- Davies and Kalish, 1989: water quality survey of upper estuary. Monitored physico-chemical parameters at 12 sites on a monthly basis. Also surveyed fish populations, tested fish for metals;
- TasUni/Aquahealth/HECEC, 1989 - 1995: series of sediment and macroinvertebrate surveys of the upper estuary on characteristics and distribution of paper mill sludge;
- CSIRO, 1992 - 1994: as part of CSIRO Coastal Zone Program, conducted a series of physical oceanography and water quality surveys (nutrients, metals, other hydrochemical data). Some circulation modelling also completed;
- Dineen and Noller (DELM), 1995: snapshot survey of entire estuary for heavy metals in biota (10 -30 sites); fieldwork carried out in 1990;
- Coughanowr (DELM), 1995: Derwent Estuary Nutrient Program. Fortnightly surveys of nutrients, TSS and physico-chemical parameters at 51 sites over a 1-year period (1993/1994);
- Pirzl, 1996: snapshot survey of sediments at 40 sites throughout estuary (texture, % LOI, heavy metals);
- DELM, 1994 - present: bimonthly monitoring of physical parameters, nutrients, chl *a*, phytoplankton at 20 - 25 sites throughout estuary.

6 Environmental quality of the Derwent Estuary

6.1 Suspended particulate matter

Suspended particulate matter (also termed non-filterable residues or total suspended solids) consists of silt and clay, phytoplankton, decaying organic matter and other particles derived from both natural and anthropogenic sources. Suspended particulate matter (SPM) levels in estuaries often vary widely in response to river discharges, wind and tidal mixing, phytoplankton blooms and other factors. Typically, SPM tends to accumulate and thus is highest at the interface between salt and freshwater. In the Derwent, the turbidity maximum is generally found at the toe of the salt wedge between New Norfolk and Bridgewater.

High levels of SPM may adversely affect aquatic ecosystems both when in suspension and during settling. In suspension, high SPM levels may reduce light penetration, affecting primary production. As particulate matter settles out, it may also smother sessile organisms and change the nature of the substrata. ANZECC guidelines for the protection of aquatic ecosystems recommend that increases in SPM should be limited such that optical guidelines are maintained and the seasonal mean nephelometric turbidity does not change by more than 10%. Aquaculture guidelines recommend that SPM levels in marine waters should not exceed 10 - 25 mg/L (depending on the species), while previous US and European guidelines recommended acceptable SPM levels of 25 mg/L (ANZECC, 1992).

The largest external source of suspended particulate matter to the estuary is the Derwent River, while urban run-off probably contributes the largest anthropogenic/natural load, followed by ANM and sewage treatment plants. Internal and oceanic sources also undoubtedly contribute to SPM levels within the estuary via phytoplankton production and sediment resuspension.

SPM was monitored as part of Derwent Estuary Nutrient Program, which found that concentrations averaged about 8 mg/L throughout the estuary, with slightly higher values observed at depth and in the lower estuary, and slightly lower values in surface waters of the upper and middle estuary (Coughanowr, 1995). These concentrations are relatively low, as compared to other estuarine systems, however, SPM levels were not monitored at the freshwater/saltwater interface, where concentrations should be highest. Davies and Kalish (1989) also monitored SPM in the upper estuary and found concentrations to be typically low (<100 mg/L), with elevated levels associated with the toe of the salt wedge and with high river flows. At no time were SPM levels sufficient to directly harm freshwater aquatic biota.

6.2 Organic matter/sludge

Organic material in estuaries is derived from living material, either directly (from phytoplankton, macroalgae, aquatic plants) or indirectly (from terrestrial organic matter), and is also a constituent of many waste materials and effluents - particularly sewage, wood and food processing.

Organic matter consists predominantly of carbon, in both particulate and dissolved forms, and is usually directly measured as total organic carbon (TOC), dissolved organic carbon (DOC) or particulate organic carbon (POC). In most surface waters, DOC levels exceed POC levels, and are in the range of 1 - 20 mg/L; but during river floods and throughout the year in turbid rivers, POC is the most abundant form. An indication of the amount of organic matter present in water can also be obtained by measuring related properties, principally chemical oxygen demand (COD) and biochemical oxygen demand (BOD). In most samples, COD>BOD>TOC. In sediments, organic matter is often approximated by measuring % loss on ignition (% LOI).

Typical carbon concentrations in surface waters are indicated below (Chapman, 1992):

COD	<20 - >200 mg/L
BOD	<2 - >10 mg/L
TOC	<1 - >100 mg/L

Humic and fulvic acids constitute the majority (up to 80%) of dissolved organic carbon in fresh water bodies. Humus is derived from soils and wetlands or can be formed directly in water as a result of biochemical transformations. It is separated into fulvic and humic acid fractions, each being an aggregate of many organic compounds of different masses. These natural organic compounds are not usually toxic, but may exert major controlling factors on the hydrochemical and biochemical processes in a water body. During chlorination, humic and fulvic acids act as precursor substances in the formation of trihalomethanes, such as chloroform. In addition, these compounds determine the speciation of heavy metals because of their high complexing ability, and often affect the toxicity and mobility of metal complexes. Fulvic and humic acid concentrations are usually in the range of tens to hundreds of µg C/L, but can be much higher in marshy/woodland areas. These compounds are difficult to measure directly, and DOC is often used as an approximation.

Large inputs of organic matter can have a number of effects: the carbon in organic matter (together with other nutrients) may stimulate bacterial and algal growth, resulting in accelerated primary productivity and subsequent oxygen depressions. Organic matter also has a strong affinity for metals, hydrocarbons, pesticides, and many other contaminants, and may scavenge these substances from the water column, transferring them through the food chain or sequestering them in sediments. At very high loading rates, organic matter may accumulate as organic-enriched sludge, characterised by very low oxygen levels, impoverished benthic fauna and production of toxic gases such as hydrogen sulphide and methane. The major anthropogenic source of organic material to the Derwent is ANM, followed by sewage treatment plants and urban runoff.

No data is available for water-column organic matter in the Derwent Estuary or the Derwent River, although the river has been described as being humic-rich by a number of investigators. There have been numerous investigations of the organic-rich sediments (sludge) of the upper and middle estuary. The majority of this sludge is attributable to ANM, particularly prior to 1988, when pulp mill effluent was discharged to the river without treatment. In August 1988, Stage 1 of primary treatment commenced, reducing the discharge of solids from approximately 100 tonnes/day to 50 tonnes/day. In August, 1990, Stage 2 primary treatment was commissioned, further reducing the solids loading to below 15 tonnes/day. Combined, the two stages also reduced BOD loads by 15 to 20% (D. Richardson, ANM, pers. comm..). By the late 1980s, it was estimated that 800,000 cubic metres of sludge had accumulated in the river between ANM and Green Island - in part due to low river flows and few major floods between 1975 and 1988. The majority of this sludge was flushed out in a flood during October 1988, resulting in problems with floating rafts of sludge, fish kills and noxious odours, and was presumably flushed from the estuary or settled out further downstream.

Since this event, a series of sludge surveys have been carried out in the estuary above the Bowen Bridge to determine sludge characteristics, changes in distribution and estimated volume. In some surveys, heavy metals and macrobenthos were also included. The majority of samples consisted of surface grabs, with some limited coring to better estimate volumes. Sludge-related surveys carried out to date include the following:

- February 1989 - physico-chemical properties and heavy metals (HECEC/TasUni, 1989);
- February/March and July 1990 - physico-chemical properties and macrobenthos (Garland, Horwitz and Holloway, 1990; Horwitz and Blake, 1992);
- September-November 1990 - physico-chemical properties, heavy metals, some toxicology tests (Garland and Statham, 1991);
- November 91 and February/March 1992 - physico-chemical properties (Garland and Statham, 1992);
- March 1995 - physico-chemical properties and macrobenthos (Garland and Jameson, 1995; Moverley and Garland, 1995; Garland, 1995).

Typical pulp mill-derived sludges in the upper estuary are described as being green to black in colour, gelatinous in texture and having a sulphurous odour. Redox potential values are negative (-70 to -170) and pH values range from 6 to 7. Sludges have low % solids (8 - 25%), high % LOI values (20 - 65%) and wood fibre content of up to 20% (Garland and Jameson, 1995).

Some significant improvements have been observed since the surveys were initiated in 1989: the sludge has 'aged' in many areas of the upper estuary, and the sludge-affected area is decreasing, as is the total estimated volume, from approximately 800,000 cubic meters in 1992 (Garland and Statham, 1992) to 568,000 cubic meters in 1995 (Garland and Jameson, 1995). It is unclear, however, to what degree this is due to in situ degradation as opposed to redistribution, since there were several significant river floods in the interim.

The macroinvertebrate community in the upper estuary has also recovered significantly, particularly in the vicinity of the outfall. In 1992, sediments for a distance of 5 km below ANM's outfall were found to be essentially azoic (lifeless), and the benthic fauna in many areas of the upper estuary were found to be impoverished (Horwitz and Blake, 1992). The 1995 survey indicated a generally higher species richness and total abundance of individuals in samples; this trend was widespread and appeared to be related to temporal changes throughout the upper estuary. However, there were some notable improvements, particularly the colonisation of the previously azoic zone downstream of ANM's outfall (Moverley and Garland, 1995).

A recent study of estuarine sediments (Pirzl, 1996) also confirms that the majority of sediments between New Norfolk and Tasman Bridge contain high levels of organic matter (>20% LOI) and a high proportion of fines (>90%).

6.3 Dissolved oxygen

Dissolved oxygen (DO) levels in estuarine waters are dependent on a number of factors, including temperature, salinity, biological activity, turbulence and mixing, and may fluctuate widely over a period of hours, weeks or months. Oxygen dissolves more readily at low temperatures and low salinities; thus DO levels are significantly higher in cold, freshwater than in warmer seawater. Aquatic plants are net producers of oxygen during daylight hours, but are net consumers at night; therefore, DO levels also vary over a 24 hour period (diel cycle), with the lowest concentrations occurring around sunrise. Saturated levels of DO in a healthy estuarine environment generally lie between 6.5 and 9 mg O/L (as measured over at least one diel cycle), as levels of < 5 mg are known to be stressful to many species of fish (ANZECC, 1992). Unusually low or high DO levels may be indicative of a large plant biomass and eutrophic conditions.

The following factors may lead to or exacerbate dissolved oxygen depressions:

- elevated water temperatures;
- stratified conditions (i.e. poor vertical mixing);
- high organic loading.

In the Derwent, these conditions are usually present during summer months in the upper estuary, and a number of studies have documented low dissolved oxygen levels, particularly in the area between New Norfolk and Bridgewater.

Davies and Kalish (1989) documented seasonally low dissolved oxygen levels in the upper estuary during a series of surveys conducted in 1988/1989. They noted that only surface water less than two meters deep were suitable for fish life, and that a DO sag (5-6 ppm) was observable downstream of Boyer for approx. 3 months/year. At depth, oxygen levels at depth were too low to support any benthic life between New Norfolk and Bridgewater (0.1 to 2 ppm) for most of the year. These low oxygen levels were attributed to a very high respiratory demand from underlying organically enriched sediments, exacerbated by poor flushing.

The Derwent Estuary Nutrient Program (1993-1994) also observed seasonally low dissolved oxygen levels at depth in the upper estuary, with levels of < 2 to 4 mg/L frequently recorded at depth during the summer months (Coughanowr, 1995). ANM's river monitoring program also shows a consistent dissolved oxygen sag downstream of Boyer, with mid-summer levels of < 2 mg/L frequently recorded at depth. A detailed survey carried out by Environment Tasmania near dawn on 15 January 1997 confirm these findings (Figure 25).

One problem with these surveys is that they all consist of spot sampling, carried out during daylight hours, when DO levels tend to be higher - and thus probably do not reflect the lowest oxygen levels occurring. Ideally, DO should be monitored continuously over an extended period, so as to document shifts in DO during daylight and darkness.

6.4 Pathogens and faecal indicator bacteria

There is a long international experience of disease outbreaks associated with contaminated water. Disease-causing micro-organisms (pathogens) associated with bathing areas include salmonellae, shigellae, enteropathogenic *Escherichia coli*, cysts of *Entamoeba histolytica*, parasite ova, enteroviruses and infectious hepatitis. Generally, the most common types of diseases that have been associated with swimming and other primary contact are eye, nose and throat infections, skin diseases and gastrointestinal disorders. Gastrointestinal disorders, hepatitis and other diseases may also be caught by ingesting contaminated seafood, particularly shellfish. In severely contaminated areas, there can also be risks associated with secondary contact recreation (wading, fishing, rowing, etc.).

Direct detection of pathogens is not a feasible option for routine assessments, since they occur intermittently and are difficult to recover from water. For this reason, "indicator" micro-organisms are generally used to assess the health risks associated with pathogens in recreational waters. Several different micro-organisms are used as indicators of health risks. NH&MRC favours the use of faecal coliforms, a subgroup of the total coliform population that are easy to measure and are present in virtually all warm blooded animals. Faecal coliform bacteria in human faeces comprise about 97% *E. coli*, around 2% *Klebsiella*, and a further 2% *Enterobacter* and *Citrobacter* together.

A number of investigators, including McBride *et al.* (1991), have documented a number of deficiencies with the use of faecal coliforms as indicator organisms of health risks in recreational waters and waters used for shellfish growing. Recent studies have shown poorer relationships between faecal coliform densities and illness rates in bathers than are obtained using *enterococci* (marine waters) and either *enterococci* or *E. coli* in fresh waters. Further, there is now considerable evidence that faecal coliforms die off faster than pathogens under certain circumstances; therefore, pathogens may go undetected during beach monitoring programs, resulting in the disease risks being underestimated. Because of this, New Zealand, Canada and the USA now recommend guidelines for recreational waters based on either *E. coli* or *enterococci*.

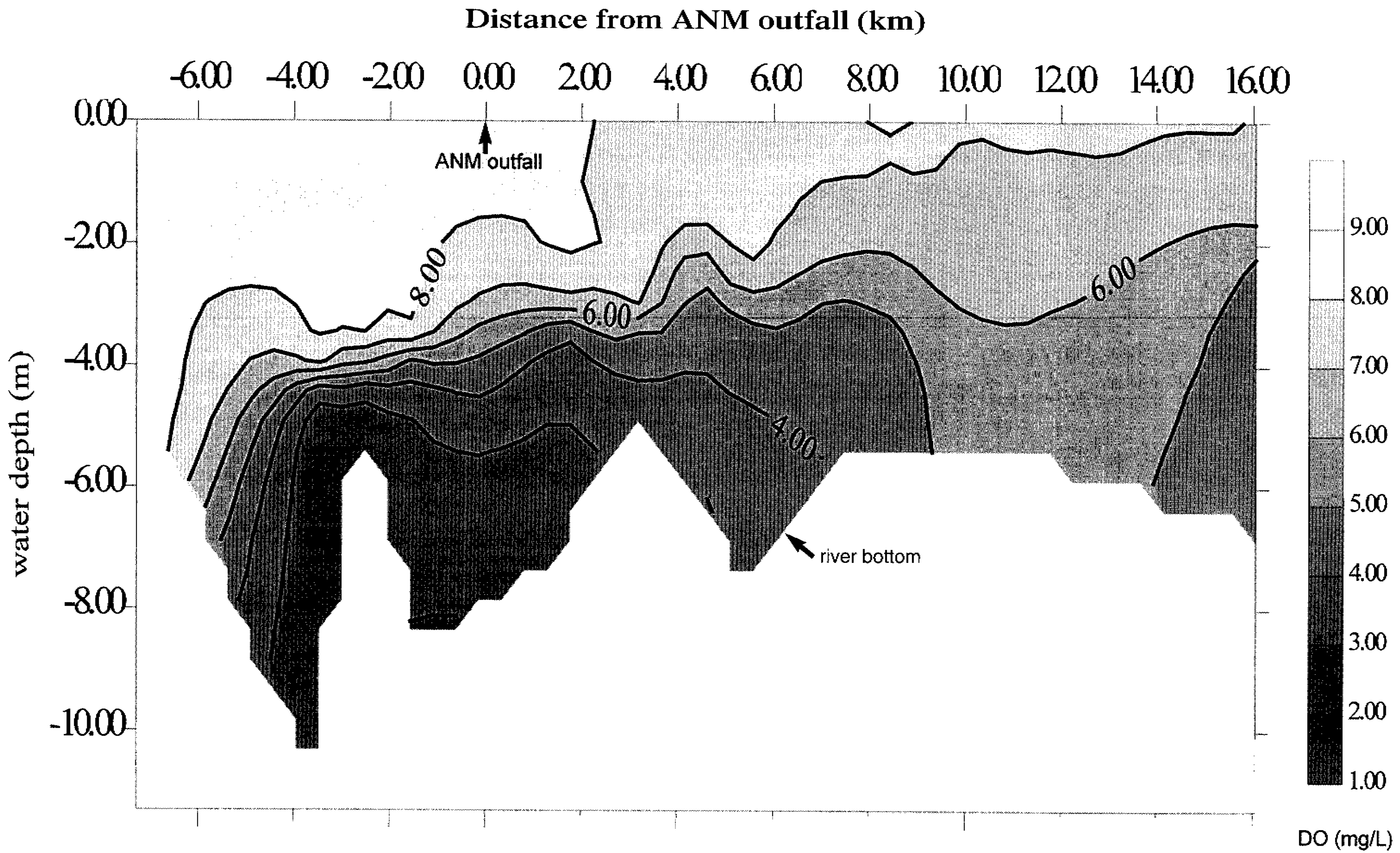


Figure 25 Dissolved oxygen profile of the upper Derwent Estuary 15 January 1997

To minimise risks, ANZECC recommends the use of both the NH&MRC guidelines for faecal coliforms and guidelines recommended by McBride *et al.* (1991) for *enterococci*. See Table 25 below for specific recommended levels.

Table 25 ANZECC guidelines for faecal indicator bacteria in recreational waters

Primary contact recreation	The median bacterial content in fresh and marine waters taken over the bathing season should not exceed: • 150 faecal coliform organisms/100 mL, with four out of five samples containing less than 600 organisms/100 mL.* • 35 enterococci organisms/100 mL, with a maximum number in any one sample 60-100 organisms/100 mL.
Secondary contact recreation	The median bacterial content in fresh and marine waters should not exceed: • 1,000 faecal coliform organisms/100 mL, with four out of five samples containing less than 4,000 organisms/100 mL.* • 230 enterococci organisms/100 mL, with a maximum number in any one sample 450-700 organisms/100 mL.

* These guidelines are based on a minimum of five samples taken at regular intervals, within a thirty-day period.

The Derwent bacteriological monitoring program

The Derwent Estuary bacteriological monitoring program was initiated in 1987 as a joint monitoring effort between Local Councils, the Department of Community and Health Services (DCHS) and DELM and has been operating for nearly 10 years. The purpose of the program is to monitor water quality at bathing and other recreational areas throughout the Derwent Estuary. Approximately 30 sites have been monitored (15 by DELM, 15 by Councils) at the locations indicated in Figure 26. In 1996/1997, Hinsby Beach and Browns River were added to the list.

A preliminary review of summarised data for 1987/88 through 1993/94 (DCHS, 1994), compared with data collected during 1995/6 and 1996/97 suggests that there has been a significant decrease in median faecal coliform levels at a number of sites. Improvements in water quality were particularly notable at sites near the middle reaches of the estuary, for example, at Kangaroo Bay, Lindisfarne Bay, Geilston Bay, off Bellerive and Howrah, and at Prince of Wales Bay, New Town Bay and Battery Point. It is recommended that this data be compiled and fully analysed to better assess water quality improvements.

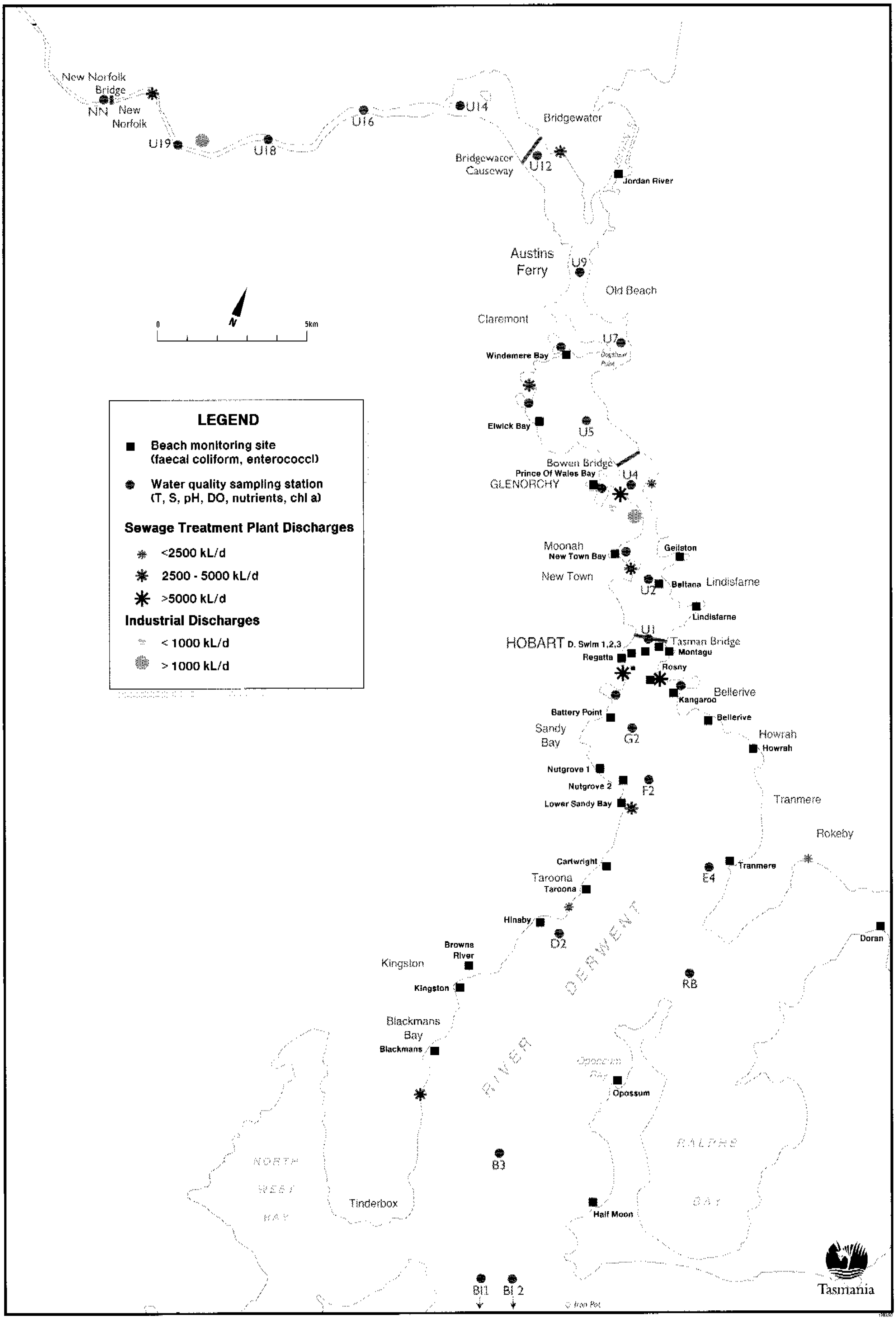


Figure 26 Derwent Estuary water quality monitoring sites 1996

Water samples are collected every Monday morning during the months November through March. Samples are cultured and analysed for faecal coliform and enterococci (presumptive) by the Public Health Laboratory. Results are shared between councils, DELM and DCHS. Results for the two most recent monitoring seasons are presented in Figures 27 and 28, which illustrate median faecal coliform and enterococci values along the eastern and western shores of the estuary. It should be noted that 1995/1996 was an unusually cool and wet summer, and this is reflected by the generally higher values recorded during this season.

Which sites did not meet guidelines for primary contact recreation?

Results from the 95/96 and the 96/97 summer season indicated that the following sites had median faecal coliform and/or median enterococci levels in excess of recommended guidelines for primary contact recreation:

Table 26 Sites which did not meet bacteriological guidelines

site	1995/1996		1996/1997	
	F. coliform	*enterococci*	*F. coliform*	*enterococci*
Jordan River	X	X	X	X
Geilston Bay		X		
Windemere Bay	X	X		X
Elwick Bay	X	X		
New Town Bay	X	X		X
Regatta Pavilion		X		
Lauderdale Canal		X		
Blackmans Bay				X
Browns River	No data			X

In addition, a number of other sites failed to meet faecal coliform criteria which require that 4 out of 5 consecutive samples contain less than 600 organism/100 ml during part of the summer season, although median levels were within guidelines for the season as a whole. At nearly all sites, enterococci levels were occasionally >60, particularly at Browns River, Windemere Bay, Jordan River, Blackmans Bay, New Town Bay and Regatta Pavilion.

Which sites did not meet guidelines for secondary contact recreation?

In 1995/96, Jordan River exceeded guidelines for secondary contact recreation, with median faecal colifom levels of 670. None of the other sites showed median faecal coliform or enterococci levels in excess of recommended guidelines for secondary contact recreation. However, on several occasions, enterococci values exceeded 450 organisms/100 ml at approximately half of the sites.

Which sites had the lowest bacteriological levels?

The cleanest sites in the estuary were Opossum Bay, Half Moon Bay and Cartwright Point

What are the causes of bacteriological contamination?

Sources of contamination are varied and may include direct discharges of untreated sewage (e.g. the Sandy Bay outfall at Blinking Billy Point, spills and overflows, discharges from recreational vessels), inadequate disinfection of treated sewage, malfunctioning septic systems and faecal material washed into the estuary during rainfall events.

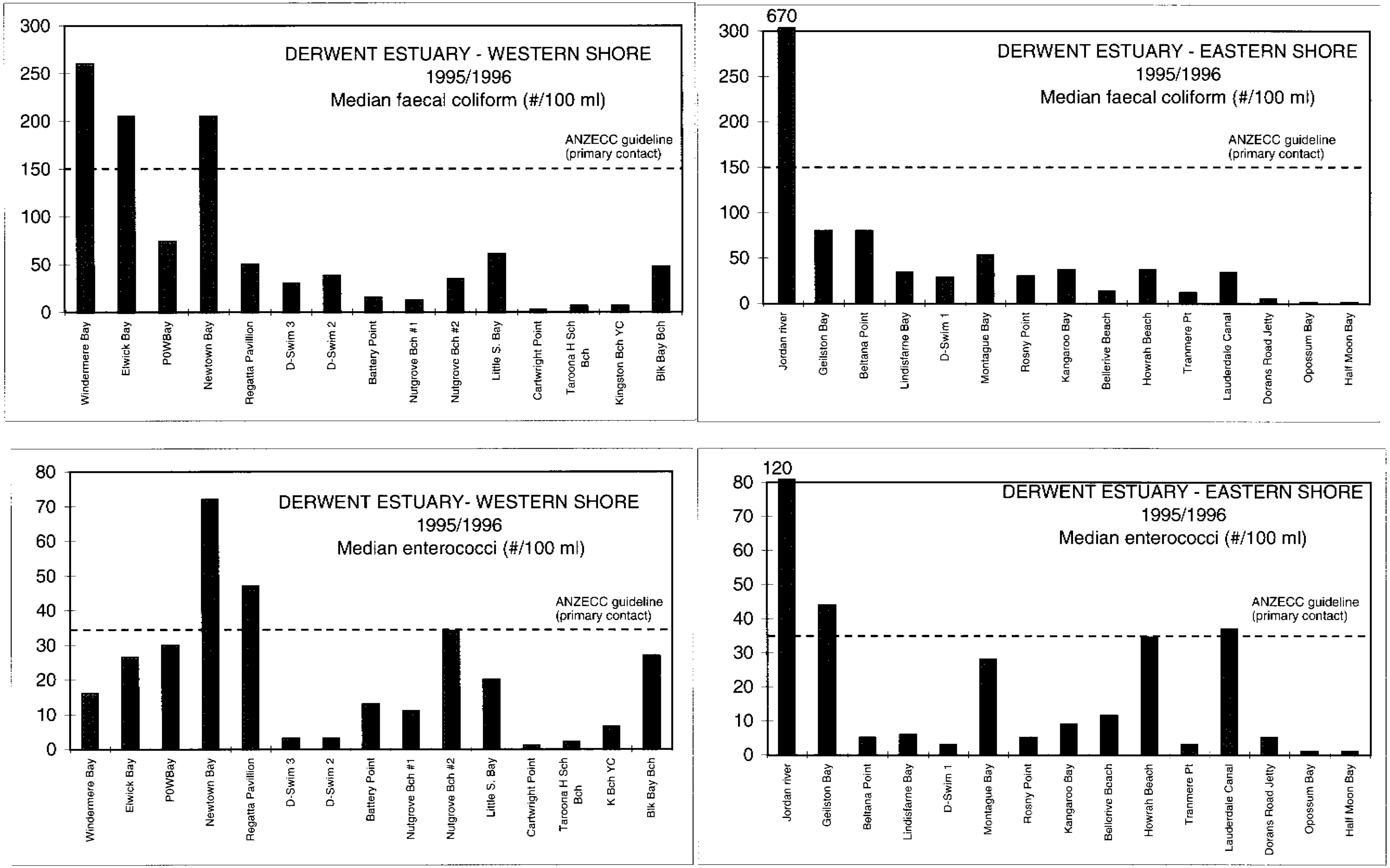
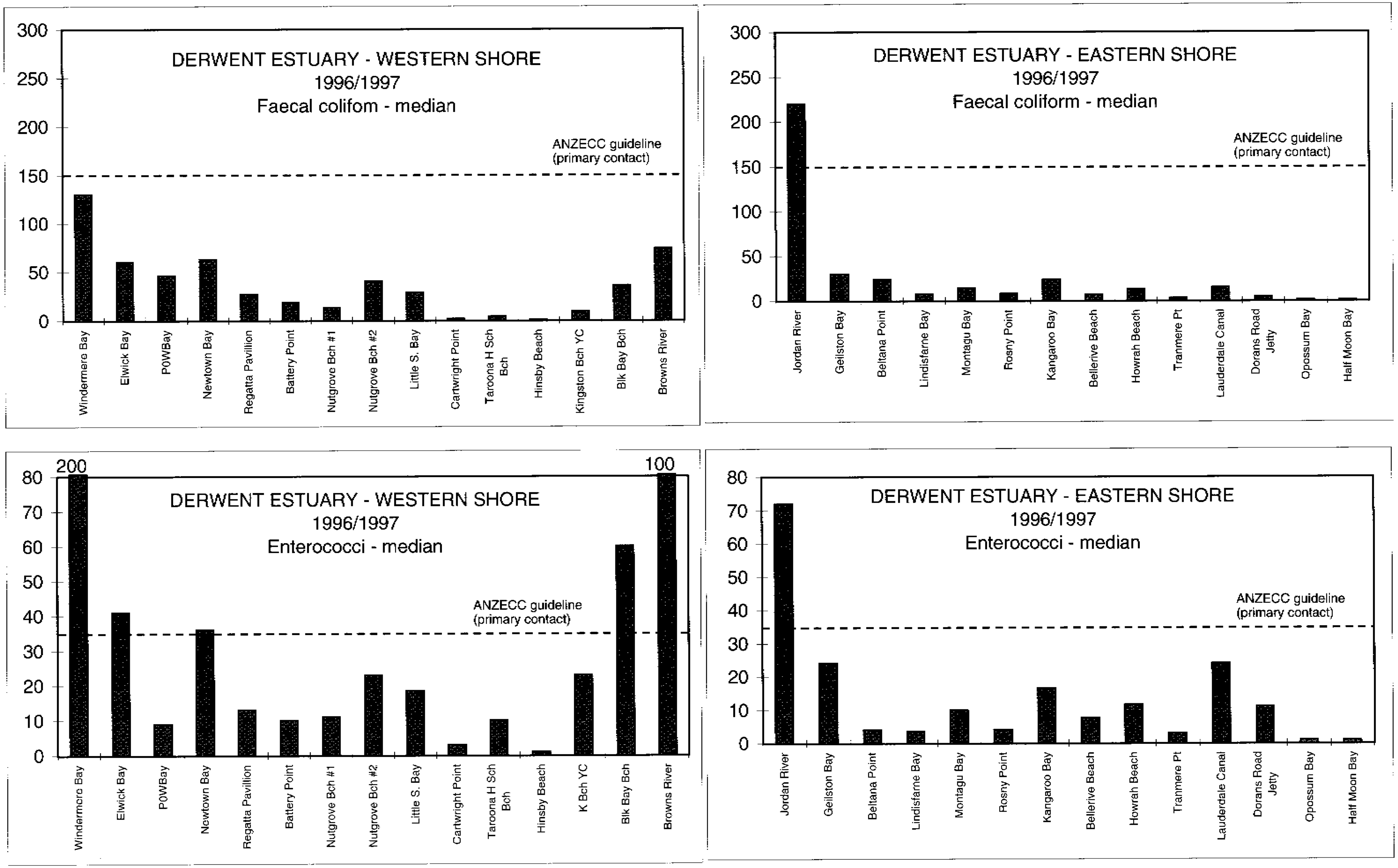


Figure 27 Bacteriological water quality in the Derwent - 1995/1996
(see Figure 26 for site locations)



DERWENT ESTUARY - WESTERN SHORE 1996/1997 Faecal colifom - median

DERWENT ESTUARY - EASTERN SHORE 1996/1997 Faecal coliform - median

DERWENT ESTUARY - WESTERN SHORE 1996/1997 Enterococci - median

DERWENT ESTUARY - EASTERN SHORE 1996/1997 Enterococci - median

Figure 28 Bacteriological water quality in the Derwent - 1996/1997
(see Figure 26 for site locations)

6.5 Nutrients

Estuaries, nutrients and algal blooms

A number of water quality problems have been attributed to elevated nutrient levels in estuaries, particularly the excessive growth of algae, which in extreme cases can become algal blooms. Excessive algal growth can have a number of adverse effects on estuarine ecosystems, including the following:

- gradual and often undesirable changes in the species and numbers of aquatic flora and fauna in the estuary;
- fluctuating oxygen levels in the water mass. Algae, like all plants, are net producers of oxygen during the daytime and net consumers at night. Excessive algal growth thus results in high oxygen levels during the day, but low levels at night, which can cause physiological stress to fish and other organisms. If the algal biomass is sufficiently high, oxygen levels may fall low enough to cause the death of fish and other organisms;
- blooms of certain toxic species of algae may result in the contamination of aquatic organisms, endangering human health (e.g. paralytic shellfish poisoning) and closing down aquaculture operations;
- diminished aesthetic appeal due to odours, scum, rotting algae and fish, and discoloration of the water.

Algal growth is broadly dependent upon four factors: light, temperature, salinity and nutrient supply. However, of these, only the nutrient supply can be controlled. Thus strategies to control algal problems have usually focused on the major nutrients (nitrogen and phosphorus), in particular by reducing the loads entering the system. The most biologically available form of phosphorus is orthophosphate (PO_4) and the most bioavailable forms of nitrogen are ammonia (NH_3) and nitrate (NO_3). Silicon has also been identified as a limiting nutrient for diatom growth.

Nutrient sources and dynamics

Nutrients are derived from a variety of natural and anthropogenic sources in the watershed and may be transported to the estuary via rainfall, rivers and streams, groundwater, surface runoff and direct discharges. In addition to external sources, significant quantities of nutrients may be derived from internal sources within the estuary (e.g. sediments) and from coastal waters.

Major anthropogenic sources of nutrients include sewage, industrial effluents, urban runoff, air pollution, agricultural and residential fertilisers, rubbish tips and numerous lesser sources. These are commonly categorised as either point-sources or diffuse sources. Point source discharges, such as sewage treatment plants or industrial discharges are usually easily identified, and as such can often be mitigated through wastewater treatment improvements. Diffuse sources, such as agricultural or urban runoff, are much more difficult to quantify and may require a broader catchment management approach for effective control.

Nutrients are constantly cycling in aqueous environments between the water column, the biomass, and the sediments. In order to fully understand the cycling and availability of nutrients in a given system, a complete nutrient "budget" is required, which accounts for the nutrients contained in each of these "pools", and the rates of transfer or "flux" of nutrients between the pools. The cycling of phosphorus, and particularly nitrogen, in estuarine systems is complex and linked to many other variables, including the type and distribution of biota and sediments, dissolved oxygen and pH levels, water temperature, and the presence of humic substances and other organic matter.

Nutrient guidelines

No absolute guidelines have been established for what constitutes safe or acceptable levels of nutrients in all estuaries, nor is this a feasible goal, given the unique characteristics of individual estuaries. Nuisance algal growth can be the result of a number of factors, including water temperature, salinity, circulation, water transparency and nutrient concentrations. Levels of nutrients which may induce nuisance algal blooms in a brackish, tropical estuary may have no effect on a well-flushed, temperate system.

The ANZECC guidelines (1992) have identified a range of nutrient concentrations at or above which problems have been known to occur in estuaries and coastal waters (see Table 27), however, they strongly recommend that site-specific studies be undertaken to determine appropriate concentrations for specific systems.

Table 27 ANZECC guidelines for nutrients in estuarine and coastal waters

	Estuaries	Coastal Waters
PO_4-P	5-15 µg P/L	1-10 µg P/L
NO_3-N	10-100 µg N/L	10-60 µg N/L
NH_4-N	<5 µg N/L	<5 µg N/L

The Derwent Estuary Nutrient Program (DENP) - 1993/1994

Nutrient concentrations in the Derwent Estuary were monitored over a one-year period, commencing in March 1993. Water samples were collected fortnightly at 51 stations, both at the surface (0.1 m) and at depth (5 - 20 m). Considerable variability was observed, both seasonally and spatially. Nitrate+nitrite levels during the study period averaged 14 µg N/L for surface samples and 16 µg N/L at depth, with generally higher levels (15-30 µg N/L) observed in the upper estuary, reflecting river inputs. Nitrate-nitrite concentrations were seasonally elevated at the estuary's mouth (May through July), due to oceanic inputs. Ammonia concentrations averaged 20 µg N/L in surface waters and 25 µg N/L at depth, with the highest ammonia levels (100-200 µg N/L) observed at depth in the middle and lower estuary. Orthophosphate levels in the estuary averaged 6 µg P/L in surface waters and 9 µg P/L at depth, with slightly higher values observed in the middle estuary.

A comparison of nutrient levels measured in the Derwent with other estuaries and with the ANZECC guidelines suggests that nitrate and phosphate concentrations are within the middle to lower end of ranges at which problems have been known to occur, and that ammonia concentrations are relatively high. Given the variability between estuaries, however, these guidelines strongly recommend that site-specific studies be undertaken to determine appropriate concentrations for specific systems.

1996 Nutrient monitoring program

The 1996 program was conducted as a coordinated exercise between DELM and ANM. ANM monitored 17 sites in upper estuary (above Bridgewater) for nutrients and also measured water column profiles of T, salinity, pH, DO and light penetration. DELM monitored 19 sites below Bridgewater for nutrients, phytoplankton/chl *a* and water column profiles of T, salinity and DO. Joint monitoring was carried out at approx. six-week intervals over a period of 2 days, for a total of 9 nutrient surveys in 1996. See Figure 26 for site locations. The majority of nutrient analyses were carried out using surface water samples; however, where strong salinity gradients were observed, DELM collected and analysed bottom samples as well. On the whole, 1996 was a very cold and wet year and water temperatures much lower than usual. The Derwent River was in flood on a number of occasions, including during or just prior to surveys on 16/4, 9/7, 20/8 and 1/10.

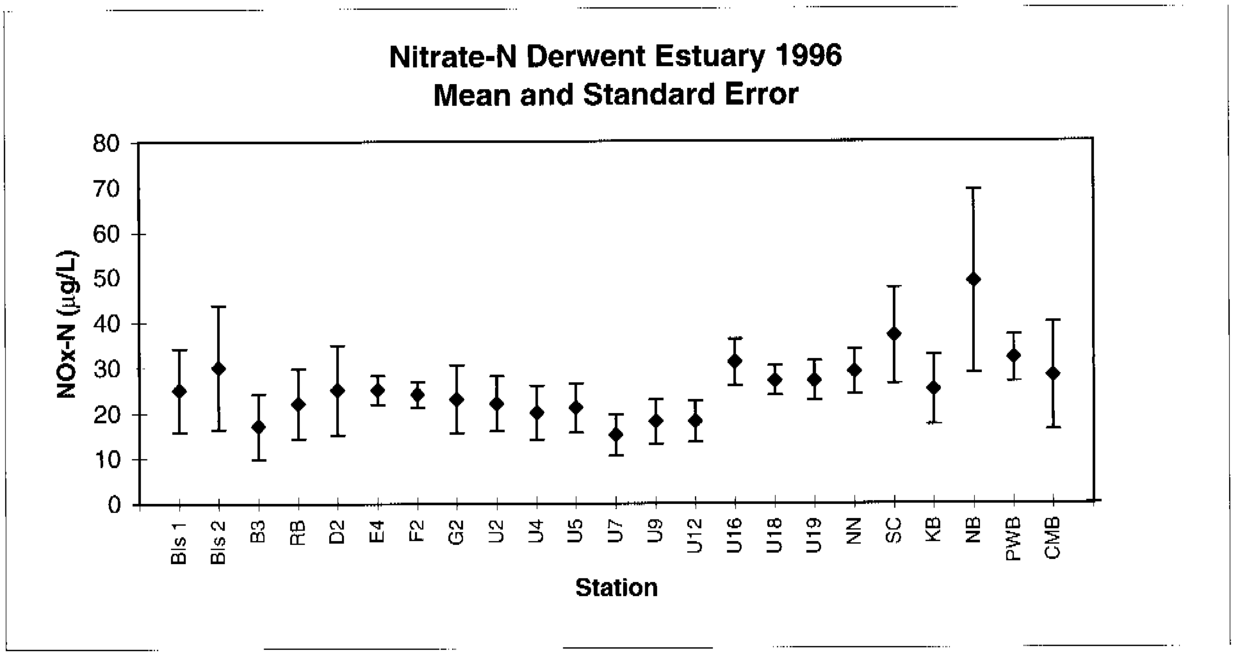
Nutrient data for 1996 is summarised in Figures 29 and 30. The data shows considerable spatial and temporal variation. However, on the whole, ammonia-N, orthophosphate and total phosphorus concentrations showed similar magnitudes and trends to values observed in DENP, with higher mean concentrations in middle reaches of estuary, particularly in embayments. Nitrate-N concentrations were significantly higher (nearly double) those observed in DENP, probably reflecting elevated oceanic concentrations in May - July. Total nitrogen concentrations (which had not been monitored in DENP) showed a progressive increase with distance up estuary, with mean concentrations ranging from 110 µg/L at mouth to a maximum of 310 µg/L near ANM-Boyer, decreasing to 240 µg/L in the river at New Norfolk.

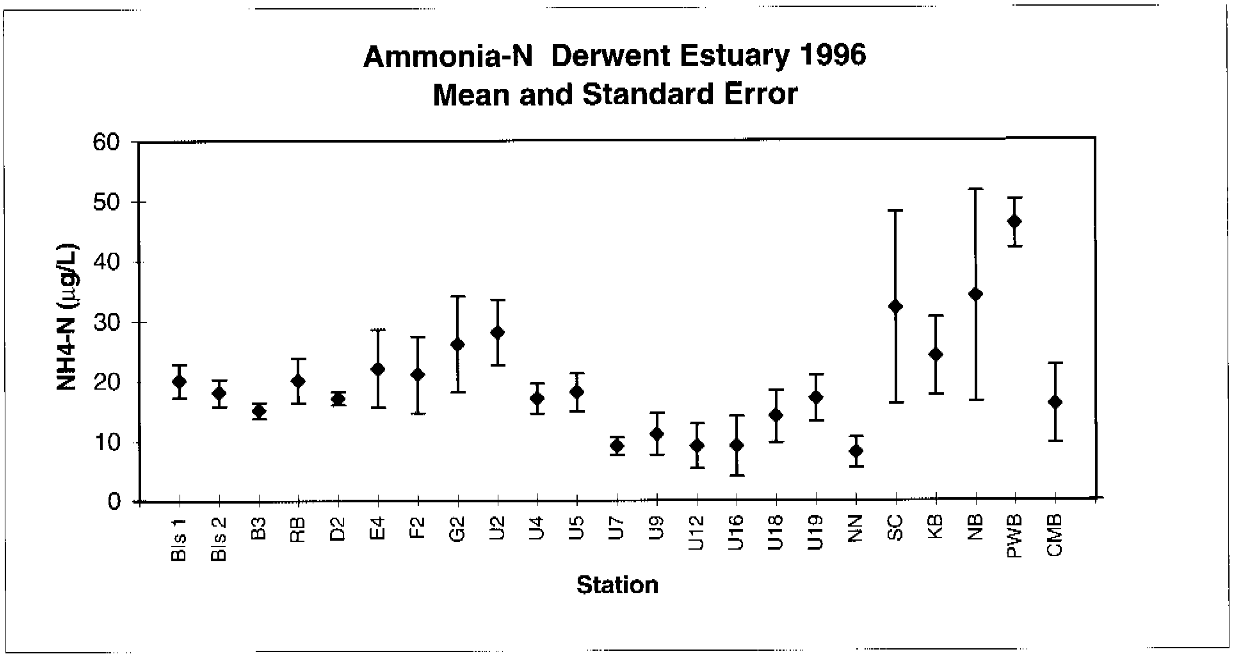
6.6 Algal biomass/chlorophyll *a*

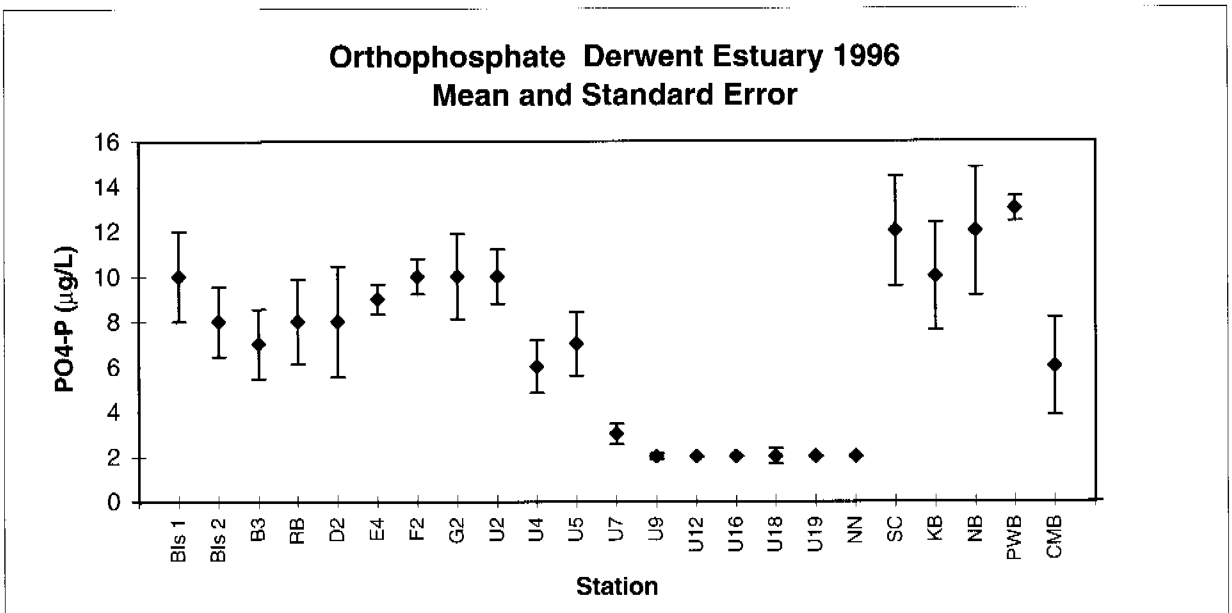
The green pigment chlorophyll (which exists in 3 forms: chlorophyll *a, b* and *c*) is present in most photosynthetic organisms and provides an indirect measure of algal biomass and an indication of the trophic status of a waterbody (Chapman, 1992). High levels of chlorophyll *a* in water bodies can be indicative of eutrophication associated with high phytoplankton biomass. Algal blooms and high chlorophyll *a* in estuaries typically occur in the upper and lower estuarine areas, and in confined embayments. Cyanobacterial (blue-green algae) problems have been reported in the upper, brackish reaches of certain estuaries (e.g. Hawkesbury, NSW) or embayments (e.g. Orielton Lagoon), while dinoflagellate blooms (red tides) have been reported in the lower reaches of the Derwent and Huon estuaries. Algal blooms are uncommon in the middle reaches of most estuaries due to light limitation from high turbidity (ANZECC, 1992).

There is no widespread agreement on the best indicator to use in assessing what constitutes a 'nuisance growth' of algae in estuarine or coastal waters, however, ANZECC (1992) has identified range of 1-10 µg/L of chlorophyll *a* as being indicative of levels at which phytoplankton problems have been known to occur in estuaries and embayments. Guidelines for other types of problem algae (dinoflagellates, macroalgae) have not been defined.

Data on chlorophyll *a* concentrations in the Derwent Estuary have been collected (along with plankton samples) since 1994. In 1996, samples were collected once a week during summer months (November through March), and once every six weeks during the remainder of year. Considerable spatial and temporal variation was observed, with chlorophyll *a* concentrations ranging from <0.5 µg/L to a maximum of 24 µg/L (Prince of Wales Bay). Trends and

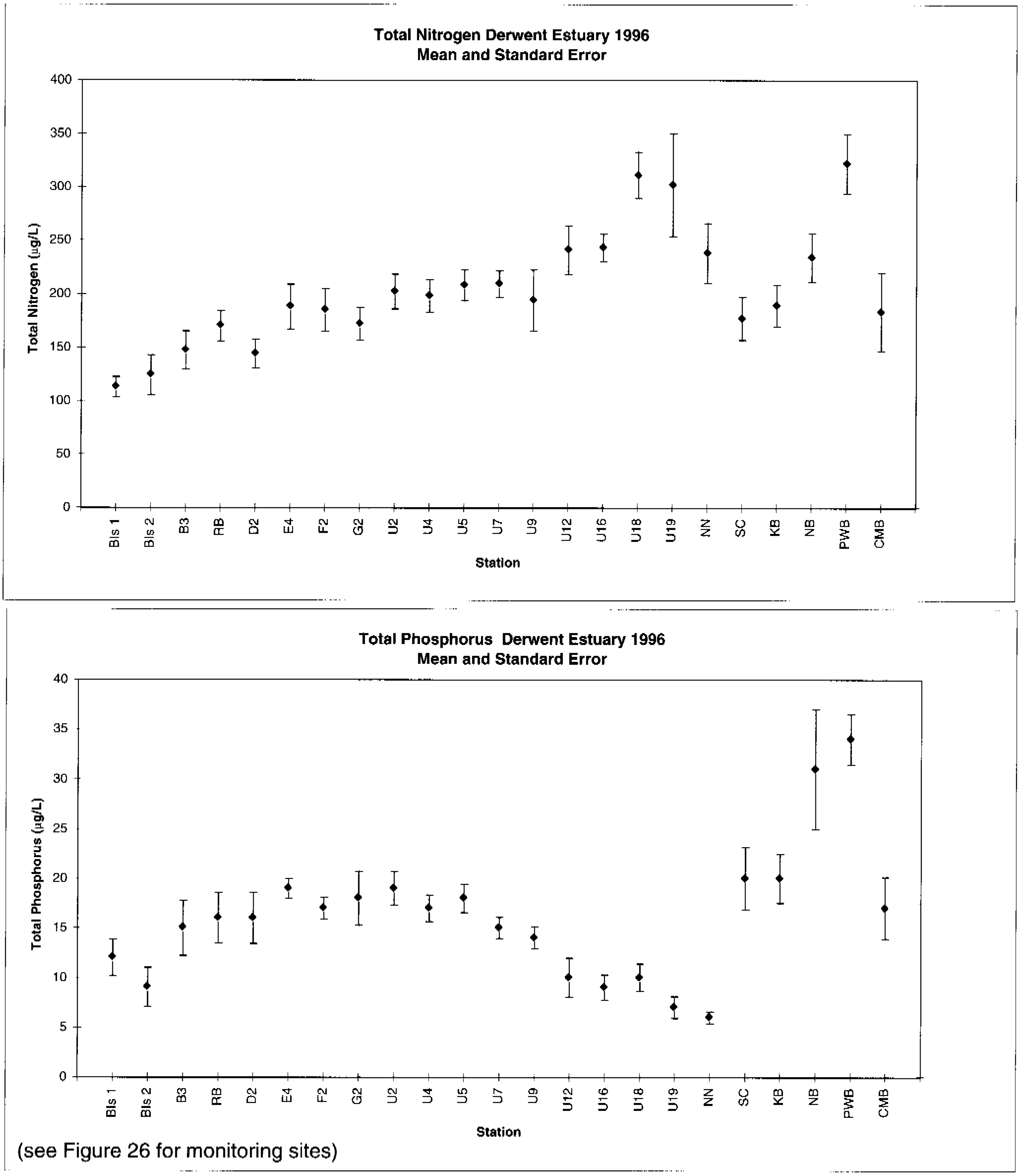






(see Figure 26 for site locations)

Figure 29 Dissolved nutrient concentrations - Derwent Estuary (1996)



(see Figure 26 for monitoring sites)

Figure 30 Total nutrient concentrations - Derwent Estuary (1996) standard errors for the entire estuary are indicated in Figure 31. In general, the highest mean concentrations of chlorophyll *a* were observed in the middle estuary, and particularly in embayments such as Prince of Wales Bay and New Town Bay. The upper reaches of the estuary were consistently low in chlorophyll *a*, while the lower estuary and nearshore coastal waters occasionally had high concentrations.

No quantitative data on the distribution or biomass of macroalgae is available for the Derwent, although there have been some reports of nuisance growth in certain embayments (e.g. Cornelian Bay). Seagrass beds at mouth of Jordan River show variable degrees of epiphytic algal growth.

Nutrient/algal dynamics

The dynamic relationship between nutrients and algal growth in the Derwent Estuary is not well understood. The Derwent may not be highly susceptible to algal problems, due to a number of physical characteristics of the estuary; particularly the relatively cold water temperatures and short water residence time. Furthermore, the estuary has been described as having poor light penetration, due to the naturally highly coloured, humic-rich waters discharged by the Derwent River. Measurements of euphotic depths in the upper estuary are typically in the order of 4 to 10 m (D. Richardson, ANM, pers. comm..), while Secchi depth measurements in the middle and lower estuary are almost always greater than 2 metres and often considerably higher (DELM, unpublished data).

On the basis of several years of monitoring data, it appears that significant concentrations of bioavailable nutrients (PO_4, NH_4, NO_3) are present in the water column throughout the year. This appears to be largely a natural phenomenon, caused by inputs of nutrient-rich Southern Ocean water - particularly during winter and spring months - although there is some further nutrient enrichment of the mid-estuary from sewage inputs. This enrichment of bioavailable nutrients does not appear to occur, however, in the upper estuary and Derwent River, where orthophosphate concentrations are consistently below detectable levels (<2 μg/L).

It is something of a puzzle as to why phytoplankton in the middle and lower estuary do not appear to be responding to this availability of nutrients. Possibly, phytoplankton may be flushed from estuary before reaching their maximum standing crop; alternatively, some other factor may be limiting phytoplankton growth. These factors could potentially include one or a combination of the following:

- low water temperatures (depresses growth rates);
- light limitation (high colour reduces light penetration, limiting rate of photosynthesis and algal productivity);
- presence of dissolved organic compounds (e.g. humic and fulvic acids, which may interfere with nutrient availability/uptake and/or exert toxic effects);
- some toxin (e.g. heavy metals) or group of toxins, which could depress phytoplankton growth;
- absence or limitation of some other essential element;
- grazing controls by zooplankton.

Some initial work has been done to try and resolve this puzzle. Hallegraeff and Westwood (1994) conducted a series of *in situ* experiments using encapsulated unialgal cultures at two sites in the estuary (off Cornelian Bay and Kingston). Growth rates were determined for two representative species of diatoms, one dinoflagellate and one green algae at two depths (0 m and 2 m) during autumn of 1994 (March - June). The diatoms and dinoflagellates showed optimal growth rates in surface waters at Kingston (single incubation), while the green algae showed optimal growth rates at different sites and different depths (4 incubations). Based on this preliminary data, and some laboratory *in vitro* growth experiments, the authors suggest that phytoplankton growth may be limited by light availability and possibly humic substances.

6.7 Heavy metals

Heavy metals in aquatic systems may be derived from both natural and anthropogenic sources. Certain heavy metals, such as zinc and copper, are essential to aquatic life and are used by organisms in trace quantities; however, these and other metals can be toxic to organisms if concentrations exceed certain levels. Physico-chemical conditions in the water column and sediments influence the specific form or 'species' of metals, which in turn determines their potential to enter the ecosystem. Species in solution are generally more bioavailable and potentially more toxic than metals bound to particulate material. Heavy metals have a strong affinity with particulate material and may accumulate to very high concentrations in sediments. Sediment concentrations and bioaccumulated metals tend to be better indicators of heavy metal pollution in the environment, as they integrate environmental levels. Metals in solution are more variable and may be transient.

A number of heavy metals, including cadmium, zinc, copper, lead and mercury are very toxic to aquatic organisms, some at low concentrations. Cadmium and mercury are highly toxic to aquatic organisms at very low concentrations, and also represent significant health hazards to humans. Inorganic forms of mercury have a relatively low toxicity to biota but are readily converted to organo-mercury forms. The most toxic form of mercury is methylmercury which is highly toxic, resistant to environmental degradation and is rapidly taken up by aquatic organisms. Although zinc is an essential element for animals and plants, concentrations in water exceeding 50 μg/L may produce toxicity in some aquatic organisms. Humans are not particularly sensitive to zinc at low concentrations. The occurrence of toxic forms of zinc in the aquatic environment is particularly dependent on the pH, concentrations of complexing ligands and the hardness of the water.

The main sources of metals to the Derwent Estuary have historically been the Pasminco Hobart zinc refining plant and the ANM paper mill. Urban runoff has been a relatively minor contributor. The zinc plant has discharged metallurgical liquid effluent containing arsenic, cadmium, copper, lead, mercury, zinc and other metals since 1917 (Bloom, 1975). In recent years, Pasminco Hobart's point source discharges have been significantly reduced, however, diffuse sources still contribute significant metals inputs. Further upstream at Boyer, ANM discharged mercury to the estuary from its earlier use of fungicides and from a chlor-alkali plant (closed down in 1993).

Heavy metals in Derwent Estuary water

High levels of heavy metals have historically been recorded in Derwent Estuary water. Long-term monitoring between 1973 and 1986, and special surveys in 1987, 1988 and 1989 by the Department of Environment (and Land Management), showed high levels of metals in the water column.. ANZECC guidelines for metals in water were frequently exceeded for all metals with the exception of arsenic. A snapshot survey by Bloom in 1975 also indicated elevated concentrations of metals, as have recent surveys by DELM and CSIRO. Ranges of metal concentrations documented in these studies are provided in Table 28 and illustrated in Figure 32.

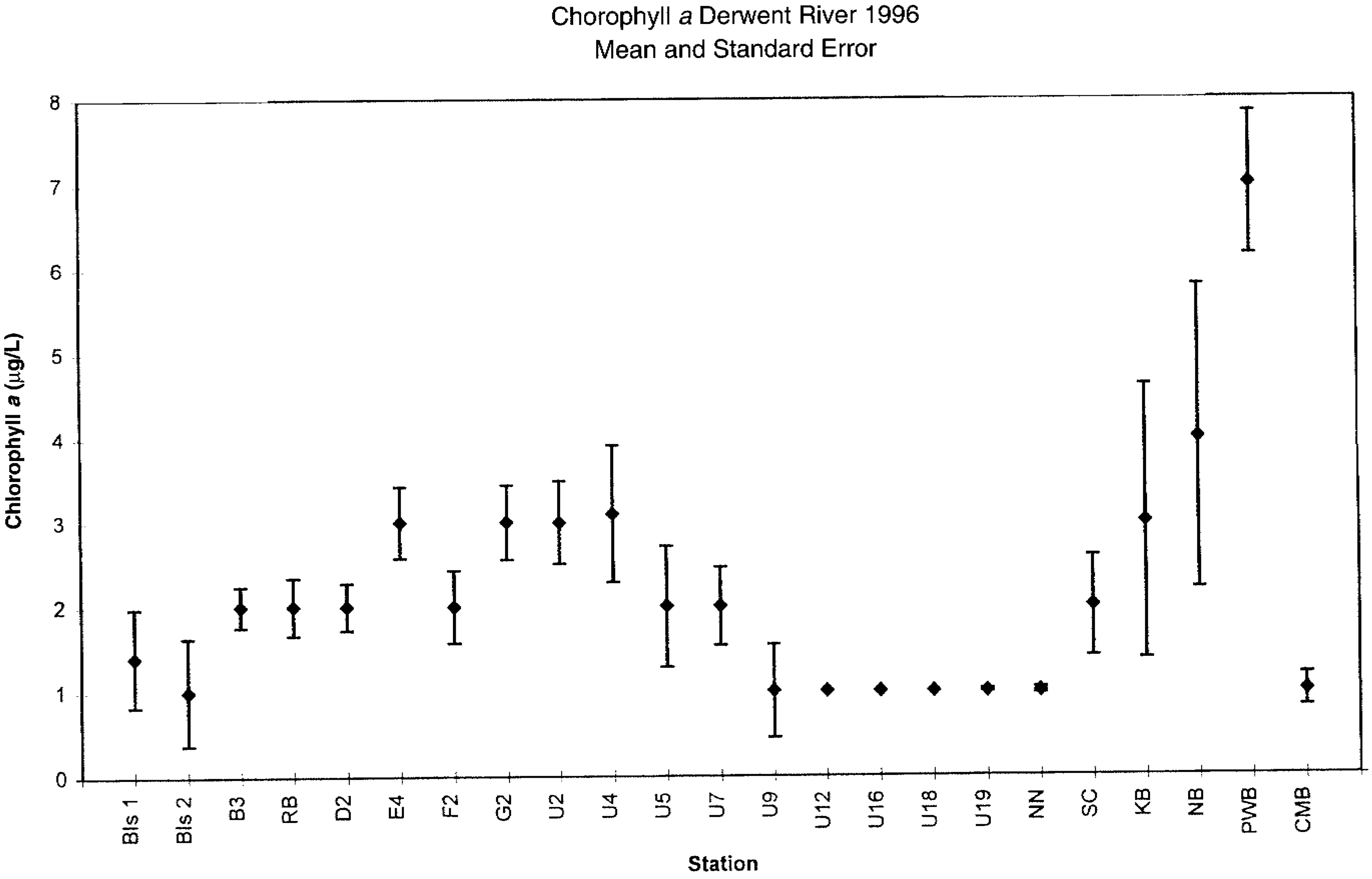


Figure 31 Chlorophyll *a* concentrations - Derwent Estuary (1996)
(see Figure 26 for locations)

Table 28 Ranges of heavy metal concentrations in Derwent Estuary waters

Metal (total) µg/L	Department of Environment	Bloom 1975/ Bloom & Ayling	Department of Environment	Plaschke *et al.*.	DELM Unpublished Results	ANZECC Marine Guidelines
	1972-1986	1977	1983-1988	1997	1997	1992
	Entire Estuary	Entire Estuary		Entire Estuary		
	14 Sites			15 to 20 Sites		
Aluminium					<50-211	*NGR
Arsenic	<0.05-6		0.4-4.3			50
Cadmium	0.3-9.5	<0.5-15	<0.5-5		<5	0.2-2
Chromium					<5	**50
Cobalt					<5	
Copper	<0.8-34	<0.5-21	0.7-171		<5-8	5
Iron					<20-173	*NGR
Lead	1.3-49.3		<1-21		<10-38	5
Manganese	<5-173		13-48		<5-25	*NGR
Mercury	<0.01-1.24	0.1-16	<0.04-0.36	<0.01-0.35		***0.01
Nickel					<5-12	15
Zinc	0-1256	12-1500	7-1103		<10-138	50

*NGR No guideline recommended

** Assuming that the chromium present is all in the chromium(VI) form

*** Provided that <10% is methyl-mercury

Bloom (1975; Bloom and Ayling, 1977) surveyed metals in Derwent Estuary water in the early 1970s. Surface water samples were collected at 46 sites in the Derwent Estuary. Cadmium, copper, iron, lead, mercury and zinc were determined on both filtered water samples (dissolved metals) and on the suspended particulates. Dissolved chromium, cobalt, manganese and nickel were also determined. The total metal ranges are shown in Table 28. Levels of zinc, mercury and cadmium were found to be highly elevated and copper levels were moderately elevated throughout the estuary.

Zinc, manganese, arsenic, copper, lead, mercury and cadmium were regularly monitored in Derwent Estuary water at 14 sites from 1973 to 1986. The metal concentration ranges which were recorded in Derwent Estuary water between 1973 and 1986 are listed in Table 28. With the exception of arsenic, concentrations for all metals significantly exceeded the current ANZECC guidelines. Zinc concentrations were highly elevated, particularly in the middle estuary, as were cadmium, copper and lead. Mercury was also high, both in the middle estuary as well as in the vicinity of ANM.

In 1987/88 the monitoring program changed emphasis to focus on monitoring the middle estuary where metal concentrations were highest. The 14 sites in the middle estuary between the Bowen Bridge and Battery Point, which were used in the updated monitoring program, had been sampled intermittently following the sinking of the *Lake Illawarra* near the Tasman Bridge in 1975. Subsequent surveys were carried out in the vicinity of the sunken vessel in 1983, 1984, as well as two surveys in 1985 and six surveys (which took place as part of the updated Derwent River monitoring program) in 1987 and 1988. The ranges of metals recorded in the surveys from 1983 to 1988 are shown in Table 28. The levels recorded were similar to those found in the initial Derwent River Monitoring Program, with concentrations of cadmium, copper, lead, mercury and zinc exceeding the ANZECC guidelines for metals in water. No evidence was found to suggest that the sunken cargo of the *Lake Illawarra* was affecting metal concentrations.

CSIRO conducted several surveys of metals in Derwent Estuary water during 1993 - 1994. Results for acid-labile and $SnCl_2$-reducible (easily reducible) mercury have been published (Plaschke *et al.*, 1996). Acid-labile mercury was found to be elevated above the ANZECC criteria (although ANZECC criteria are based on total metal levels). Data for other metals have not yet been published.

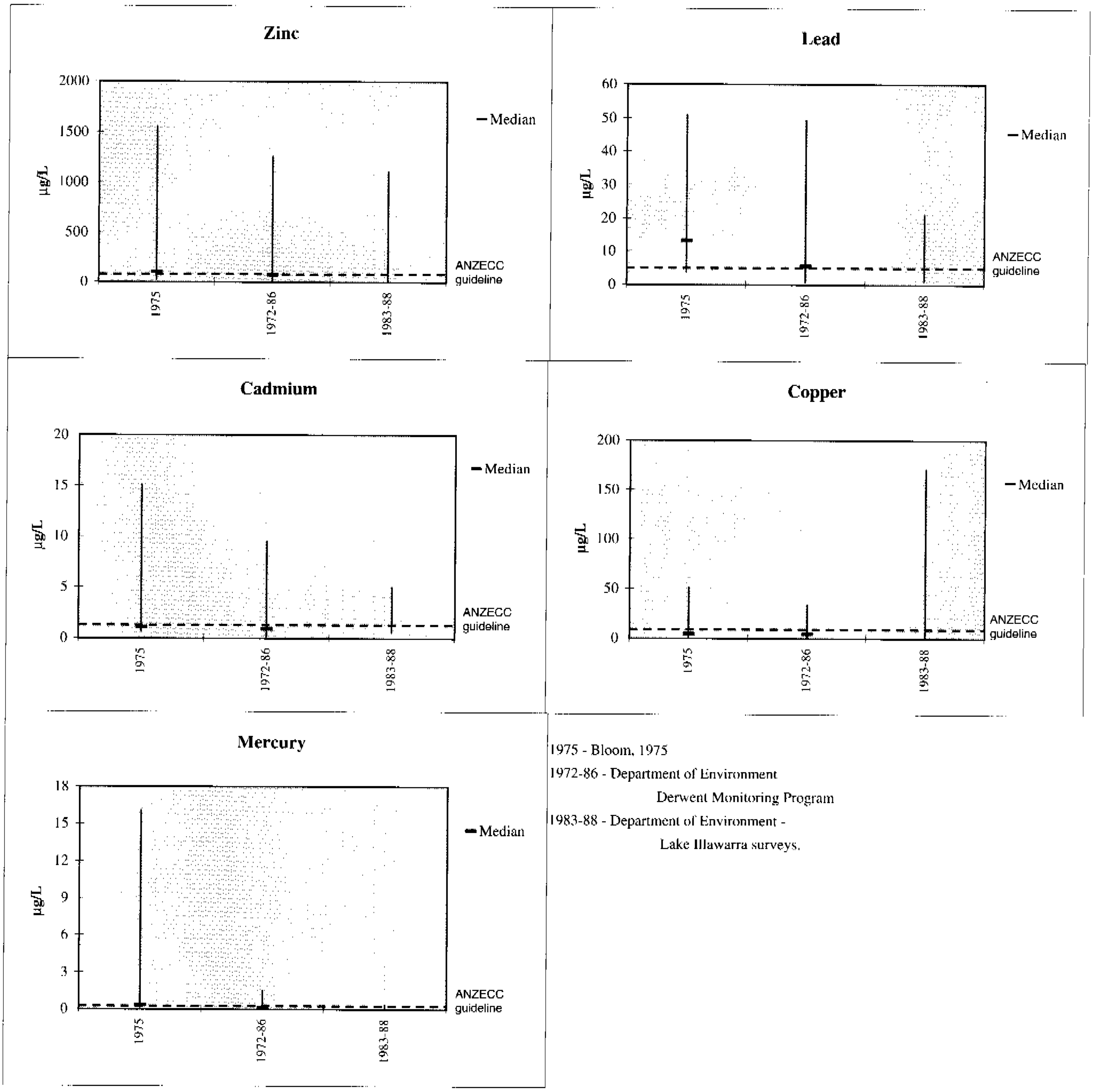
The Department of Environment and Land Management has recently recommenced monitoring heavy metals in Derwent waters. Results from initial surveys indicate that lead and zinc were notably elevated in New Town Bay, Prince of Wales Bay and Elwick Bay. Copper was also slightly elevated above the ANZECC guidelines in New Town Bay and Prince of Wales Bay.

In summary, metals which have exceeded ANZECC water quality guidelines in the Derwent Estuary include cadmium, copper, lead, mercury and zinc. From recent data, it appears that zinc, copper, lead and mercury are still significantly elevated, and probably cadmium as well. Concentrations are highest in the middle estuary, particularly in New Town Bay. Several "priority pollutant" metals have never been surveyed in Derwent Estuary waters, specifically Cr, Se and Sb.

Heavy metals in Derwent Estuary sediments

There are currently no sediment quality guidelines in place in Australia. It is thus necessary to rely on criteria established in other countries, primarily the United States and the Netherlands, and background levels such as the Global Shale Standard (Förstner and Wittmann, 1979). The criteria used in this report are quality standards developed for marine and estuarine sediments by the National Oceanic and Atmospheric Administration, US Department of Commerce (NOAA). These criteria focus on the biological effects of contaminants in sediments (Long and Morgan, 1990).

Only two full estuary surveys of metals in sediments have been carried out in the Derwent Estuary. These studies were done by Bloom (1975) and Pirzl (1996). Other pertinent studies include two surveys of heavy metals in sediments from the upper estuary (HECEC/TasUni, 1989; Garland and Statham, 1991), and several smaller studies of bays in the middle estuary (Lindisfarne Bay, New Town Bay, Prince of Wales Bay). Ranges of heavy metal concentrations documented in these and other studies are presented in Table 29 .



1975 - Bloom, 1975

1972-86 - Department of Environment
Derwent Monitoring Program

1983-88 - Department of Environment -
Lake Illawarra surveys.

Figure 32 Metal concentrations ranges in Derwent Estuary water

Table 29 Ranges of heavy metal concentrations in Derwent Estuary sediments

Metal	Bloom	Dept. of Env.	Wood	Garland and Statham	Hanslow	Env. Tasmania	Pirzl	Long & Morgan	
	1975	1986	1988	1990	1994	1996	1996	1990	
	Entire Estuary	Sandy Bay	Lindisfarne Bay	ANM to Green Island	POW/NT Bays	NT Bay	Entire Estuary	Sediment Quality Standards	
(µg/g)	102 Sites	4 Sites	8 Sites	30 Sites	10 sites	14 sites	40 Sites	ERL* (µg/g)	ERM** (µg/g)
Aluminium							2,139-31,668		
Arsenic					36-1,310	4-135	0.001-20.9		
Cadmium	0.3-1,400	1.4-6.8	8 (max)	<0.5-3.8	7.2-370	2-70	0-134	5	9
Chromium	1.1-258					11-61		80	145
Cobalt	0.4-137								
Copper	1.5-10,050	10-71	56 (max)		140-1,540	25-269	7-530	70	390
Iron	570-161000				40,000-86,800		35-57,477		
Lead	0.7-41,700	160-445	7675 (max)		510-8960	96-1,230	10.5-2,078	35	110
Manganese	0.8-8,900						6.5-781		
Mercury	0.01-111	1.3-9.8		<0.02-11	3.8-82	0.1-12	0.023-55.7	0.15	1.3
Nickel	0.05-36					11-27			
Zinc	22-104,000	260-1,140	1010 (max)	23-1,590	2,300-48,100	252-6,760	26.8-19,201	120	270

*ERL effects range low - adverse effects 10% of the time

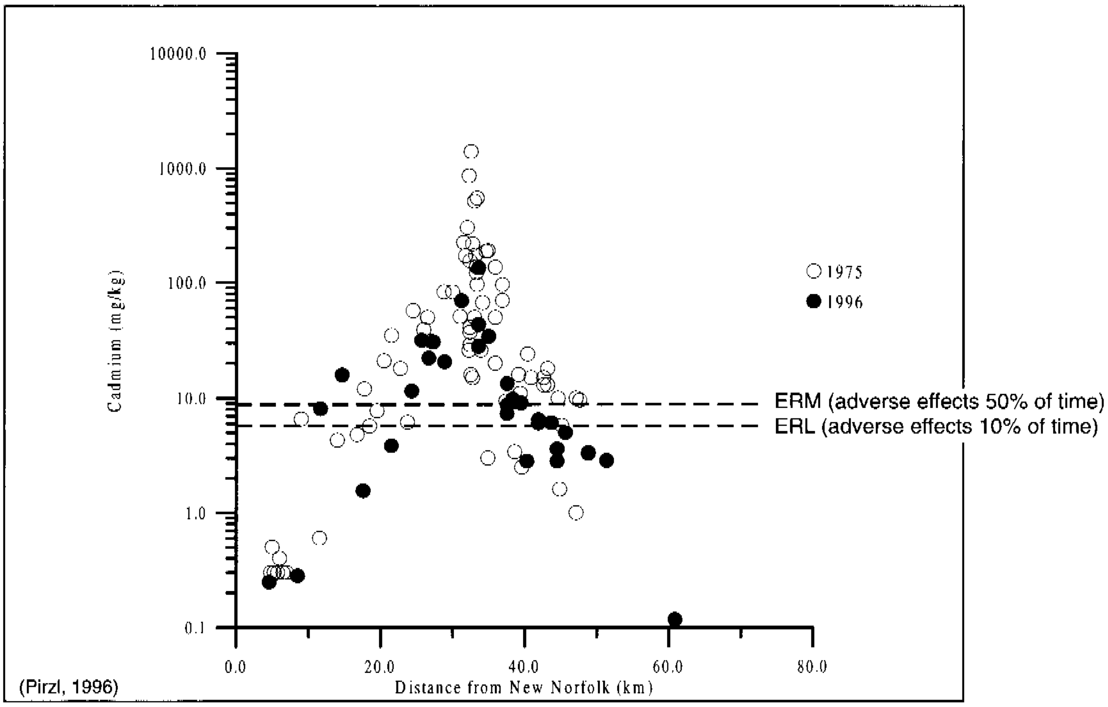
**ERM effects range median - adverse effects 50% of the time

(Note: in studies where cores have been collected, the concentration ranges are for *surface* sediments only).

An investigation in the early 1970s (Bloom, 1975) established that metals levels in the Derwent Estuary were extremely high, identifying it as one of the world's most polluted estuaries. Surface sediments were sampled from 102 sites throughout the estuary and were tested for cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel and zinc. Most of the sites in this survey were concentrated in the middle estuary and around the margins. Levels of zinc, lead, cadmium, mercury, chromium and copper exceeded sediment quality criteria which have been established in the USA, with levels of zinc, lead, cadmium and mercury being particularly elevated near the zinc works.

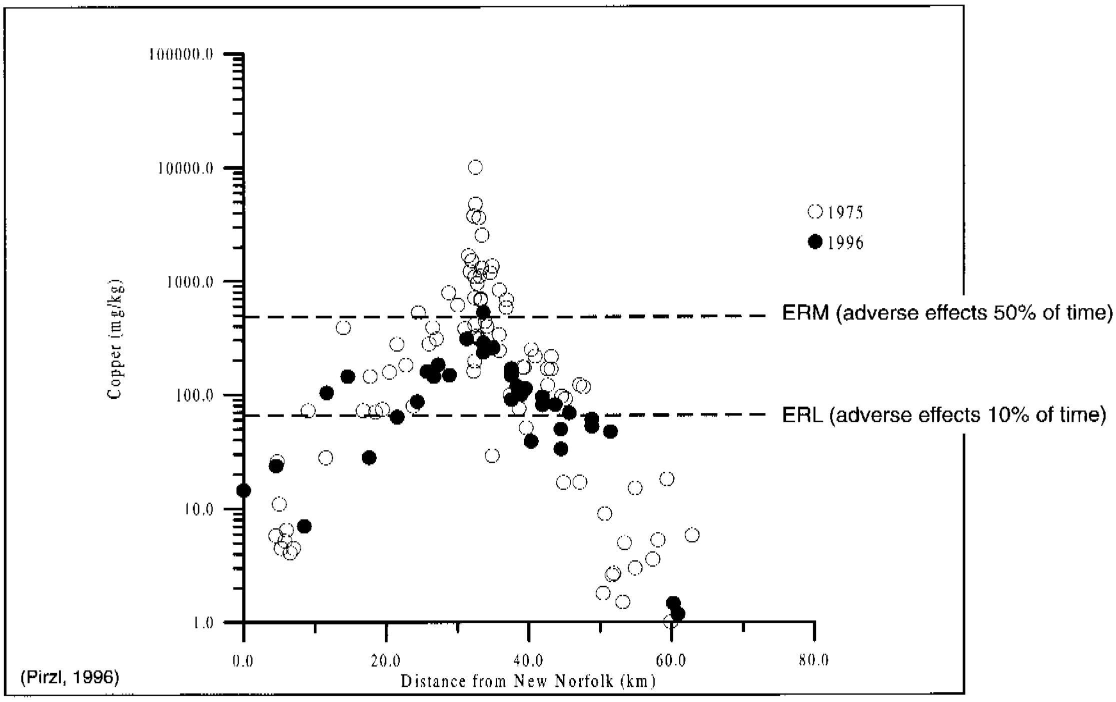
Pirzl (1996) examined surface sediments from 40 sites throughout the entire Derwent Estuary with the aim of identifying current metal distributions and determining changes in concentrations since 1975. The study tested sediments for aluminium, cadmium, copper, zinc, mercury, arsenic, manganese, lead and iron. Pirzl identified very high metal concentrations in the middle section of the estuary, which decreased gradually towards the marine and riverine extremities (Figures 33 to 37). Two major factors influence this distribution:

- the location of the zinc refining plant in the middle estuary, which is the major source of metals in the Derwent; and
- the sediment types in the estuary (i.e. size characteristics and organic content).



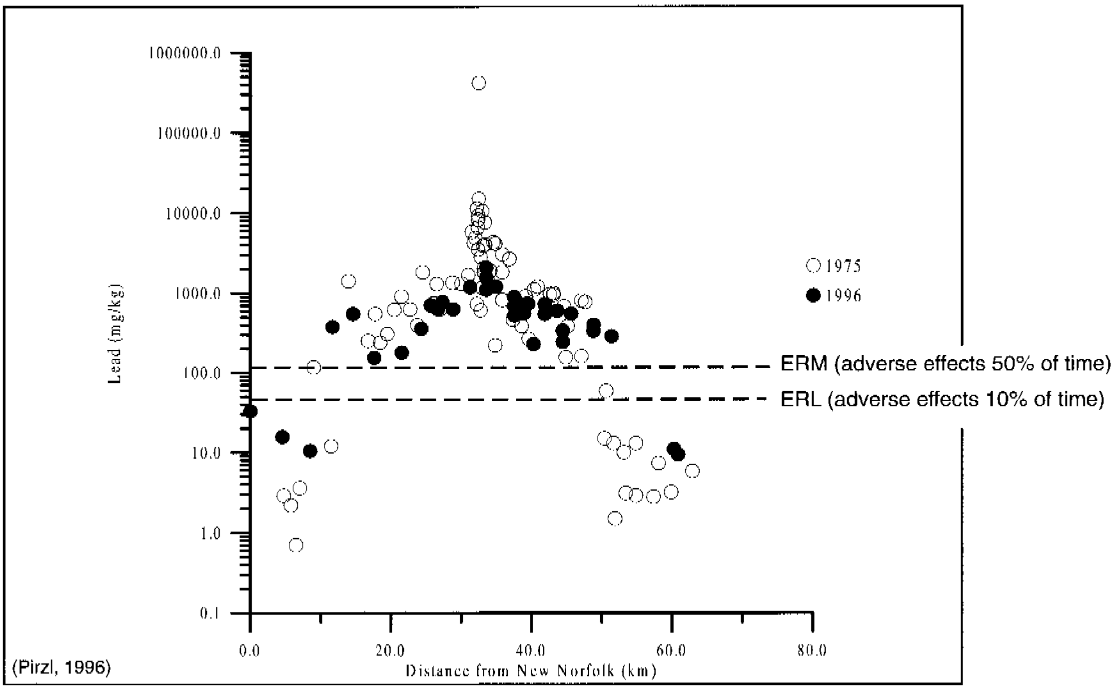
(Pirzl, 1996)

Figure 33 Cadmium concentrations in Derwent Estuary sediments (1975 and 1996)



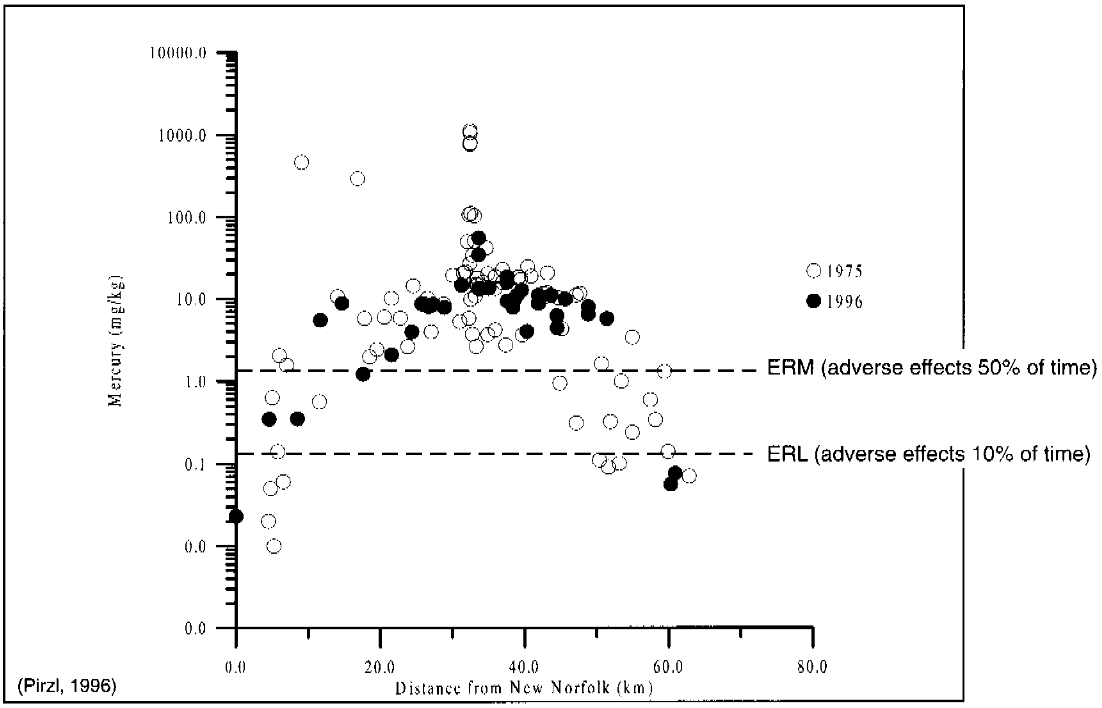
(Pirzl, 1996)

Figure 34 Copper concentrations in Derwent Estuary sediments (1975 and 1996)



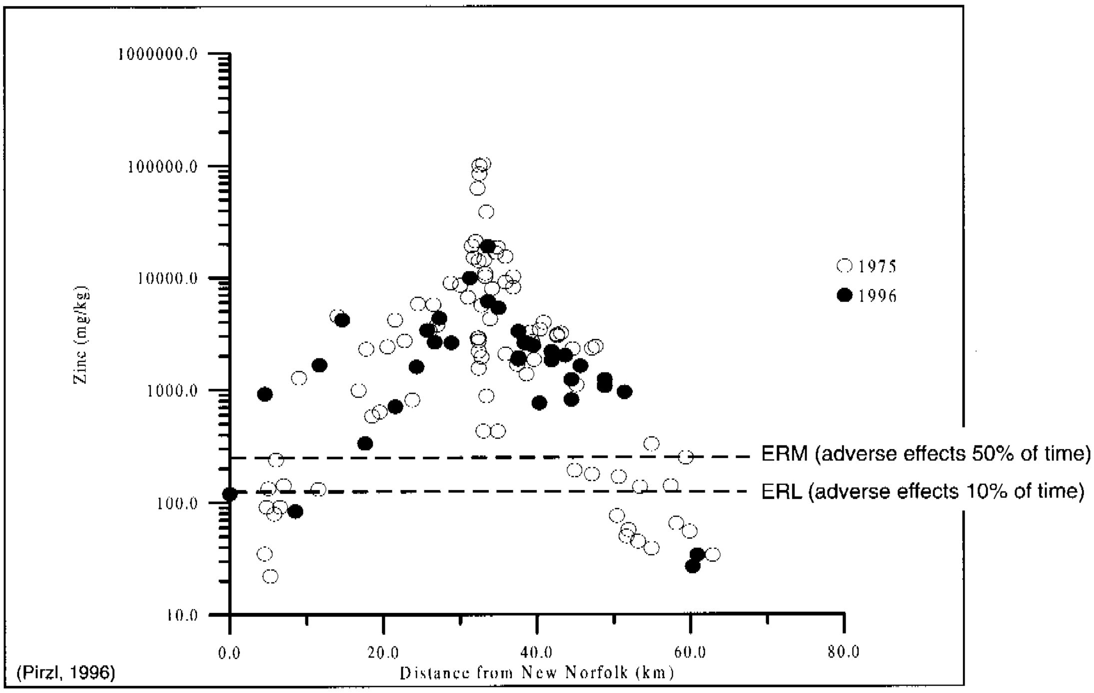
(Pirzl, 1996)

Figure 35 Lead concentrations in Derwent Estuary sediments (1975 and 1996)



(Pirzl, 1996)

Figure 36 Mercury concentrations in Derwent Estuary sediments (1975 and 1996)



(Pirzl, 1996)

Figure 37 Zinc concentrations in Derwent Estuary sediments (1975 and 1996)

Concentrations for all metals were very high in the middle estuary, and copper, lead, cadmium, mercury and zinc all exceeded sediment quality criteria. Statistically significant reductions in cadmium, copper, lead and manganese were observed in the middle estuary, and in the region nearest the zinc works, cadmium, copper, zinc, mercury and manganese were significantly reduced. In the lower estuary, only cadmium was found to have significantly decreased. No change was detected in the upper estuary for any metals since 1975 (Pirzl, 1996).

A number of metal studies on sediments in smaller regions of the estuary have also been carried out. In 1986, surface sediments and water samples were collected at 10 sites in the Sandy Bay area to assess potential impacts of a dredging operation at Wrest Point (Department of Environment, 1986). Sediments were analysed for zinc, cadmium, copper, lead and mercury. The results showed elevated concentrations of lead, mercury and zinc at levels exceeding sediment quality criteria established in the United States (Table 29).

Wood (1988) conducted a study of the sediments in Lindisfarne Bay in the middle estuary. Levels of cadmium, copper, lead and zinc were determined in sediment cores from eight intertidal sites in Lindisfarne Bay. The sediments were also dated. The highest concentrations were found at about 0.8 metres down the sediment cores, which appeared to correlate with the period of highest emissions during the early 1970s.

Sediment surveys were carried out in the upper Derwent Estuary between New Norfolk and the Tasman Bridge in 1989 and 1990, and found significantly elevated concentrations of mercury and zinc. Levels of cadmium were below the sediment quality criterion (HECEC TasUni Research Joint Venture, 1989; Garland and Statham, 1990).

Hanslow (1994) determined concentrations of arsenic, cadmium, copper, lead, zinc, iron and mercury in sediment cores from sites around the Pasminco wharf at Risdon, New Town Bay and Prince of Wales Bay. Acid volatile sulphide analysis was also carried out to ascertain the remobilisation potential of the metals, indicating their bioavailability. Most metals were found to be more highly concentrated in the base section of the core, with lower concentrations in the surface sediments, probably reflecting reductions in mass emissions since the early 1970s. The metals in Prince of Wales Bay were found to be in the form of insoluble sulphide particles and not readily leached to the water column, while in contrast, the sites around Risdon Wharf and in New Town Bay had the potential to remobilise, thus becoming bioavailable.

Metal concentrations in sediments adjacent to the EZ wharf were also measured in 1989 as part of a dredging feasibility study (Pollution Research, 1991). The full data set is not available; however, Hanslow (1994) reported that concentrations of cadmium up to 2270 μg/g, copper up to 19,700 μg/g, mercury up to 108μg/g and zinc up to 243,000 μg/g were recorded in this survey in the vicinity of the Pasminco wharf. These concentrations are the highest recorded in the estuary, and probably reflect handling losses of zinc concentrate from the wharves.

DELM investigated metal (and hydrocarbon) concentrations in 14 sediment cores collected in New Town Bay in January 1996. These sediments were found to have high concentrations of zinc and cadmium and elevated levels of lead, copper, mercury and arsenic. Concentrations of chromium and nickel were not found to be elevated (DELM, 1996).

In summary, concentrations of zinc, cadmium, lead and mercury have been found to be consistently elevated in sediments throughout most of the Derwent Estuary. Copper is also elevated, though to a lesser extent.

Heavy metals in Derwent Estuary biota

Numerous investigations of heavy metal concentrations in Derwent Estuary biota have been carried out since the early 1970s, when oysters produced at a shellfish farm in Ralphs Bay caused severe emetic (vomiting) symptoms in consumers, as a result of high concentrations of zinc and other heavy metals. Early surveys include those of Thrower and Eustace (1973a; 1973b), Ratkowsky *et al.* (1974) and Bloom (1975), while more recently published data include that of Dineen and Noller (1995). All of these studies have documented elevated concentrations of zinc and cadmium; Bloom, 1975 also found elevated lead and mercury. Dineen and Noller (1995) found some evidence of decreasing heavy metal concentrations in biota, when comparing results of a 1990 survey with Bloom's data from 1975. Data for oysters from these studies is summarised in Table 30.

Table 30 Ranges of heavy metal concentrations in Derwent Estuary oysters

Metal	Thrower & Eustace	Ratkowsky *et al.*	Bloom	Dineen and Noller*	Pasminco Hobart	National Food Standards
(µg/g)	1973a; 1973b	1974	1975	1990	1974 - 1995	
	Ralphs Bay	Ralphs Bay	Entire Estuary	Entire Estuary	Entire Estuary	(metals in oysters)
Aluminium						
Barium						
Cadmium	10.1-31.7	10.1-34.5	0.1-45	0.5 - 5.1	1 - 29	2.0
Chromium						
Copper	55.7-127	55.7-148		14 - 56	17 - 230	70
Iron						
Lead			<0.1-73	0.6 - 5.2	0.6 - 5.3	0.5
Manganese						
Mercury			0.08-2.05	0.05 - 0.22	0.05 - 0.18	0.5
Zinc	6,244-9,122	6244-10,019	102-8580	1200 - 7100	1600 - 15,000	1,000

The most comprehensive and continuous monitoring program, however, has been that carried out by Pasminco Hobart since the early 1970s. During the first two years of the program, over 100 sampling sites were established in the Derwent Estuary and Storm Bay areas. The program has been refined over the years and now consists of monitoring oysters and mussels for a suite of 5 heavy metals at 25 locations within the estuary (and 12 sites outside estuary) as shown in Figure 38. Flathead are also caught in 5 regions of the estuary and monitored for mercury. The two main edible shellfish in the estuary - oysters and mussels - exhibit different responses to heavy metal uptake. Oysters (both the native *Ostrea angasi* and the introduced *Crassostrea gigas*) accumulate zinc to a higher extent than mussels (*Mytilus edulis*), while mussels accumulate lead more efficiently. All three shellfish are sampled and analysed as part of the Pasminco Hobart monitoring program. Flathead (*Platycephalus bassensis*) are considered to be good bioindicators for mercury as they are bottom feeders and relatively territorial. (PMEZ, 1996)

Pasminco Hobart's monitoring data on heavy metal concentrations in oysters for the period 1974 to 1995 is provided in Figure 39. The majority of oysters have been found to have zinc, cadmium and lead concentrations well in excess of NH&MRC guidelines, particularly in areas above the Tasman Bridge, along the eastern shore and in Ralphs Bay. Lead concentrations in mussels (Figure 40) also largely exceed NH&MRC guidelines. Although some initial decline in concentrations was observed in the early to mid-1980s, no further decrease and a slight possible increase in some metals has been observed since then. There is some indication of a decrease in mercury concentrations, in both shellfish and flathead, however levels in Ralphs Bay are still slightly in excess of NH&MRC guidelines (see Figure 41). Copper concentrations have also increased slightly over the years, particularly in the area above the Tasman Bridge. (PMEZ, 1996)

The lack of a substantial decline in heavy metal concentrations in shellfish - despite significant end-of-pipe reductions in mass emissions from Pasminco Hobart - is of concern. Possible explanations include:

- continued heavy metal inputs from both non-point industrial sources (e.g. dust, contaminated ground-water) and urban and/or sewage sources;
- on-going releases of metals from contaminated sediments within the estuary;
- climatic/hydrologic factors;
- aging population of shellfish sampled.

6.8 Hydrocarbons

Hydrocarbons

Petroleum products are a complex mixture of linear, cyclic, branched, saturated, unsaturated and aromatic compounds. Hydrocarbons are also derived from the epicuticular waxes of higher plants.

The input of hydrocarbons to waterways adjacent to urban areas is believed to be considerable, in fact, of the estimated 3.2 million tonnes of petroleum hydrocarbons that enter the global marine environment annually (NRC, 1985), 30% is believed to be from municipal and industrial discharges (Fig. 42).

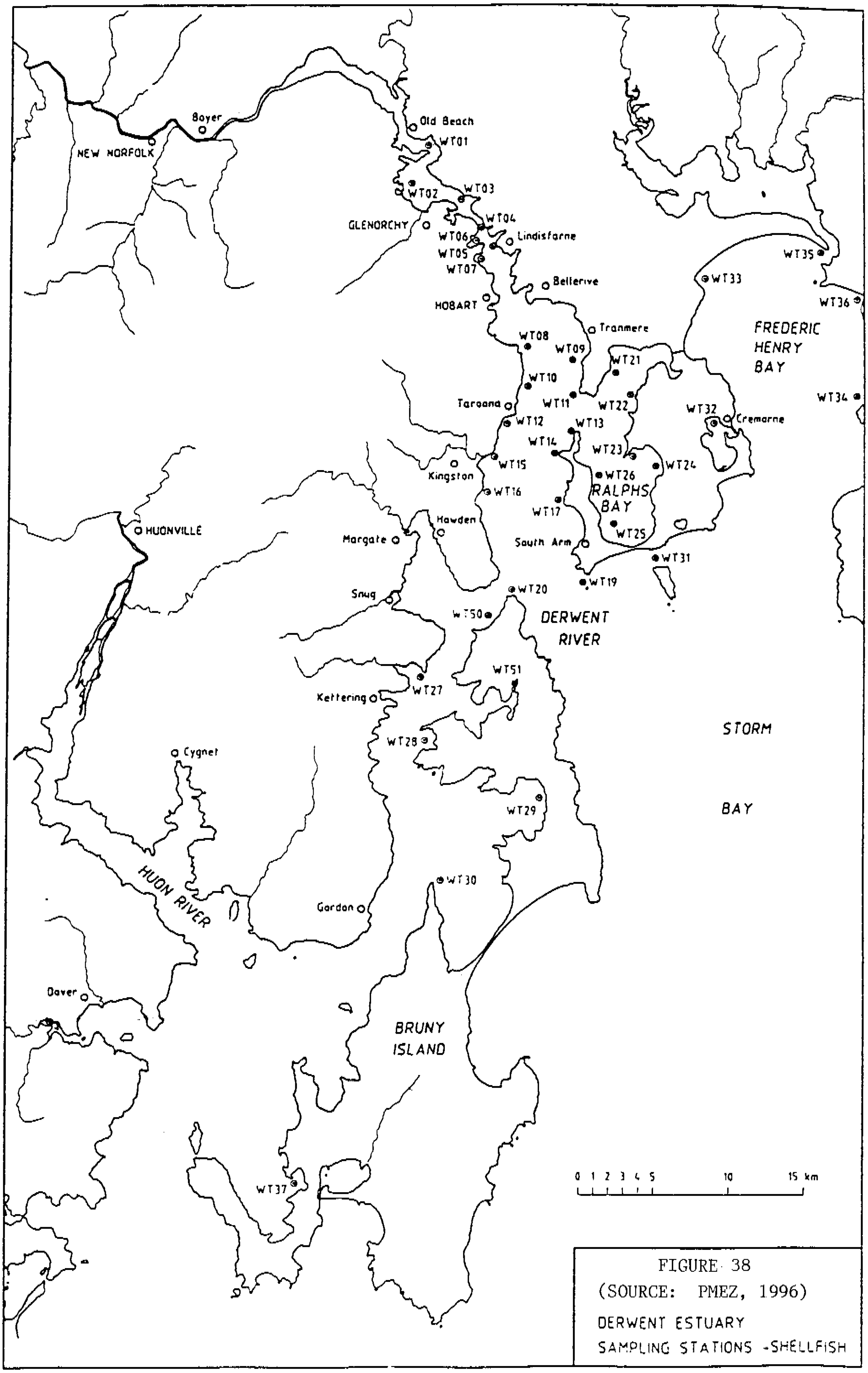
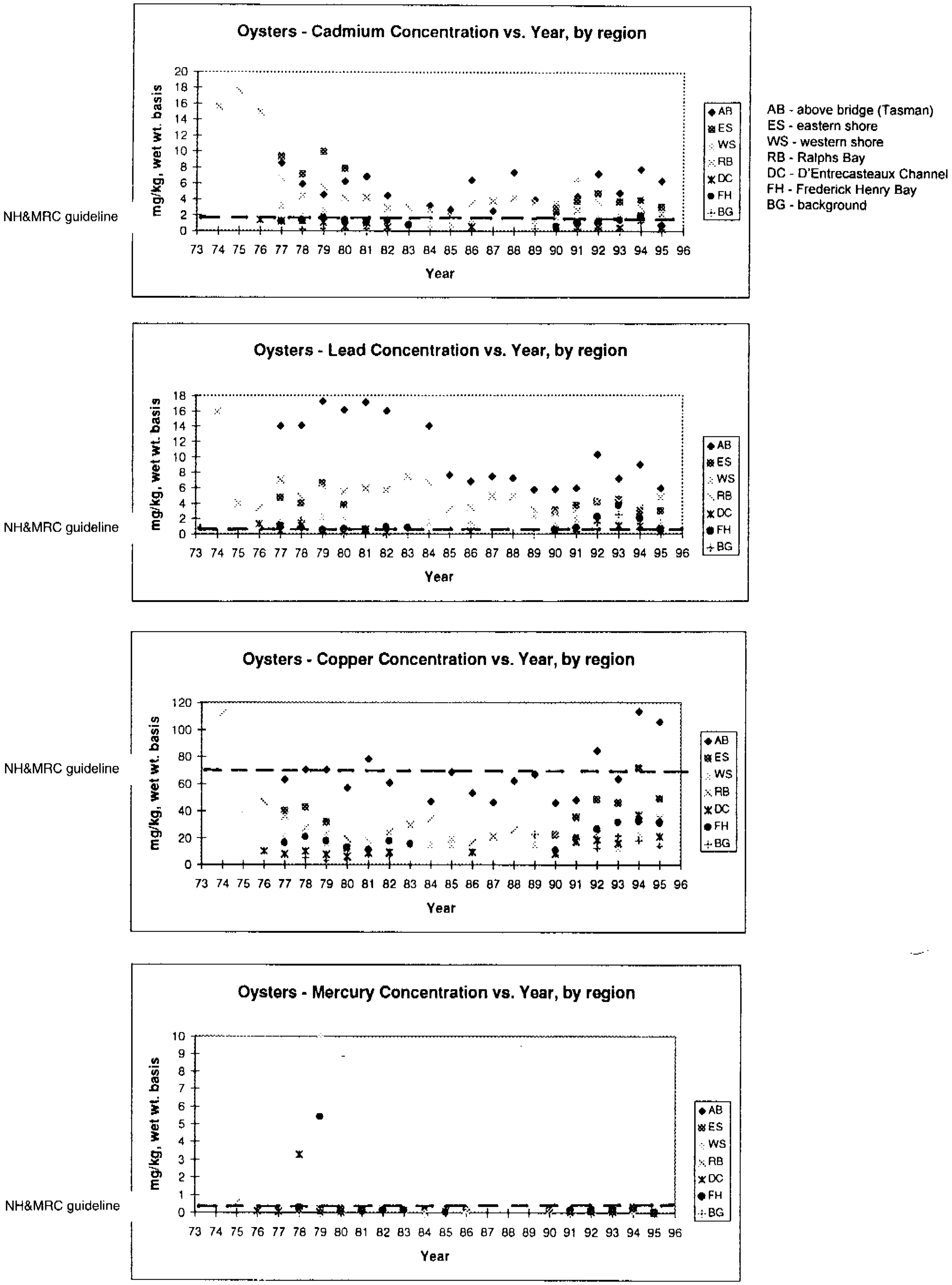
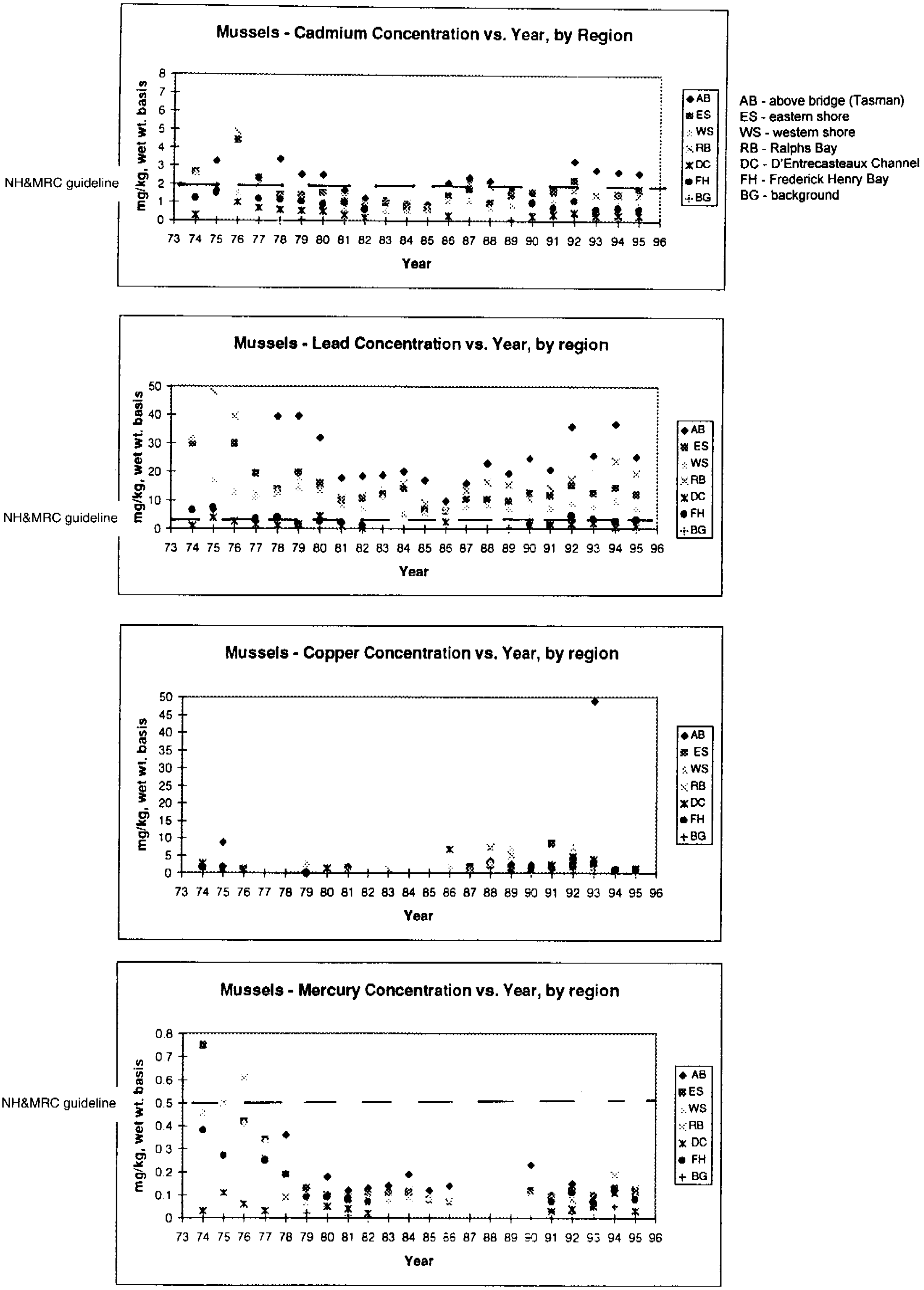


Figure 38 Monitoring sites - heavy metals in shellfish



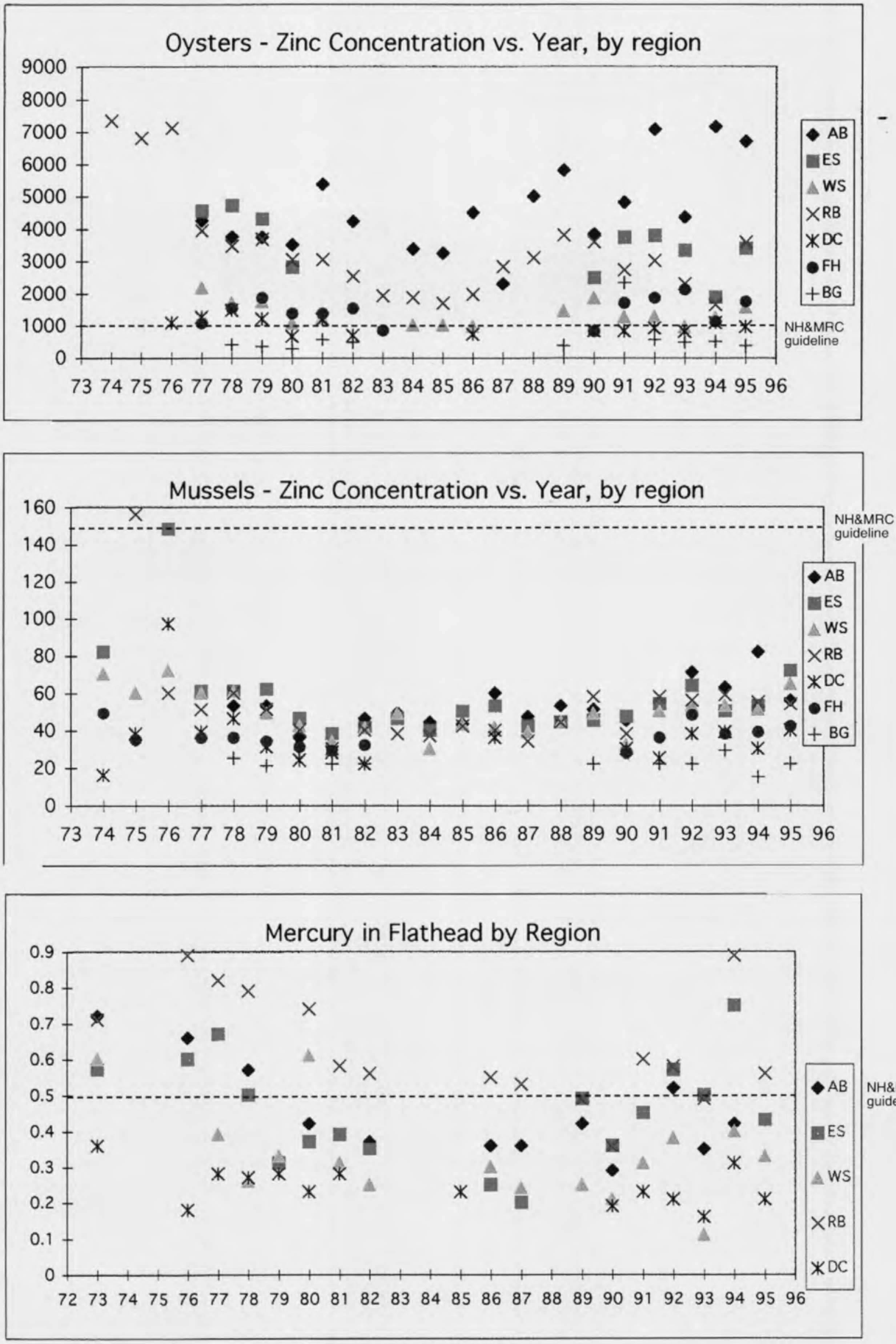
(after PMEZ, 1996)

Figure 39 Heavy metal concentrations in oysters (1973 - 1996)



(after PMEZ, 1996)

Figure 40 Heavy metal concentrations in mussels (1973-1996)



(after PMEZ 1996 EMP)

Figure 41 Zinc concentrations in shellfish and mercury concentration in flathead (1973 - 1996)

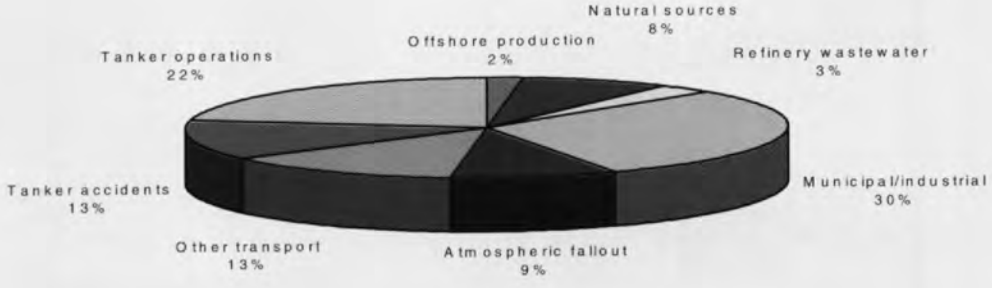


Figure 42 Sources of hydrocarbons in the marine environment

In Australia, lubricating oils have been recognised as a major cause of hydrocarbon pollution in many estuaries and coastal areas (Volkman *et al.*, 1992), derived from sources such as shipping, industry and urban inputs. A study of hydrocarbons in Victorian coastal ecosystems (Burns and Smith, 1982) brought attention to the collective importance of chronic low-level inputs of hydrocarbons to the coastal environment from urban and industrial sources.

Studies of aliphatic hydrocarbons in the Derwent Estuary

Three studies have been conducted on hydrocarbons in the Derwent Estuary. Volkman *et al.* (1988) measured biogenic and petroleum hydrocarbons in sediments from D'Entrecasteaux Channel at the mouth of the Derwent Estuary; Volkman *et al.* (1989) measured hydrocarbons in sludge samples from the upper Derwent Estuary, and Green (1997) measured hydrocarbons in sediments from the middle Derwent Estuary, predominantly at Prince of Wales Bay.

The studies of Volkman *et al.* (1988) and Volkman *et al.* (1989) demonstrated a gradation from extremely high hydrocarbon concentrations in sediments collected from the upper estuary (1,100-4,600 µg/g) to much lower levels of primarily biogenic hydrocarbons in the lower estuary sediments (0.8-6.4 µg/g) (Table 31). At Prince of Wales Bay, hydrocarbon contamination in sediment samples was indicative of extreme pollution (400-10,100 µg/g); see Table 31. Many of the sediment samples collected within Prince of Wales Bay contained hydrocarbon levels higher than any yet reported for Australian marine surface sediments (Table 31) and were of similar magnitude to levels (26-101 µg/g) near Sydney's Malabar sewage outfall, which were considered high for a coastal marine environment (Nichols and Espey, 1991). These levels are also well above those recorded in sediments from Victoria Harbour, Hong Kong (60-646 µg/g; Hong *et al.*, 1995) and Alexandria Harbour, Egypt (61-1,360 µg/g; Aboul-Kassim and Simoneit, 1995) (Table 31) which is considered to be heavily polluted with sewage-derived hydrocarbons.

Table 31 Concentrations of hydrocarbons in marine surface sediments

Location	Hydrocarbons (µg/g)	Reference
Westernport Bay, Victoria	2.3 - 5,271	Burns & Smith (1977)
Port Phillip Bay, Victoria	6 - 1,520	Burns & Smith (1982)
Great Barrier Reef, Queensland	0.2 - 0.8	Coates *et al.*, (1986)
Sydney coastal, NSW	3 - 42.3	Nichols & Leeming, (1991)
Malabar sewage outfall, Sydney	26 - 101	Nichols & Espey, (1991)
Rowley Shelf, Western Australia	0.02 - 0.05	Pendoley, (1992)
Lower Derwent Estuary, Tasmania	0.8 - 6.4	Volkman *et al.*, (1988)
Upper Derwent Estuary, Tasmania	1,100 - 4,600	Volkman *et al.*, (1989)
Prince of Wales Bay, Tasmania	400 - 10,100	Green (1997)
Victoria Harbour, Hong Kong	60 - 646	Hong *et al.* (1995)
Alexander Harbour, Egypt	61 - 1,360	Aboul-Kassim & Simoneit (1995)

Hydrocarbon analysis showed that sediments of Prince of Wales are strongly impacted by petrogenic hydrocarbons predominantly from used lubricating oils (automobile sump oil) (Green, 1997). Given the loadings of hydrocarbons detected in stormwater entering Prince of Wales Bay (mean 2.88 mg/L) and the high hydrocarbon discharge per storm event (up to 341 kg) (Green, 1997), stormwater is implicated as the potential major contributor to oil contamination in the Derwent Estuary.

A hydrocarbon budget compiled for the Derwent Estuary by Green (1997) indicated that stormwater was the major contributor of hydrocarbons to the Derwent Estuary, with estimated hydrocarbon generation rates of 17.1 kg HC/ha/yr during wet weather and 4.14 kg/ha/yr during dry weather (total 164 tonnes/yr). Other major inputs included hydrocarbons in sewage effluent (58 - 84 tonnes/yr), industrial inputs (18 - 31 tonnes/yr) and atmospheric deposition (5 - 14 tonnes/yr) (Table 32).

Table 32 Estimation of the major hydrocarbon inputs to the Derwent Estuary

	Volume (kL/day)	Concentration (mg/L)	Quantity (kg/day)	Quantity (tonnes/year)
Urban runoff				164
Sewage effluent	55,600	2.85 - 4.15	158 - 231	58 - 84
Industrial effluent	199,500	0.24 - 0.41	48 - 82	18 - 31
Atmospheric deposition			13 - 37	4.9 - 13.7

(Green, 1997)

This estimate of hydrocarbon discharge from the Hobart urban area to the Derwent Estuary does not include sporadic hydrocarbon discharge due to accidental spillages or leakage of fuel from underground tanks. Inputs of this nature can be considerable (Green, 1997).

The hydrocarbon discharge to the Derwent Estuary from stormwater alone is in the order of 0.96 kg per capita per year (Green, 1997). This compares to estimates from the USA of 0.969 kg/capita/yr at Narragansett Bay (Hoffman *et al.*, 1982) and 0.875 kg/capita/yr for the Los Angeles River drainage basin (Eganhouse *et al.*, 1981).

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) occur in relatively low concentrations in most petroleum substances. Some PAHs occur naturally in the environment; however, their main sources are related to human activities. PAHs are introduced into the environment via spillages of petroleum hydrocarbons (i.e. shipping operations) or more frequently, by combustion or as a result of urban runoff. As such, high concentrations are usually found near population centres and industrial operations. Concern over PAHs relates to the fact that some are known to cause cancer in man and higher animals, although not all are carcinogenic. The most well known carcinogen is benzo (a) pyrene. Toxic effects of PAHs in the aquatic environment may be either acute (immediately toxic to aquatic life) caused by PAHs with 2-3 rings, or chronic (causing longer-term effects such as cancer) which are caused by 4, 5 and 6 ringed compounds. PAHs with more than 6 rings are generally inactive (Gawne and Richardson, 1992).

The water solubility of most PAHs is extremely low and they are usually sorbed onto particles soon after entering a water body. However PAHs are very soluble in animal fat and tend to bio-accumulate in the tissues of organisms. Oysters and mussels are good bio-indicator species for PAHs in the environment, as they do not excrete PAHs as metabolites and they can accumulate PAHs without the deleterious effects suffered by fish (Gawne and Richardson, 1992). Concentrations of PAHs generally tend to be lowest in the water column, intermediate in biota and highest in sediments (ANZECC, 1992). According to the current Australian guidelines, concentrations of polycyclic aromatic hydrocarbons in fresh and marine waters should not exceed 3 µg/L (ANZECC, 1992).

Studies of PAHs in Derwent Estuary sediments

PAHs in sediments of the Derwent Estuary were studied by Green (1997). This work was predominantly conducted at Prince of Wales Bay in the middle estuary. The PAH content of Prince of Wales Bay sediments varied greatly and ranged over four orders of magnitude.

As was the case for aliphatic hydrocarbons, PAH contamination in Prince of Wales Bay sediments was found to be localised and occurred predominantly in sheltered embayments, adjacent to stormwater outfalls and beneath marinas. Sediment PAH concentrations ranged from 21.3 µg/kg, which is relatively unpolluted and compares to a level of 7 µg/kg recorded in Antarctica (Green *et al.*, 1992) and <0.4 µg/kg in a Great Barrier Reef sediment (Smith *et al.*, 1985), to 27,000 µg/kg near a major stormwater outfall (see Table 33). This appears to be the highest PAH value for marine sediments yet recorded in Australia and is comparable to grossly polluted sites overseas, such as 29,590 µg/kg PAHs in San Francisco Harbour (Periera *et al.*, 1996) (Table 33). The value is also above concentrations recorded in many other areas of North America and Europe and indicates significant pollution. It is, however, well below values recorded for extremely polluted sites; e.g., 718,364 µg/kg PAHs in a surface sediment from Boston Harbour (Shiaris and Jambard-Sweet, 1986).

Table 33 Concentrations of PAHs in sediments

Location	Total PAH µg/g (dry weight)	Reference
Yarra Estuary, Melbourne	120 - 10,900	Bagg *et al.*, (1981)
Corio Bay, Geelong	490 - 3,000	Bagg *et al.*, (1981)
Mallacoota Inlet, Victoria	80 - 1,100	Bagg *et al.*, (1981)
Greenwich Bay, Melbourne	16,406	Clementson, (1981)
John Brewer Reef, Qld	<0.4	Smith *et al.*, (1985)
Gladstone Harbour, Qld	1,497	Smith *et al.*, (1985)
Townsville Harbour, Qld	42 - 13,400	Smith *et al.*, (1985)
Brisbane River, Qld	3,940 - 16,110	Kayal & Connell, (1989)
Malabar sewage outfall, Sydney	180	Nichols & Espey, (1991)
George's River, Sydney	56 - 21,400	Brown & Maher, (1992)
Lake Burley Griffin, Canberra	80 - 538	Leeming & Maher, (1992)
Derwent Estuary, Hobart	21 - 27,040	Green 1997

Gas chromatography/mass spectrometric analysis of sediment samples from Prince of Wales Bay showed that PAHs were derived from several different sources (Green, 1997). Adjacent to the major stormwater outfall and in poorly flushed back waters, automobile sump oil was the major contributor to hydrocarbon contamination in the sediments. Other PAH compounds derived from boating activities and combustion were identifiable at sites away from stormwater discharge points.

6.9 Other contaminants

Resin acids

Resin acids are a component of softwoods, such as *Pinus radiata*, which are produced and released in the thermo-mechanical pulping process. At ANM, approximately 70% of these resin acids are removed through the primary treatment process (clarification with alum addition); average resin acid concentrations in the treated effluent over 5 year period (Aug 89 to Aug 94) was 3.2 mg/L (range from <1 to 7 mg/L). In 1996, average resin acid concentrations were 2.3 mg/L. Biological secondary treatment would achieve removal rates of > 98%, resulting in average resin acid concentrations in effluent of < 0.1 mg/L.

Resin acids are toxic to fish, with 96hrLC50 levels as low as 0.5 mg/L being recorded. Davies *et al.* (1988) conducted a series of experiments in which a range of native species were subjected to flow-through bioassays using Boyer Mill effluent. The time independent LC50 resin acid concentration for the most sensitive species (juvenile *Salmo gairdneri*) was 0.22 mg/L. The 1996 average effluent resin acid concentration of 2.3 mg/L is nearly 10 times the LC50 value. Monitoring of resin acid levels in the river was made a licence condition of the mill's operation, in order to ascertain/demonstrate levels following dilution.

Richardson *et al.* (1995) review monitoring data collected at 5 sites in the upper Derwent between February 1991 and January 1995. Four of these (sites C1 to C4) were arranged as a cross-river transect about 600 m downstream of ANM's effluent outfall, while the fifth (site F) was situated approximately 2 km below the outfall. Monitoring was carried out every three months, with surface samples collected once every two hours over a 6-hour period. ANM's effluent generally forms a surface plume extending downstream along the northern side of the river. Resin acid concentrations within this plume ranged from below the detection limit (0.005 mg/L) to greater than 0.6 mg/L; typically, resin acid concentrations dropped off rapidly from the northern to the southern bank. At site F average resin acid concentrations over the 4 year monitoring period was 0.02 mg/L, corresponding exactly to the threshold limit suggested by Davies *et al.* (1988).

CSIRO conducted field and modelling studies of the upper estuary in 1993 to evaulate the dispersion and degradation of resin acids (see Richardson *et al.*, 1995). Certain classes of resin acids (particularly levopimaric/palustric) were found to degrade substantially within the water column. Resin acids were not found to accumulate in sediments to a large concentration.

Phenolics

Phenols are used in large quantities as raw materials in the manufacture of plastics, dyes, drugs and other chemicals. Some are used as wood preservatives and in herbicides and phenolic wastes are produced during the coking of coal, distillation of wood, in oil refineries and in pulp and paper industries. Effluents from these processes represent obvious sources of phenolic contamination in the aquatic environment; however phenolics may also be present as a result of natural processes such as the degradation of complex organic substances (Australian Water Resources Council, 1984). The persistence of phenolics in the aquatic environment is variable. However, some phenolics have been shown to degrade in natural waters. Individual phenolic compounds vary widely in their toxicity to aquatic organisms (ANZECC, 1992). Toxicity may arise as a result of direct toxic action or through low oxygen levels brought about by the BOD of the phenol. The toxicity is increased by low dissolved oxygen levels and also increases with salinity (Australian Water Resources Council, 1984). ANZECC guidelines for the protection of the aquatic ecosystem recommend that levels of phenolics in marine waters should not exceed 0.2 to 50 μg/L, depending on the specific compound.

No data has been published on phenolics in the Derwent Estuary.

Fluoride

Although fluoride is known to adversely affect terrestrial ecosystems at high concentrations - damaging vegetation and weakening bones and teeth of animals, effects on the marine environment have not been well documented, and ANZECC (1992) does not list any guideline for fluoride concentrations for the protection of aquatic ecosystems.

No data have been published on fluoride in the Derwent Estuary.

Pesticides

The presence of pesticides is generally due to direct application to the environment through agricultural or domestic activities. Pesticides find their way into natural waters via accidental spillage, spray drift, agricultural runoff after rain or via atmospheric deposition (ANZECC, 1992). DDT and Dieldrin are organopesticides, with low water solubility but high solubility in animal fat, and have high chemical and biological stability. The persistence of organochlorines in the environment results in a greater chance of contact with non-target organisms. In addition to accumulation through direct contact, organochlorines may also bioaccumulate along the food chain. ANZECC guidelines for DDT in water are set at 1 ng/L and for Dieldrin, the suggested guideline is 2 ng/L.

Few data have been published on pesticides in the Derwent Estuary, with the exception of some preliminary analyses of organochlorine compounds in brown trout (*Salmo trutta*) caught in the upper Derwent Estuary in 1989. This preliminary study suggested that organochlorine concentrations in these specimens far exceeded normal background concentrations (Davies and Kalish, 1989).

Polychlorinated biphenyls

Polychlorinated biphenyls (PCBs) are organic compounds which are widely used in industrial applications. Sources of PCBs entering the environment include wastes containing PCBs or open burning/incomplete combustion of PCBs. PCBs accumulate readily in sediments and biota and are toxic to marine aquatic organisms at low concentrations. ANZECC (1992) recommends that concentrations of PCBs in marine waters should not exceed 0.004 µg/L.

No data have been published on PCB concentrations in the Derwent Estuary.

7 Summary and recommendations

The environmental quality of the Derwent Estuary is a function of its physical setting, as well as historic and on-going inputs of pollutants. These physical features play an important and often controlling role in the ultimate fate and distribution of contaminants. The Derwent is a relatively deep, microtidal estuary, which is highly stratified in its upper reaches, and partially- to well-mixed in its broad lower reaches. Estuarine circulation is characterised by a relatively short residence time (approximately 2 weeks), and a large and consistent freshwater input from the Derwent River. Freshwater surface flows are directed toward the eastern shore, and saline bottom water travels slowly up-river. The Derwent is affected by strong seasonal influences: temperatures, coastal currents, winds and other factors which ultimately affect water quality. The Derwent River catchment is very large and sparsely populated. Water quality from the catchment is generally good, however, flows are strongly regulated for hydropower generation.

The Derwent, together with Mt Wellington, provide the focal point for Hobart, Tasmania's capital city. The estuary is heavily used for recreation, marine transport, boating and fishing, and is internationally known as the venue for the Sydney-to-Hobart Yacht Race. The Derwent is Tasmania's third largest port, and supports a large zinc refinery (Pasminco Hobart) and a large paper mill (ANM-Boyer). Despite existing degradation, it is an important and productive ecosystem and was once a major breeding ground for the Southern Right whale.

Since Hobart was established in 1803, the Derwent has received the majority of the City's urban and industrial wastewater, much of which was untreated or poorly treated until the 1980s/90s. Major contaminants of concern associated with wastewater discharges include pathogens, nutrients, BOD, TSS, heavy metals, arsenic, resin acids hydrocarbons and other organic compounds. There have been significant decreases in most end-of-pipe emissions over the past 5 to 10 years - particularly as a result of sewage treatment plant upgrades and improved treatment of wastewater from ANM and Pasminco Hobart. In 1996, ANM still contributed substantial end-of-pipe emissions to the estuary (BOD, TSS, resin acids), as did 12 sewage treatment plants (nutrients), but the remaining significant inputs to the estuary are primarily derived from diffuse sources, such as urban runoff, ground-and surface-water emissions from tips and contaminated sites (particularly ground-water leaching of heavy