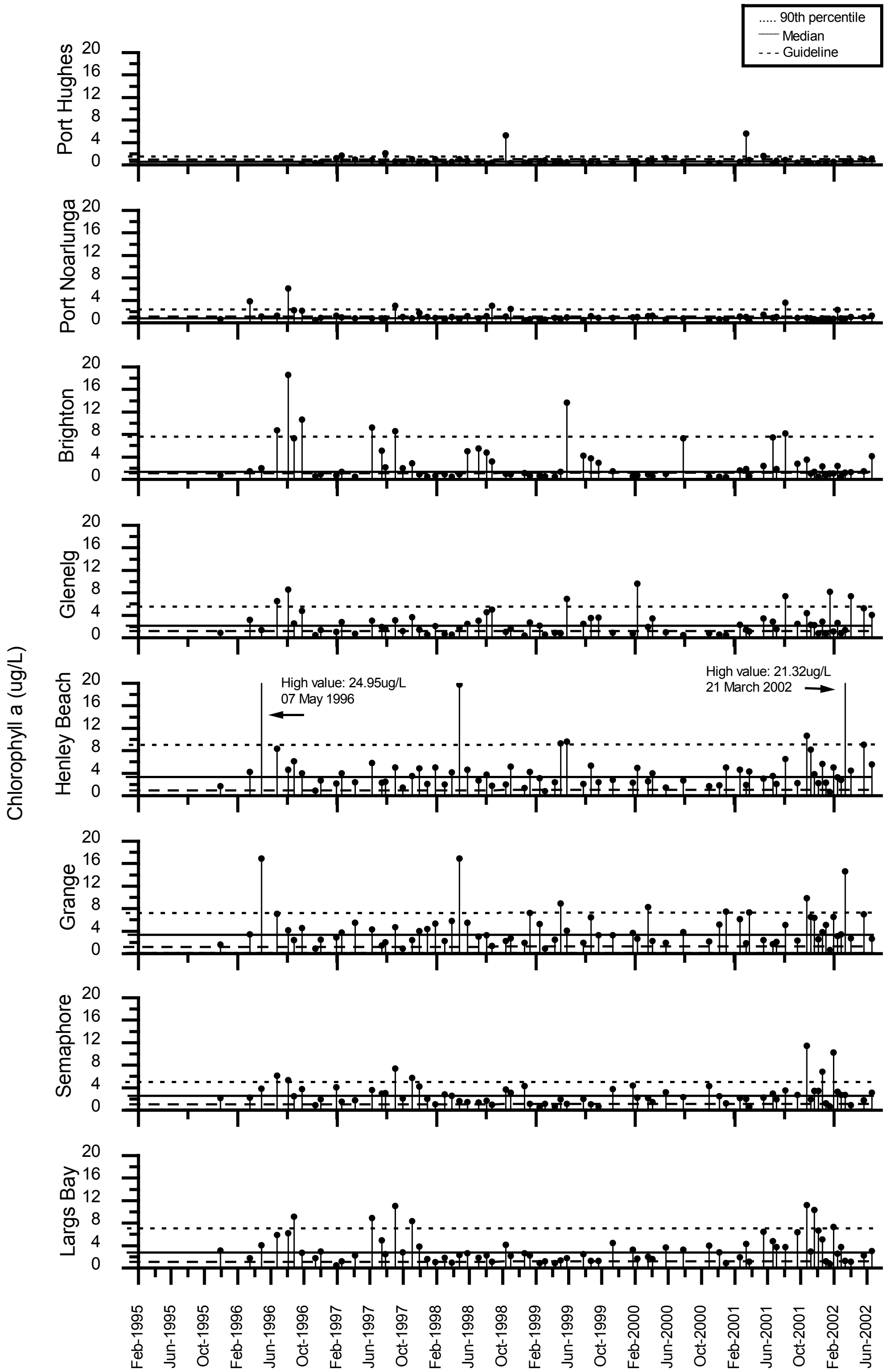

Figure 42 Time series plot for chlorophyll *a* 1995–2002

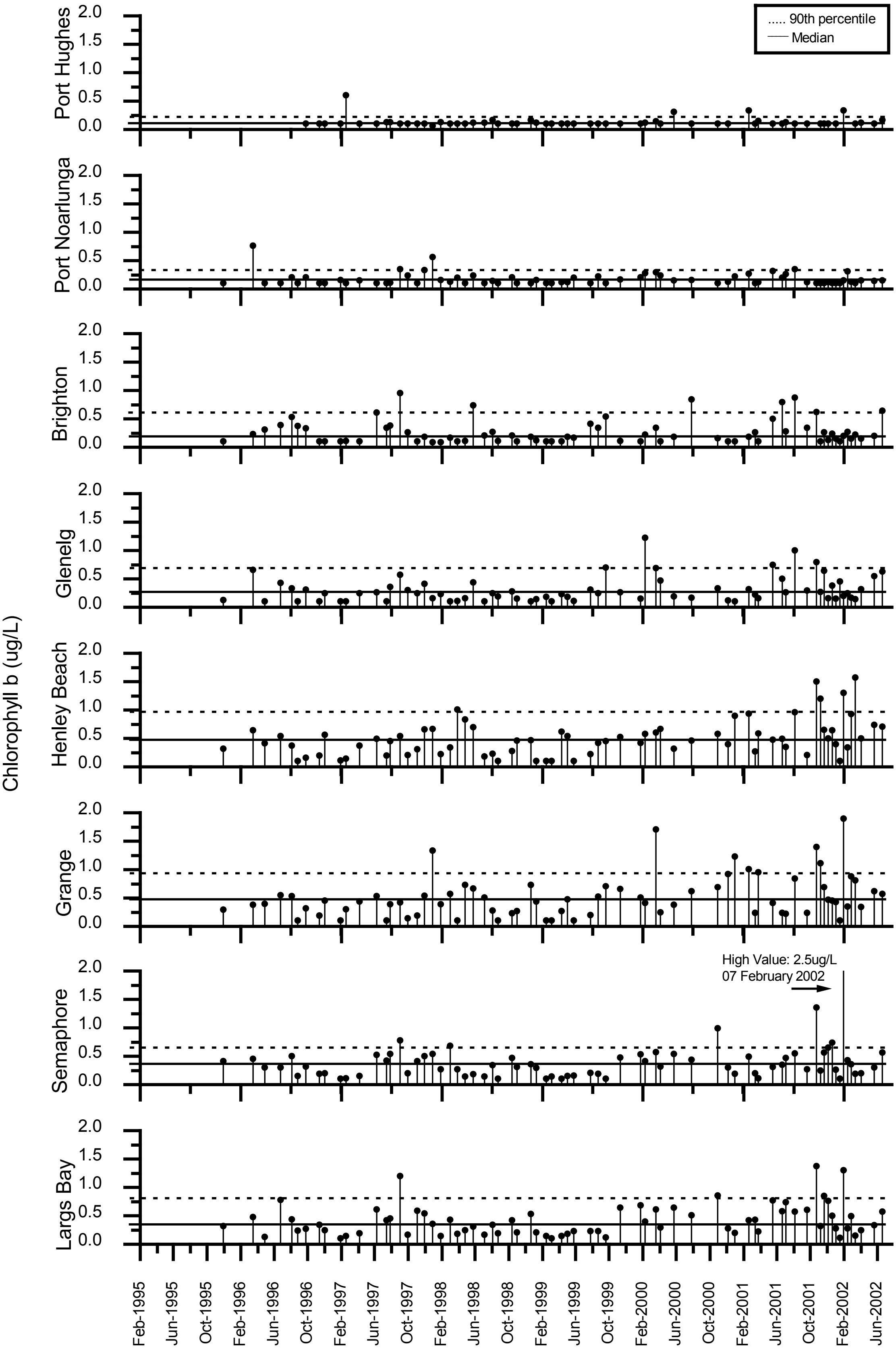

Figure 43 Time series plot for chlorophyll *b* 1995–2002

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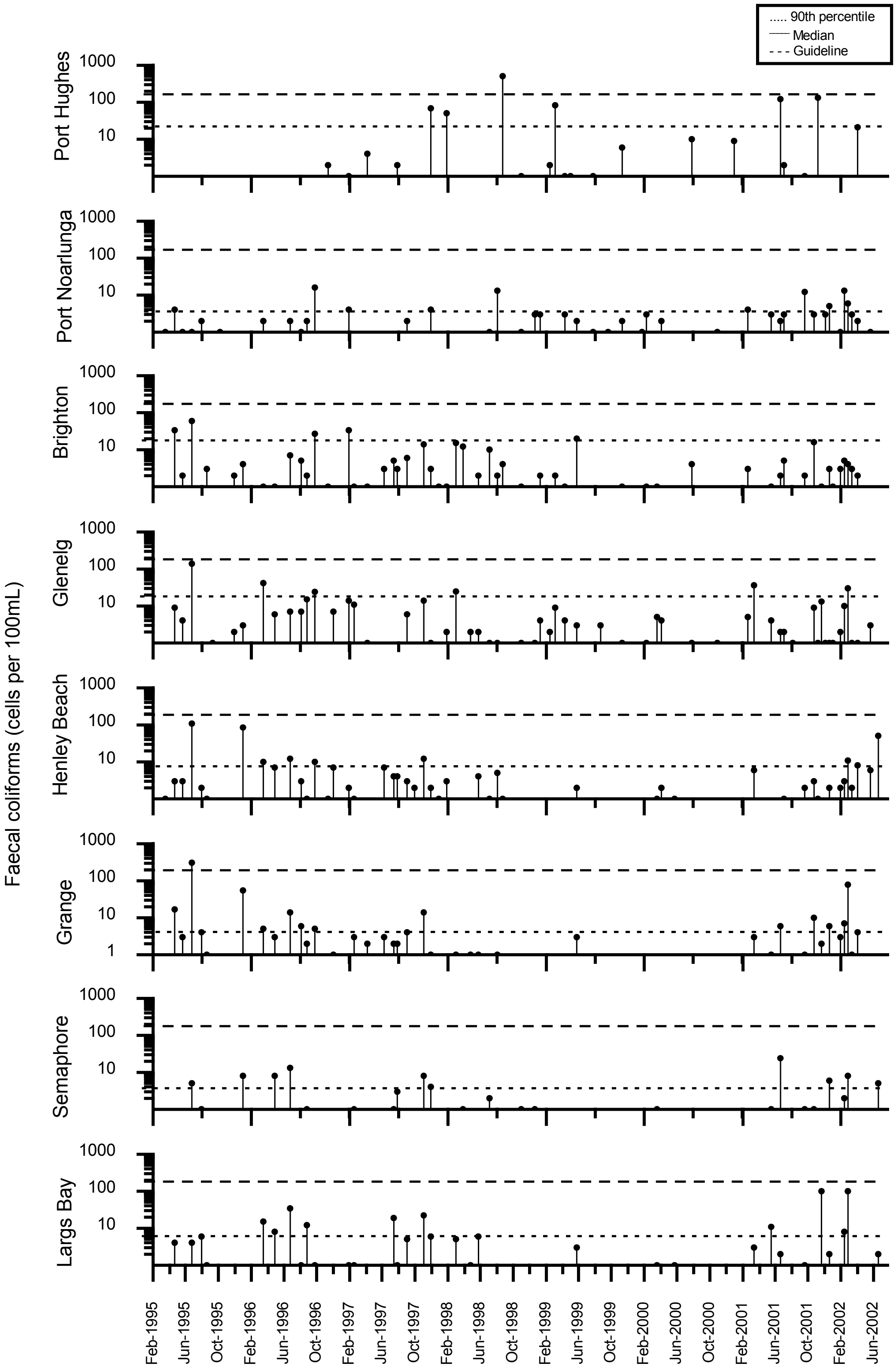

Figure 44 Time series plot for faecal coliforms 1995–2002

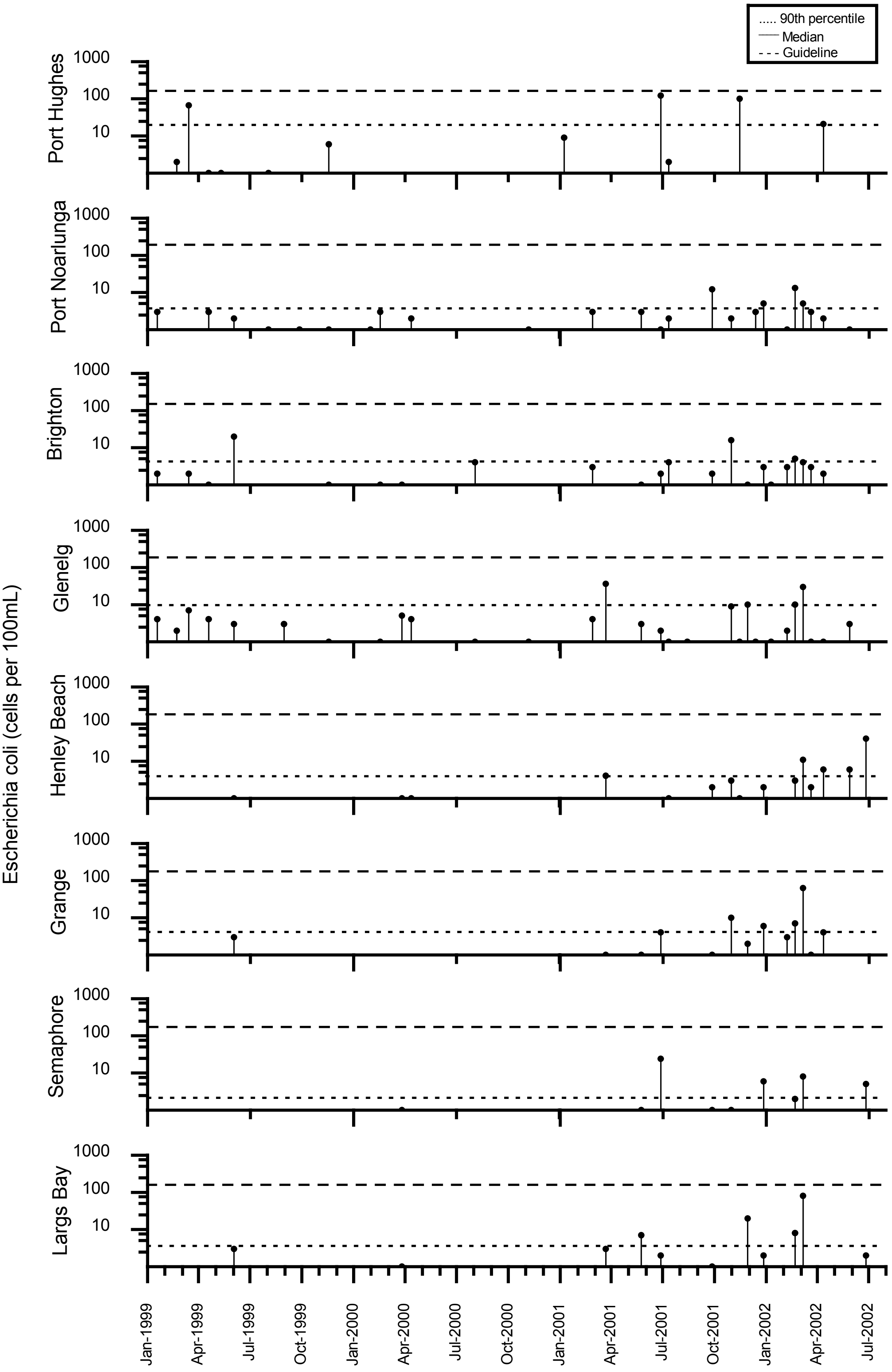

Figure 45 Time series plot for *Escherichia coli* 1995–2002

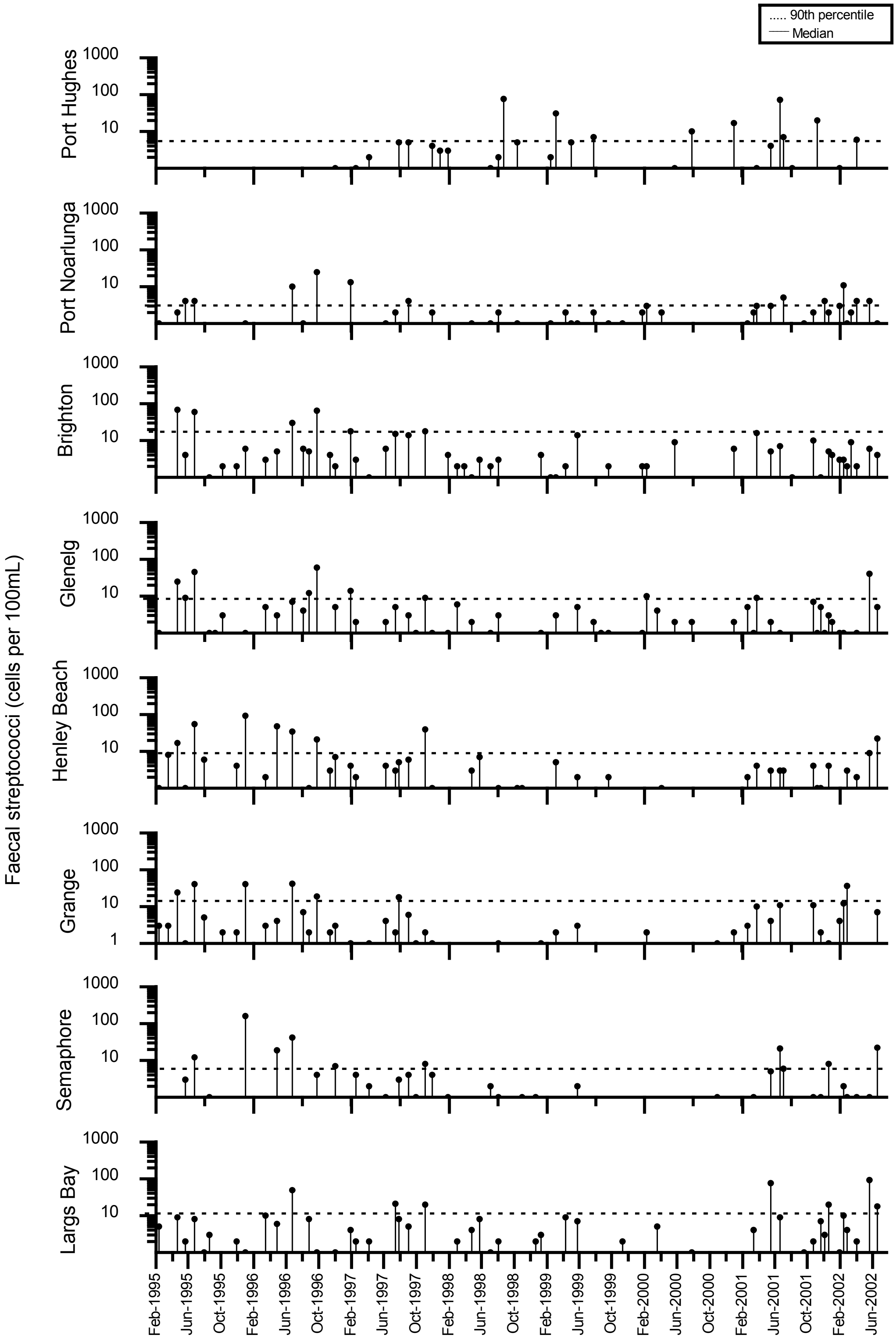

Figure 46 Time series plot for faecal streptococci 1995–2002

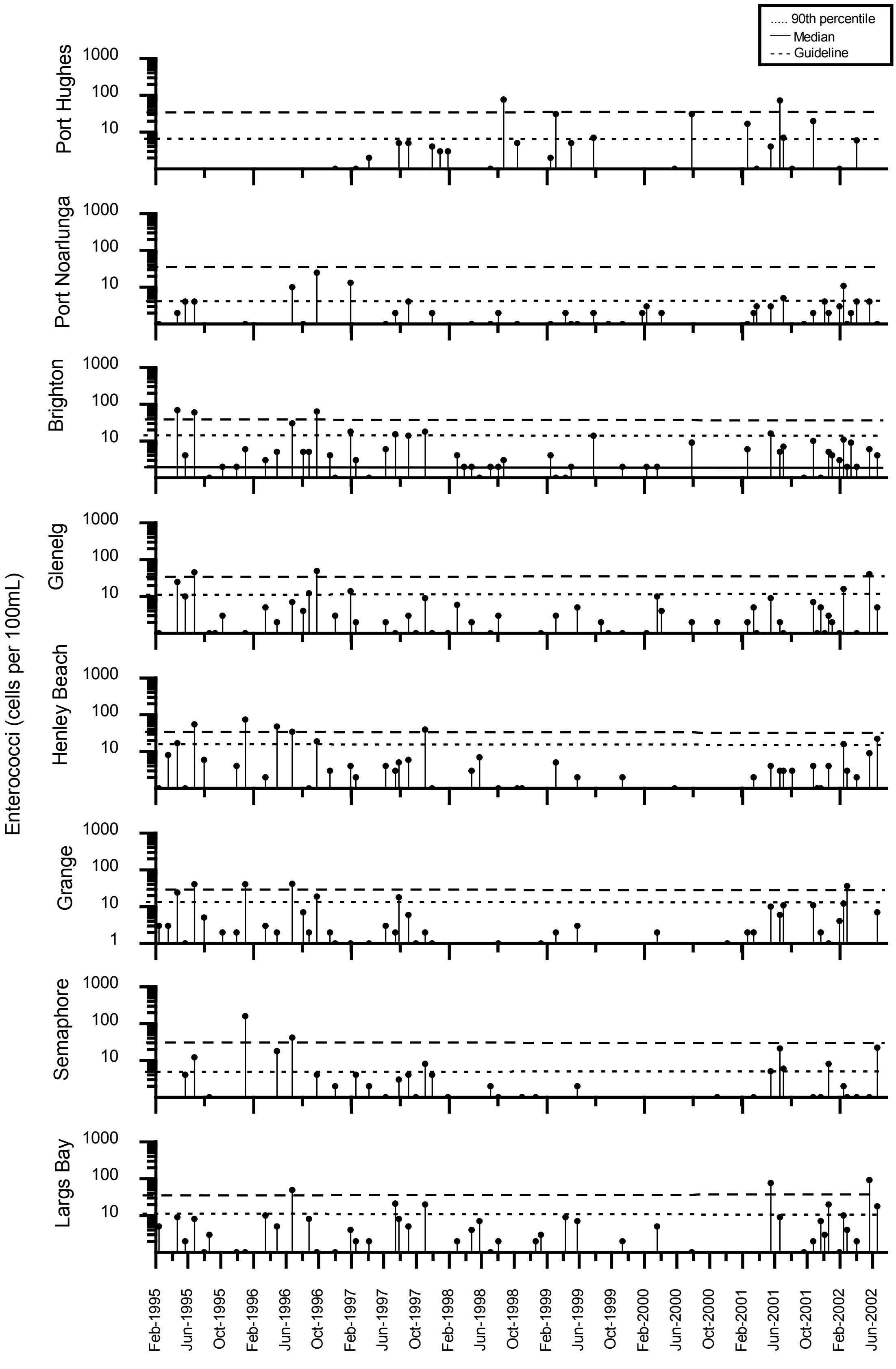

Figure 47 Time series plot for enterococci 1995–2002