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**Chromium and zinc levels in
the water, sediment and biota
of the Swan-Canning Estuary,
Perth, Western Australia**

**Swan River Trust
Report No. 9
June 1993**





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Chromium and zinc levels in the water, sediment and biota of the Swan-Canning Estuary, Perth, Western Australia

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Photographic Plates



The Perth CBD in 1989 courtesy of Geoff Parsons, Hydrologist for the Waterways Commission



SUMMARY

Air-conditioner plants for large buildings in the Perth Central Business District (CBD) achieve cooling by evaporation of water. The evaporation process loses water, thus concentrates impurities in the scheme input water and those picked up from cooling towers. Make-up water is added to the system in excess to replenish lost water and to carry away some of the contaminants with the overflow. Chromium and zinc chemicals are used in the air-conditioners to protect the metal components from scaling and corrosion caused by the impurities in recirculating water.

Bleed off from air-conditioners in Perth (CBD) are drained into city street drains which drain into the Swan River estuary. Both zinc and chromium are known for their toxicity to animals. The Swan River Trust has been concerned for some time that zinc and chromium may be increasing in the physical environment and bio-accumulating in the food chain and animals harvested by recreational and commercial fishermen.

Chromium and zinc levels in the waters, sediments and biota of the Swan River estuary in the vicinity of the Perth (CBD) were studied in the period from November 1988 to April 1989. Concurrently, a survey of air-conditioner chemical suppliers, building owners and chemical loads in drains was carried out by the Water Authority of Western Australia. That survey confirmed that actual and theoretical chromium and zinc loads to the river had increased during the peak air-conditioner usage period from spring to autumn.

The CBD stormwater drainage system, carries stormwater, groundwater, air-conditioner bleed-off/wastes for disposal into the Swan River estuary. Previous surveys by the Swan River Management Authority indicated that on an annual basis, between 200-800kg of chromium and 250-450kg of zinc may be entering the Swan River estuary from chemicals applied to treat the water and pipes in air conditioner cooling towers.

This survey measured the level of chromium and zinc in the Swan River estuary and animals adjacent to the Perth CBD over a grid pattern of around 40 sites on two occasions.

The data obtained in this survey for the levels of chromium and zinc in the waters, sediments and biota of the Swan adjacent to the Perth CBD were compared with levels at control sites considered to be representative of background concentrations and to other available data.

The Environmental Protection Authority has established water quality criteria for various beneficial uses of marine and estuarine waters. When compared with these criteria, the estuarine concentrations for zinc and chromium were all below the six-month median and single sample criteria. In the estuary adjacent to the drain outfalls however, a substantial area of the surface waters consistently exceeded the six-month median and once-off sample criteria, as would be expected in the drain-mixing zone.

River sediments showed variable concentrations of zinc and chromium. In Melville Water and adjacent to CBD drain outfalls, there was a good correlation between chromium and zinc concentrations and sediment organic matter.

The highest mean zinc concentrations in estuarine sediments were nearest to the Central Business District in both 1988 and 1989. The mean sediment total chromium concentration nearer to the CBD were higher in 1989 than in 1988. A number of zinc 'hot spot' sites were identified. These were in the river areas adjacent to the Mounts Bay, Plain Street and Claisebrook Main Drains. These sites are of concern to the Swan River Trust.

In the absence of criteria for zinc and chromium in estuarine sediments, these data were compared with terrestrial soil criteria. Over 22 estuarine sites exceeded the draft soil criteria for zinc ($>350\text{mg/kg}$) and 4 sites for chromium ($>100\text{ mg/kg}$) as recommended by the Australia and New Zealand Environment Council (ANZEC) and the National Health and Medical Research Council (NHRMC) as being acceptable for terrestrial soils. The site adjacent to the Mounts Bay Main Drain exceeded the draft zinc concentration criteria by 140%. In Melville Water and Maylands estuarine sediments, the concentrations of metals did not exceed the soil criteria for either chromium or zinc.

The survey indicated that the muscle tissue of fish caught from the estuary, adjacent to the CBD drainage outfalls contained concentrations of chromium and zinc well below health limits. No local Maximum Permitted Concentration is available for chromium.

The organs of some fish, especially Perth herring, showed very high levels of accumulation of the metals relative to the muscle tissue. The liver, viscera, male and female gonads (which are not normally eaten) contained high levels of chromium and zinc, which raises concerns of the possible sub-lethal effects of those concentrations on the fish metabolism and reproduction.

Without action, the amount of these heavy metals being used in air-conditioning cooling towers in the CBD will continue to increase with further expansion and development. The current Perth City Council Bylaws do not prohibit the discharge of air-conditioner cooling tower bleed-off into the stormwater drainage system which empties to the Swan River.

Although current levels of chromium and zinc are not critical, there is evidence that some contamination has occurred in sediments and in estuarine biota. Elevated levels in the organs of some fish species raise concerns about sub-lethal effects on fish.

The US Environmental Protection Agency has banned the use of toxic metals in air-conditioning systems. Alternative water treatments which do not use heavy metals are available. As newer corrosion resistant materials such as stainless steel are being used in modern cooling towers scaling and bacterial treatments will become the primary maintenance concerns. Some efficient alternative treatments using cathodic protection and ozone injection in these systems have been used successfully both locally and in other Australian states.

Perth City Council, on reception of plans for proposed buildings in the Perth Central Business District should consider the incorporation of alternative air-conditioning treatments (subject to approval by the Environmental Protection Authority), which do not require the discharge of toxic and harmful chemicals to the stormwater drainage system and the thus to the Swan River.

In view of the slightly elevated concentrations of chromium and zinc in the Swan River estuary, current policy on metal use and disposal may need to be reviewed.

1. Introduction

Located on the Swan Coastal Plain in Western Australia, the Swan-Canning River system is estuarine for a distance of over 60 km from its mouth at Fremantle (Figure 1.1). The estuary is a drowned river valley system which occurred about 6,000 years ago following a rise in sea level. The estuary sediments range from silty sand to black to sulphurous estuarine silt (Collins, 1987). Perth city, the capital of Western Australia, is situated on the north shore of Perth Water, approximately 20 km upstream of the Port of Fremantle.

Perth Water forms a sill between the basin downstream of the Narrows Bridge and the riverine reaches of the upper estuary. The daily astronomical tidal range in Perth Water is about 80% of that at Fremantle (Hodgkin, 1987).

Most air conditioner cooling plants in the Perth Central Business District (CBD) use a system of recirculating water with either chromium or zinc-based chemicals added to prevent corrosion and scale build-up of the metal pipes and heat transfer surfaces. Water is lost from the recirculating system by evaporation, bleed-off and also by the routine maintenance cleaning of built-up sludge (Water Authority of Western Australia, 1990). Bleed-off contains, beside chromates and zinc, dispersants, dust, algae, slimes and dissolved solids at many times the concentration of scheme water. In small cooling systems bleed off water is spent intermittently, while larger systems are continuously or semi-continuously bled off. This can be coupled with the complete renewal of the cooling system with cleaning of the entire system of scale, rust and slime (Institute of Sanitary Engineering, Polytechnic of Milan, 1982).

In the Perth CBD, waste from high-rise building air conditioners is discharged into Perth City Council (PCC) storm-water drains which form part of the catchment to the Swan River estuary (Figure 1.1). The current Perth City Council (PCC) Bylaws do not prohibit the discharge of air conditioning cooling tower bleed-off to the stormwater drainage system. This is currently under review (R Curry PCC pers. comm., 1992). Most of the waste finally empties into the adjacent waters of the Swan River estuary either through one of six Water Authority of Western Australia (WAWA) Main Drains or directly through a number of PCC drains, located between the Narrows Bridge and the Bunbury Railway Bridge at East Perth (Figure 1.1).

The number and sizes of high-rise buildings in the CBD is increasing rapidly, estimated at 20% over the three year period since 1987, (Lush, PCC pers. comm. December 1990). As more, older buildings are replaced by larger new air-conditioned high-rise,

the potential volume of air-conditioner waste to the Swan River estuary will correspondingly increase.

Based on the estimated chromium load (Griffiths and Holt, 1985; Schulz and Hosja, 1988) and the current estimated office space growth rate in the Perth CBD, the projected annual load of chromium into Perth water from air-conditioners might exceed one tonne by the year 2000. The equivalent zinc load would be 3.7 tonnes, discharged into an area of approximately 4.5 square kilometres between the Narrows and the Bunbury Bridge.

The Water Authority of Western Australia (WAWA) does not accept untreated air-conditioner waste to sewer because of possible poisoning of biological treatment systems and the physical inability of the sewerage system to handle the volumes.

Table 1.1

WAWA concentration and treatment criteria for acceptance of chromium and zinc discharges into the WAWA sewerage reticulation systems.

Metal	Daily mass of metal discharge-g/day	Concentration Limit mg/L
Cr	<23	no limit
Zn	<46	no limit
Cr	>23<420*	10
Zn	>23<560*	10
Cr	>420	No accepted to sewer
Zn	>560	No accepted to sewer

(Water Authority of Western Australia, 1992.) *denotes treatment prior to discharge to sewer.

When considering trace metals in the marine environment, there is principally no zero level. Residues in uncontaminated samples will reflect local geochemical characteristics, the 'background levels' (Harms and Kerkhoff, cited in Salomons et al., 1989).

The literature indicates that the total chromium concentration in primary wastewaters may reach concentrations as high as 700µg/L. If present in the hexavalent state these concentrations may be toxic to many marine animals and certainly to alga and

other micro-organisms. The significance of chromium present in municipal waste discharges therefore remains an important matter for investigation (Langard in Waldron, 1980).

1.1 Aim of this investigation

The aims of this survey were to establish in conjunction with the Water Authority of Western Australia, the concentrations and the load of chromium and zinc being discharged from the Perth CBD to the Swan River estuary, and also the distribution of total chromium and zinc in the Swan River estuarine environment adjacent to the Perth Central Business District.

It is also intended to compare these data to the background levels and to previous studies of metals in the Swan/Canning estuarine system.

It is intended to compare the results of this study with those from other estuaries and water bodies both in Australia and internationally.

The results will be compared to available environmental and health standards or criteria.

To complement this investigation by the Swan River Trust the Water Authority of Western Australia carried out air-conditioning and drainage surveys to more accurately estimate the zinc and chromium loads discharged from the Perth CBD (WAWA, 1990).

Concern was raised that air conditioner wastewater containing zinc and chromium, discharging into the Swan River estuary might either be causing an accumulation of trace metals in the environment or causing lethal or sub-lethal effects on the biota. Concern was also raised that if it continued unabated, the increase of trace metal load may exceed the estuary's assimilating capacity for these metals.

The Swan River Trust currently has no policy on the discharge of air-conditioner waste into the Swan River estuary and has initiated this investigation to determine the environmental impacts of continued discharge of these metals to the riverine environment.

Three

3



2. Literature Review

This section summarises information contained within international literature information for this topic.

2.1 Toxicity of chromium to estuarine and marine life

Typical chromium concentrations in unpolluted seawater ranges between 0.1-1.5µg/L. In natural waters chromium (Cr) exists in two oxidation states, Cr³⁺ and Cr⁶⁺. Cr³⁺ is 10 times more toxic than Cr⁶⁺ (Holdway, 1988). The reduced and oxidized forms are interchangeable in the natural environment and therefore water quality criteria takes into account the total chromium concentrations. Chromium concentrations as low as 10µg/L can produce sub-lethal effects on the crustacean *Daphnia magna*. Chromium concentrations of 20µg/L can reduce the photosynthetic activity of algae (Hart, 1982). Though bio-accumulation of chromium by marine organisms is demonstrated, there is little evidence of bio-magnification. The recommended maximum allowable concentration of chromium in aquatic environments is 10µg/L (Hart, 1982).

The 96 hr LC₅₀ values for both Cr³⁺ and Cr⁶⁺ in juvenile yellow-eye mullet, were 53,000 and 24,000µg/L respectively (Negilski, 1976).

Chinook salmon is more susceptible to the toxic effects of hexavalent chromium than other species., a 4 to 5 week exposure producing 53% mortality at chromium levels of 200µg/L (Langard, cited in Waldron, 1980).

There are a wide range of recommended 'safe' or Maximum Acceptable Toxicant Concentration (MATC), depending on fish species tested ;

- i) 50-3950µg/L for Cr⁶⁺ and
- ii) 0-380µg/L for Cr³⁺, depending on the fish species.

Toxicity data are usually confined to exposures of 16 days or less. The range of 4-day LC₅₀'s for 4 phyla are summarised in Table 2.1 (Mance, 1987).

Table 2.1

The 4-day LC₅₀ toxicity data for chromium for four phyla.

Phylum	Ranges of 4-day LC ₅₀ (µg/L)
Annelids (larvae)	8000
Annelids (adult)	2200 - 80000
Molluscs (larvae)	4540
Molluscs (adult)	14000 - 190000
Crustaceans (zoeae)	3440
Crustaceans (adult)	2000 - 98000
Fish (larvae)	12400 - 14300
Fish (juvenile)	20100
Fish (adult)	11000 - 297000

From Mance, 1987.

A substantial increase in toxicity by chromium solutions to some annelids can be elicited by reducing the salinity or raising the temperature of the water in which test species are immersed. Longer exposure data indicate that adverse effect concentrations on the annelid *Capitella capitata*, are lowered to a 28-day LC₅₀ of 500µg/L from a 4-day LC₅₀ of 5000µg/L (Reish, 1976, cited in Mance, 1987). Exposure to concentrations as low as 30µg/L of chromium disrupted the reproductive success of *Neanthes arenaceodentata* which emphasises the importance of long-term exposures in assessing potential adverse effects. This species had a 4-day LC₅₀ of 2200-4300µg/L of potassium dichromate (Oshida, cited in Mance, 1987).

The larva from the mussel *Mytilus edulis* has a 2-day EC₅₀ (development abnormal) at a potassium dichromate concentration of 4470µg/L.

2.2 The toxicity of zinc to estuarine and marine life

Typical zinc concentrations in unpolluted seawater ranges between 0.01µg/L and 10.0µg/L. The recommended criteria for the protection of aquatic ecosystems is 10µg/L (Hart, 1982).

Toxicity data for zinc indicate that all stages of marine fish are relatively resistant to zinc-when compared to crustaceans, bivalves, molluscs and larval polychaete worms. The adult polychaetes and

gastropods response to zinc is similar to marine fish (Mance, 1987). *Mytilus edulis* adults showed reduced nominal growth at zinc concentrations of 10-50µg/L (Stromgren; cited in Mance, 1987) while their larvae showed abnormal development at zinc concentrations of 175µg/L (Martin,; cited in Mance, 1987).

Table 2.2

The 4-day LC₅₀ toxicity data for zinc for four phyla.

Phylum	Ranges of 4-day LC ₅₀ (µg/L)
Annelids (larvae)	1700
Annelids (juvenile)	900
Annelids (adult)	1800 - 55800
Molluscs (larvae)	2500 - 950000
Crustaceans (larvae)	175 - 1000
Crustaceans (larvae)	498 - 16000
Fish (larvae)	2730 - 83000
Fish (adult)	3600 - 60000

From Mance, 1987.

In contrast to freshwater fish, adult marine fish are amongst the least sensitive of the taxa of marine and estuarine animals tested (Mance, 1987). Larval fish are only marginally more sensitive to zinc than adult fish. Two fish species exposed to zinc at a variety of salinities were most susceptible to zinc at low salinities (Herbert and Wakeford; cited in Mance, 1987). Those species were found to be least sensitive at intermediate salinities.

Comprehensive reviews of metal contamination and accumulation in aquatic environments have uncovered very few studies which demonstrate bio-magnification (Mance, 1987).

Table 2.3

Summary of metal content of groups of commercial species sampled in 1975 in the UK Coastal waters in mg/kg (converted to approximate wet weight from dry weight. factor 0.17)

Phylum	Chromium range (mg/kg)	Zinc range (mg/kg)
Molluscs filter feeding	0.03-0.5	2-36
Molusc predators	0.2-0.3	11-120
Crustacean predators	<0.1-0.3	2.4-6.5
Fish - coastal	<0.1-0.1	0.4-6.5
Fish - midwater	<0.1	0.4-4.8
Fish - distant water	<0.1-0.1	0.4-3.7

(Ratkowsky, cited in Mance, 1987).

Various studies have been carried out on trace metals in fish, water and sediments of the Swan and Canning rivers systems; Plaskett and Potter 1980; Chegwiddden, 1980-a, Chegwiddden 1980-b, Taylor, 1980; McConchie 1985; Griffiths and Holt, 1985; Griffiths 1985; Blackmore, 1985; Schulz and Hosja, 1989; WAWA, 1990; Klemm and Deeley, 1991 and Parker I (in progress).

In static tests on juvenile yellow-eye mullet, the acute incipient lethal limit was 9000µg/L for zinc. Similar tests for 168 hr LC50 values on pre-adult hardyheads, the acute incipient lethal level for zinc was 33,000µg/L. Based on available toxicological information, mullet and hardyheads were more sensitive to chromium and zinc than other marine and estuarine fishes. The static bio-assay on mullet did not produce mortality at less than 20,000µg/L of zinc. In continuous-flow assays, zinc concentrations of as low as 7,200µg/L mucous secretions frequently covered the rear of test mullet and erosion of the caudal and anal fins, which severely affected swimming activity (Negilski, 1976). Zinc caused the test fish to turn dark. From the potency ratios Negilski found that zinc to be between 2.2 and 3.5 times more toxic to mullet than hexavalent chromium.

2.3 Sublethal Effects

Sub-lethal effects can be just as important as lethal effects. They can manifest themselves as altered behaviour (feeding and moulting), slower growth rates and changes in the number of offspring. Some species are more susceptible than others, with the egg, larvae and embryo being more sensitive than the adult (Bell, 1983; Holdway, 1988). The male gamete is the most sensitive parameter (Holdway 1988).

Fish require a zinc intake at a rate of approximately 100mg per kilogram of diet. Deficiencies can lead to; poor growth, epithelial erosion, central lens cataracts and even death at levels of 1-5mg/kg of diet. Levels in excess of 300mg/kg of diet can induce primary toxicity. Zinc can induce spinal deformities by inducing muscle spasm (Langdon 1986).

The lowest values for Minimum Effect Concentrations (MEC's) in the marine amphipod *Allorchestes compressa* were >250µg/L and 99µg/L for chromium and zinc respectively (Ahsanullah and Williams, 1991). At the MEC's the concentration of chromium and zinc in the animals were >4.4 mg/kg and 24µg/L approximate wet weight (factor 0.17). Accumulation of chromium showed some evidence of metabolic regulation. Regulation of chromium may occur at around 5mg/kg (wet weight) over a water concentration of zero to 100µg/L in water. Zinc accumulation showed clear evidence of regulation. As the concentration of zinc in sea-water rose above 100µg/L, mortality increased to almost 100% at 300µg/L, without extra zinc being taken up by the amphipods' bodies. It was speculated that the site of the toxic effect may have been external such as the surface of the gills. Crustaceans are generally more tolerant of chromium than other species (Ahsanullah, 1982).

2.4 Waters

In the summer months the salinity of the drain waters are low compared to that of the receiving estuary during the survey. Compared with the behaviour of metals in oceans and lakes, the estuarine system is more complex and more dynamic because of the strong gradients in chemical composition of the water, the variable suspended matter concentrations and complex hydrodynamic processes (Salomons and Forstner, 1984).

2.4.1 Main Drains

In the Mounts Bay Main Drain (MBMD), which empties into Perth Water, just upstream of the Narrows Bridge (Figure 1), Taylor in 1980 reported high concentrations of chromium, at 740µg/L in December 1979 and 350µg/L in March 1980. Also Taylor reported zinc concentrations of 530µg/L and 260µg/L in the MBMD.

In the Claisebrook Main Drain at East Perth (Figure 1.1), Taylor reported zinc concentrations of 200µg/L and 140µg/L in December 1979 and March 1980 respectively. These high values in the drains, Taylor pointed out, would create localised mixing zones exceeding the water quality objectives of the Californian Environmental Quality Act (CEQA) of 2µg/L for total chromium and 20µg/L for zinc.

Concentrations of chromium, as high as 22,000µg/L have intermittently been detected in drains which carry discharged cooling water effluent from the CBD. Similarly, opportunistic sampling has revealed high zinc concentrations in some of these drains (Swan River Trust; unpublished data). Schulz and Hosja in 1988 found total chromium and zinc concentrations of up to 12,000µg/L and 6,600µg/L respectively, in a tributary of the Mounts Bay Main Drain.

From a detailed survey of buildings within part of the Perth CBD, Griffiths and Holt (1985) estimated that 373kg of chromium and 373kg of zinc were being discharged into the Swan River estuary from CBD-based air conditioning units.

Concentrations of chromium inhibitors in the cooling water effluent from two major buildings located in the Perth CBD were analysed by Griffiths in 1985. He found that a building which had steel water cooling pipes, used higher chromium dosage levels (mean: 17,000µg/L, maximum: 24,000µg/L of chromium), than a building with copper piping (maximum: 2,300µg/L; mean: 1,400µg/L). Both of these buildings are located within the catchment of the Mounts Bay Main Drain to the Swan River estuary (Figure 1.1).

Analysis of the outfalls of three Water Authority of WA drains which discharge from the Perth CBD, revealed that the Victoria Avenue Main Drain had the highest concentrations of chromium at between 680µg/L and 410µg/L (Hosja, 1987). The calculated chromium loads based on the flow rates in March 1980 however, revealed that the Mounts Bay Main Drain contributed the highest chromium load at 35 g/hr. The load from the Claisebrook Main Drain was 20g/hr. An instantaneous chromium load from the MBMD in December 1979 was 700 g/hr (Taylor, 1980).

Table 2.4

Summary of theoretical and sampled annual chromium and zinc loads from the Perth CBD.

Authors	Method	Annual Cr load (kg)	Annual Zn load (kg)
Groffotjs * Holt, 1985	Sirveu	372.8	159.1
Schulz & Hosja 1988 (5 CBD drains)	sampling	406	463
WAWA * 1990	survey	831	425
WAWA * 1990 (2 CBD drains)	sampling	190	268

*Water Authority of Western Australia, 1990.

Weekly sampling of Perth CBD drains and tributaries which are in the catchment of the Swan estuary at Perth was carried out between December 1987 and March 1988. It was estimated that 406kg of chromium and 463kg of zinc were being discharged via these drains over a 200 day period (Schulz and Hosja, 1988). The highest chromium values were found in the City Council drains at the foot of William Street, tributaries of the Mounts Bay Main Drain. Chromium concentrations of between 2,000-6,700µg/L were found in early December 1987. The highest concentration chromium at the Victoria Avenue Main Drain outfall was 5,700µg/L in mid-December. The highest instantaneous zinc concentration was 8,600µg/L in the William Street (PCC) tributary of the MBMD.

From a survey of chemical air-conditioning inhibitor suppliers, it was estimated that 46 tonnes of inhibitor (including solvents), were used in the Perth CBD annually (WAWA, 1990). Using a conversion that on average chromium accounted 1.8% of the chemical and zinc approximately 0.9%, the WAWA estimated that the annual load was 831kg of chromium and 425kg of zinc. Sampling by the WAWA (based on two drains) in 1988/89, revealed that the 200 day annual chromium and zinc loads to the Swan River estuary from the Perth CBD totalled 190kg and 268kg respectively. The WAWA concluded that the survey confirmed that the amount of zinc and chromium being discharged to the Swan River estuary had increased since 1985.

Table 2.5

Summary of calculated annual areal chromium and zinc loads from the CBD. in the area of the Swan River estuary between the Narrows Bridge and the Bunbury rail bridge (4.5 x 10⁶ square metres). Calculated areal metal loads, based on survey and sample data in table 2.4 above.

Authors	Method	Annual Cr load (µg/cm ²)	Annual Zn load (µg/cm ²)
Griffiths & Holt, 1985	survey	8.3	3.5
Schulz & Hosja, 1988	sampling	9.0	10.3
WAWA * 1990	survey	18.5	9.4
WAWA * 1990	sampling	4.2	6.0
Average	all	10	7.3

*Water Authority of Western Australia, 1990.

The above calculated annual areal loading rates of chromium and zinc to the sediment of the Swan River estuary between the Narrows Bridge and the Bunbury rail bridge are similar to those found in San Francisco Bay, which annually receives the equivalent of 71 tonnes of chromium (6.8µg/cm²) and 172 tonnes of zinc (16.5µg/cm²) contained in wastewater.

2.4.2 Waterbody

It is impossible to determine the level of chromium occurring in natural unpolluted waters because traces of the metal have been detected in wind-bourne particles remote from man's activities. The sources of chromium can include airborne soil particles and industrial air pollution. The chromium levels in rivers and lakes is usually range between 0.5µg/L and 10µg/L, usually at 1µg/L.

Table 2.6

Comparison of observed chromium concentrations in oceans from various sources.

	Chromium (µg/L)	Authors
Seawater	0.005-.8	by, authors cited in Richard, 1991
Seawater	0.1-0.5	Langard in Waldron, 1980
unfiltered ocean water	0.03-0.6	Bruland; cited in Carpenter et. al., 1991

Water samples from the Swan River estuary at the Middle Swan Bridge had low concentrations (<1.0µg/L) of chromium and zinc in the summer-autumn of 1979/80 (Taylor, 1980). At the same time at the Causeway site just upstream of Perth Water chromium concentrations were <1.0µg/L in the summer/autumn period. However, the estuary water-body zinc values at the Causeway sampling site were elevated in March 1980 at 20µg/L. The zinc value was equal to the proposed Marine Estuarine Water Quality criteria EPA (WA) for a single sample, chromium was below the criteria of 7µg/L for a single sample.

Samples of Swan River Estuary water from the Bayswater area had mean chromium and zinc concentrations of 1µg/L and 6.5µg/L respectively (Atkins et. al., 1990). All 1990 chromium concentrations in the same area of water were between 1µg/L and 2µg/L. The upstream control site at Guildford had the same chromium and concentrations as the Bayswater sites downstream. The Swan River at Bayswater had a zinc concentration range of 6-20µg/L in 1990 (Klemm and Deeley, 1991).

The sampling of Cockburn Sound and associated waters in the summer-autumn of 1978 produced zinc concentrations ranging between 3µg/L and 13µg/L (Chegwidzen, 1979).

Corio Bay (Victoria.), which is heavily contaminated with cadmium, had unfiltered surface water zinc concentrations between 3.9 and 67µg/L in 1977. Zinc levels were at times considered high enough to reduce algal growth (Smith et. al., 1981).

In Lake Macquarie (NSW) surface water samples, total dissolved zinc concentrations ranged between 1µg/L and 28µg/L, with the highest level associated with a creek into which a lead-zinc smelter discharged (Batley, 1987).

In the Murray River in South Australia, all samples of water below lock 9, had chromium concentrations below 20µg/L with a median concentration at around 10µg/L. At Morgan, upstream of lock 9, the zinc concentrations were less than 20µg/L. Below lock 9 at Mannum the maximum was 220µg/L. The median concentration for all South Australian stations was 30µg/L of zinc, with no obvious trend (Mackay et. al., 1988).

The results of sampling in the urbanized Brisbane River for the period 1984-87, were reported to have chromium ranges of between <1µg/L and 23µg/L and zinc concentrations of 10-130µg/L (Australian Littoral Society Inc, 1990).

Derwent Estuary waters (Tasmania) which are heavily polluted with zinc, had concentrations of between 12 and 420µg/L from 1973 to 1974. A follow-up study produced zinc concentrations of 1,500µg/L (Bloom and Ayling, 1977).

Baseline sampling of the near pristine waters of the Gordon River in Tasmania, revealed zinc concentrations of 0.3µg/L. These were similar to the zinc concentrations in the Upper King River of 0.4µg/L. Unfiltered samples from the Macquarie Harbour had zinc concentrations of between 1µg/L and 4µg/L (Carpenter et. al., 1991).

From Table 2.7 it is apparent that other pollutants can be more important than the Lowest Adverse-Affect Concentrations. The critical concentrations for metals in salt waters as annual average concentrations for chromium and zinc are 30µg/L and 50µg/L respectively (Mance, 1987).

Table 2.7

Comparison of observed metal concentrations in estuaries and a general assessment of environmental quality together with the Lowest Adverse-Effect Concentration.

Estuary Class	Chromium (µg/L)	Zinc (µg/L)
Good	0.4	9.2-136
Fair	NA	11-25
LAEC	550	10

(Mance, 1987); NA means not available

In the St Lawrence River in which salinity ranged from fresh to marine, Campbell and Yeates in 1984 found that in the fresher (0.05 p.p.t.) waters, mean dissolved chromium concentrations (0.68µg/L) were higher than in the more saline (30 p.p.t.) estuarine waters (0.23µg/L). The Saguenay River, a tributary of the St Lawrence estuary had dissolved chromium concentrations only slightly greater than sea-water concentrations at around 0.3µg/L (Campbell and Yeats 1984; unpublished data).

Monthly average dissolved zinc in the Gulf of Elefsis, from March 1977 to February 1978, ranged between 9.3 and 29.2µg/L with an annual mean of 18.3µg/L. The mean total zinc was 20.7µg/L. The elevated zinc in the Gulf seemed to affect the level of the metal in the zooplankton (Scoullou, 1981).

Table 2.8

Locations, averages, ranges and chromium concentrations from waterbodies from around the world.

Location	chromium µg/L (mean) (range)		Authors*
Maine USA	0.2	NA	Turekian & Kleinkopf, 1956
L Superior, Huron Erie, Ontario	1.2	NA	Weiler & Chawla 1969
Streams to L Michigan	3.0	0.3-69	Robbins et. al., 1974
Danube (Ulm)	7.2	3-18	Quentin and Winkler, 1974
Ruhr FRG	25	10-115	Ruhrverband (Anon, 1975)
Lake Constance (Lindau)	5.7	2-10	Quentin and Winkler, 1974

* cited in Forstner and Wittman 1979.; NA means not available.

Table 2.9

Average zinc concentrations in the polluted Severn Estuary and the Bristol Channel.

Year	1971	1972	1975-80
Area	concentrations (µg/L)		
Briston Channel	52	14.4-14.8	19-23
Severn Estuary	12	n/a	11-22

The above data are of zinc concentrations from the Estuary and Channel which in the 1970's were considered to be polluted by cadmium.

Polluted waters can have chromium concentrations of between 500 and 1400µg/L (Permutter et. al., cited in Richard and Bourg, 1991). Rivers can have chromium concentrations from zero to 1100µg/L (Kopp and Froner 1968, Trefry and Presley 1976 and Cranston and Murray 1980-cited in Richard and Bourg, 1991).

Table 2.10

Locations, averages, ranges and zinc concentrations from coastal waters of the Mediterranean Sea.

Location	Zinc (µg/L) (mean) (range)		Authors*
Gulf of La	10.5	6.5-15	Bernhard et. el., 1977
Trieste to Ravenna	13.6	1.4-36.4	Grancini et. al., 1975
Plonim to Nim (Adriatic)	13.8	1.5-365	Bubic et. al., 1977
Rosh Hanigra to Haifa	38.3	1-257	Roth and Hornung, 1977
Saronikos Gulf	20	NA	Papadopolou 1972

*Cited in Salomons and Forstner 1984

The high levels of metals in the Mediterranean Sea were attributed to the high quantity of domestic sewerage and the virtually total absence of control on toxic components (Salomons and Forstner 1984).

Table 2.11

Observed total chromium and total zinc concentrations in the open North Sea and also in rural and urban rivers discharging into the Sea (Mance, 1987).

Metal	open waters North Sea ($\mu\text{g/L}$)	Rural Rivers ($\mu\text{g/L}$)	Urban Rivers ($\mu\text{g/L}$)
Chromium	0.4	2.4-6.0	7.4-11.0
Zinc	1.0	25.0-26.0	68.0-69.0

In the Linggi River Basin, polluted by uncontrolled inputs of domestic and industrial effluents, zinc concentration ranged from $60\mu\text{g/L}$ to $5,120\mu\text{g/L}$. The highest concentrations of zinc in the Linggi River corresponded with factory and urban waste inputs (Nather Khan and Lim, 1991).

Zinc concentrations along the coast of Aqaba were $35\mu\text{g/L}$ (Wahbeh et. al., 1985). Atlantic and Pacific waters had zinc concentrations of 2-10 and $2.2\mu\text{g/L}$ of zinc (cited in Bloom and Ayling, 1977).

Typical levels of zinc in temperate estuaries and ocean values are $2-30\mu\text{g/L}$ and $5\mu\text{g/L}$ respectively (IHD-WHO Working Group on Quality of Water, 1978).

2.5 Sediments

In the literature, trace metal data are not very often comparable because they are based on different grain-size parameters. A strategy to understanding metal concentrations in sediments is to assess their magnitude in relation to baseline levels (Martincic et. al., 1988).

Trace metals reach the sediment in three principal ways according to Warren (1981).

- i) in or on particles which settle on the bottom
- ii) in or on particles which travel along the bottom and;
- iii) By the sorption of dissolved metals from waters in contact with the sediment

Cr^{3+} tends to be associated with particulate matter in waters and is therefore subject to sedimentation (Langard in Waldron, 1980).

In Spencer Gulf it was found that 80% of total metals was found in silt-sand sized particles $10-1000\mu\text{m}$ in size (Bell, 1983). Other studies used the $<63\mu\text{m}$ fraction as most indicative of sediments bearing the most anthropogenic inputs (Poulton, 1989).

In deep holes an effect of focusing sedimentary material deposition may occur (Golterman et. al., 1977; cited in Warren 1981 and Poulton, 1989). In addition to the physical and hydraulic factors, chemical factors such as Eh, pH, salinity, temperature and the nature and the amount of organic matter are also important. Sediments with a high proportion of organic carbon are likely to contain higher concentrations of zinc than similar sediments with lower organic carbon (Warren, 1981).

Heavy metals can be mobilised from sediments by lowering of oxygen potentials and altering the redox conditions. The lowering of pH leads to the dissolution of carbonates and hydroxides and to the increased desorption of metal cations due to the competition with H^+ ions (Forstner and Wittmann, 1979).

Decontamination of sediments is in general a slow process which can be accelerated by the presence of burrowing benthic organisms. The recovery of the bottom strata is due mainly to the deposition of unpolluted sediments with a subsequent embedding of the contaminated sediment cover (Cato et. al., - cited in Salomons and Forstner (1984). Living organisms can temporarily uptake metals from sediments and return them via faeces and decaying tissues and skeletal remains (James, 1978; cited in Warren 1981).

Mean zinc concentrations in surface sediments from the Swan River upstream adjacent to Jane Brook, Lilac Park and downstream at Chidley Point were 13, 14 and 120mg/kg dry basis (Chegwiddden 1980-a) and 15, 42 and 179mg/kg Chegwiddden, 1980-b. The concentrations fell below the upper limit (350mg/kg dry basis) suggested in the Australian guidelines for management of contaminated terrestrial soils, above which further investigations should be initiated.

Chegwiddden in 1980, found that sediment in the Swan River adjacent to the outfall of the Claisebrook Main Drain at East Perth, had a mean zinc concentration of 906mg/kg . The highest value was $2,190\text{mg/kg}$. This was six-fold the soil criteria of 350mg/kg on dry weight basis, above which it was considered, further investigation should be initiated. In Perth Water sediments adjacent to the Victoria Avenue Main Drain outfall Chegwiddden in 1980 found a maximum zinc concentration of 405mg/kg , which was above the soil criteria above which further investigations should be initiated.

On a dry weight basis, mean chromium concentrations in surface sediments from the Swan River estuary adjacent to Jane Brook, Lilac Park and Chidley Point were 15, 17 and 39mg/kg (Chegwidden, 1980-a) and 9, 19 and 51mg/kg dry weight basis (Chegwidden, 1980-b). The values fell below the upper limit of 100mg/kg (dry weight basis) suggested in the Australian Guidelines for Management of Contaminated Soils, above which further investigations should be initiated.

In 1980 Chegwidden found two significant sediment values of 275 and 218mg/kg of chromium, adjacent to the Claisebrook Main Drain outfall. These values were over twice the upper limits suggested in the Australian Guidelines for Management of Contaminated soils (100mg/kg dry basis), above which further investigations should be initiated. At the Victoria Avenue Main Drain mouth the maximum chromium concentration of 83mg/kg (Chegwidden 1980) was just below the criteria for soils.

Sediments in the Swan River estuary at Bayswater had zinc concentrations of 160-360mg/kg (dry weight) and between 88 and 140mg/kg of chromium (Klemm and Deeley, 1991).

In the marine sediments off the Western Australian coast, Chegwidden (1979) detected evidence of heavy metal accumulation. The surface 2 cm of sediment contained up to 133mg/kg of zinc (Cockburn Sound) and 68.4mg/kg of chromium (Owen Anchorage). The fact that high sediment metal concentrations were found in depressions, was explained by Chegwidden that these acted as traps for particulate matter and their associated metals.

McConchie (1985) sampled sediments along a transect from the Victoria Avenue Main Drain across Perth Water. He found surface sediment chromium levels increased markedly near to the drain. The maximum total chromium concentration of 205mg/kg on a dry weight basis (total of ammonium acetate, 30% hot HCl extraction), was twice the the upper limit suggested in the Australian guidelines for management of contaminated soils 100mg/kg dry basis, above which further investigations should be initiated. Sediment zinc concentrations adjacent to the drain outlet were three times the contaminated soil criteria (350mg/kg dry basis) above which further investigations should be initiated. The highest surface zinc concentration found was 1310mg/kg (total of ammonium acetate and 30% hot HCl extraction).

Table 2.12

Surface sediment chromium and zinc concentrations from Swan-Canning River estuary sites on the 24 October 1990 (dry weight basis).

Location	chromium (mg/kg)	zinc (mg/kg)
Swan Rivervale	120	550
Swan Armstrong Spit	130	370
Canning Mount Henry	100	310

In Princess Royal Harbour at Albany, chromium concentrations in sediments ranged between 1.3mg/kg and 42.4mg/kg. Sediment zinc concentrations ranged between 3mg/kg and 1184mg/kg. The highest zinc concentration was associated with sediments with the greatest percentage of organic matter (Talbot, 1983).

Organic-rich sediment from the Olbia Bay in Italy, which receives both treated and untreated domestic sewage, had the greatest capacity to accumulate heavy metals. Concentrations of between 14 and 153mg/kg for zinc and 3 and 27mg/kg for chromium (dry weight) were found in the Bay which was considered to be indicative of a polluted environment (Phillips, 1991)..

The chromium concentrations in the sediment of the Derwent Estuary in Tasmania which is heavily contaminated with zinc, was between 0.5 and 258mg/kg as dry weight. The range of sediment zinc concentrations were from <50mg/kg to 104,000mg/kg (Bloom and Ayling, 1977).

The S Gilla brackish lagoon near to Cagliari in Sardinia is affected by the waste water from urban centres and industrial plants. In the first 100mm of sediment, chromium concentrations ranged from less than 20mg/kg to 50mg/kg (Capone et. al. 1983).

The Irtja River sediments, contained chromium concentrations of up to 17,536mg/kg, which were a thousand times higher than the published data for other freshwater polluted systems. The lowest sediment chromium concentrations in the River were still a hundred times more contaminated than unpolluted areas (Pfeiffer et. al., 1982).

The mean chromium concentrations for the Illinois River sediments was 17mg/kg which was reportedly 3 times higher than the 6 to 5.7mg/kg for unpolluted areas (Mathis & Cummings, 1973).

In Baltic Sea sediments, chromium concentrations ranged between 0.5mg/kg to 252mg/kg and zinc at between 6mg/kg and 639mg/kg as dry weight (Brugmann, 1981).

Surface sediments from Corio Bay Victoria, with restricted water exchange, had zinc concentrations ranging from 4mg/kg to 398mg/kg. The Bay is heavily polluted by cadmium and area has a major port, heavy industries and the City of Geelong lining its shores (Smith et. al., 1981).

In Spencer Gulf South Australia approximately 100 square kilometres of sediment was contaminated with zinc up to 10 times background levels, at 200mg/kg as a result of metal outfall from a lead smelter. Near to First Creek, sediment zinc concentrations were 200-300 times the background level and were judged severe by world standards (Bell, 1983).

The sediments of Lake Burley Griffin were polluted with zinc from a disused mine site, had high sediment zinc concentrations of 1080mg/kg and 441mg/kg in 1973 and 1977 respectively. In polluted sediments the highest chromium concentrations are associated with smallest particle fractions. Chromium appears difficult to release from sediments (Hart, 1982).

Sediments in the Brisbane River estuary had zinc and chromium concentration ranges of between 123 to 270mg/kg and 63 to 91mg/kg respectively as dry weight in the <0.063mm size fractions. In the fresh water section of the Brisbane River, the highest concentration of sediment chromium was 112mg/kg, suspected of being influenced by the Town of Ipswich (Department of Environment and Heritage Division of Environment-1981 unpublished data). Mean zinc and chromium concentrations in the less than 0.063mm fraction of sediments of North Queensland rivers, ranged from 55 to 149mg/kg and 43 to 235mg/kg respectively. The higher concentrations were attributed to the basaltic nature of the catchments (Moss and Bennett, 1991).

Mean zinc ranges of sediments from stations in two South Carolina estuaries, polluted by domestic and industrial effluents, were between 14.2mg/kg and 61.7mg/kg as dry wt. The highest concentration was 112.7mg/kg-dry wt (Sanders, 1984).

In San Francisco Bay sediments, the mean zinc concentrations ranged from 103mg/kg to 504mg/kg. The Bay receives a zinc load of 172 tonnes or the equivalent of 16.5µg/m² per year. Mean sediment chromium concentrations were between 144mg/kg and 310mg/kg. The Bay had been receiving untreated domestic and industrial effluent for 100 years. It presently receives approximately 70.5 metric tonnes of chromium or the equivalent of 6.8µg/m² per year, from Municipal wastewater treatment plants (Bradford and Luoma, 1980).

The Gulf of Elefsis, is receiving high loads of dissolved zinc from various industrial and other sources including sewage. The top 2 cm of sediment contained total zinc at 239mg/kg total zinc of which 55.1% was non-leachable and 1% was easily extractable (Scoullos, 1981).

Between 1975 and 1976, in the Thermaikos Gulf (Greece), the shallow organic-rich sediments showed the effects of metal inputs from rivers, factories and a port when compared to sediments in the most remote clean section of the Gulf.

Table 2.13

The means, medians and ranges of zinc and chromium concentrations in sediments in the Thermaikos Gulf Greece from August 1975 to December 1976 (Voutsinou-Taliadouri and Satsmadjis, 1983).

	Zinc-mg/kg (dry weight basis)	Cr-mg/kg (dry weight basis)
Mean	165	167
Median	150	160
Range	39-560	42-299

Table 2.14

Comparison of mean zinc concentrations in sediments from four river mouths.

River	Zinc-mg/kg (dry weight basis)
Mae Klong	50 (±11)
Chin	79 (±19)
Chao Phraya	71 (±6.9)
Bang Pakong	43 (±12)

Knutzen, 1981

The mean zinc content (dry basis) of sediments from the Severn Estuary was 282-288mg/kg (Owens, 1984; cited in Mance, 1987).

The Humber Estuary sediment had an average chromium and zinc concentration of 44mg/kg and 203mg/kg respectively (Gameson, 1982; cited in Mance, 1987).

Zinc concentrations in sediment (clay fractions <75µm) from different areas of the Adriatic Sea ranged between 47mg/kg and 353mg/kg. The distribution of all metals in the sediment was strongly dependent upon the grain-size fraction less than 20 µm of the whole sediment. As the percentage of coarse fractions increased towards the seaward direction they become metal-poor and they produced a decrease in metal concentrations of the whole sediment (Martincic, 1989).

Sediments in Hamilton Harbour, adjacent to Lake Ontario, which receives treated sanitary sewage and cooling water from steel mills had mean sediment zinc and chromium concentrations of 2700 mg/kg and 250 mg/kg respectively.

This compared with Port Hope, also on Lake Ontario with mean sediment zinc and chromium concentrations of 189 and 40mg/kg respectively on the <63 µm fraction.

2.6 Biota

The use of biological indicators has theoretical advantages over the measurement of metals in water samples or sediment samples. The use of biological indicators obviates the necessity of multiple sampling by its time-integration of ambient metal concentrations. Metal concentrations present in the indicator may be 10^3 to 10^6 times higher than the water, allowing direct analysis without pre-concentration (Phillips 1974).

The concentrations of metals in aquatic organisms varies because they reflect the nett effect of two competing processes, that of uptake and that of depuration. The balance between the two processes will depend on the ambient concentration and the rates of the two processes, and a seasonal variation (Mance, 1987). When fish migrate between waters with different background concentrations of metals, tissue metals may be at varying stages of accumulation or depuration when the organism is caught. Size or age-related equilibrium can only be assumed when fish migrate between similar concentrations (Samiullah, 1990).

Within an individual animal due to structural and biological differences, various tissues may exhibit specificity of metal uptake. The use of specific tissues in monitoring surveys can be of value in determining the significance of major routes of pollutant uptake (Samiullah, 1990). Heavy metals can be accumulated to high concentrations by bacteria without lethal effect. Since bacteria form a sizeable portion of the detritus, benthic organisms may magnify the metals in their tissues (Smith et. al., 1981). Evidence

suggests that accumulation of metals such as zinc and chromium from food by aquatic organisms is less important than their accumulation from water. It was suggested that organically-bound metals were not efficiently absorbed by the gut, compared to the highly efficient absorption by the gills (Hart, 1982).

Analyses of individual tissues of the marine Prosobranch gastropod *Littorina littorea* in low external ambient zinc concentrations showed zinc was accumulated primarily by the kidney. At higher concentrations, that is in zinc contaminated environments, the stomach and visceral complex are also major sites of zinc accumulation because the rates of turnover and flux in those tissues are different. After exposure of one week however there is no net increase of zinc in the liver, since the biological half-life is short and a rapid bidirectional flux occurs. This contrasts the stomach and visceral complex, which have long biological half-lives for zinc, which therefore showed enhanced accumulation and retention of zinc (Mason, 1988).

2.6.1 Macroalgae

Metals such as Zn, Mn, Cu, Mg and Fe are of physiological importance to macroalgae as they are present in active enzymes, proteins and vitamins. A great variation exists in the metal content of different species and different environments. (Wahbeh, et. al., 1985). Benthic algae has a concentration factor of 1,600 for chromium and 410 for zinc (Institute of Sanitary Engineering, Polytechnic of Milan, 1982).

In November 1983 samples of the green macroalga *Ulva* sp. from the Rocky Bay area of the Swan Estuary at North Fremantle had mean and range of zinc concentrations of 2.5 and 1-4.5mg/kg (equivalent drained sample basis). In April 1989 the green algae *Enteromorpha* sp. also from the Rocky Bay area had mean and range of tissue zinc of 48mg/kg and 8.1-81mg/kg (drained weight basis), Swan River Trust-unpublished data.

Samples of the macroalgae chlorophyte *Ulva lactuca* from Cockburn Sound in 1978, had approximate wet weight chromium concentrations of less than 0.1mg/kg and zinc concentrations between 2.5mg/kg and 4.4mg/kg. The highest zinc concentration was considered to be elevated when compared to baseline data (Chegwidden, 1979).

The macroalgal chlorophyte *Ulva* sp. from Cape West Coast in South Africa had zinc concentrations at 5.6mg/kg. The red algae *Porphyra capensis* from the same region had wet weight chromium and zinc concentrations of 11mg/kg and 0.47mg/kg respectively (Van As et. al., 1975; cited in Forstner and Wittmann, 1979).

Of the three macroalgal groups Rhodophyta (reds), Chlorophyta (greens) and Phaeophyta, (browns), analysed from two locations along the coast of Aqaba, the reds exhibited the greatest concentration power of metals. The reds (3 spp) had the highest concentrating power of zinc. The concentration range was 19 mg/kg to 30.7mg/kg on a wet weight basis. The zinc concentration range for the brown algae was next highest at between 4.6-10.3mg/kg wet weight basis (4 spp). The green algae (3 spp) ranged between 4.6mg/kg and 9.3mg/kg wet weight basis (Wahbeh et. al., 1985).

Similarly the red macroalga *Polysiphonia* sp. had the greatest tissue chromium concentration of algal and seagrass species analysed from a polluted lagoon in Sardinia (Capone et. al., 1983). There was a significant difference in the rate of uptake of chromium between species. The chromium uptake by *Polysiphonia* far exceeded that of *Gracilaria*, Table 2.15.

Table 2.15

Mean and ranges of chromium concentrations in 4 species of Chlorophyta, 2 species of Rhodophyta and one sea grass in a polluted lagoon in Sardinia.

Species	Mean Cr (mg/kg - wet weight basis)	Range Cr (mg/kg - wet weight basis)
CHLOROPHYTA		
<i>Ulva</i>	5.8	2.1-15.3
<i>Enteromorpha</i>	12.7	3.8-28.5
<i>Chaetomorpha</i>	5.7	2.5-8.8
<i>Cladophora</i>	18.8	8.2-25.6
RHODOPHYTA		
<i>Gracilaria</i>	3.2	1.1-8.2
<i>Polysiphonia</i>	26.6	12.5-39.8
SEAGRASS		
<i>Ruppia</i>	3.5	0.9-6.9

Capone et. al., 1983.

The advantage of using green algae rather than seagrasses as an indication of metal accumulation, is that metal accumulation occurs from the water whereas for seagrasses there is a significant uptake via sediment (Batley, 1987).

2.6.2 Seagrasses

From Cockburn Sound in December 1977 the concentrations of zinc in the seagrass *Posidonia sinuosa* ranged approximately between 3.5 and 17mg/kg on a wet weight basis (Chegwidden, 1979).

The concentration of chromium in the seagrass *Heterozostera tasmanica*, which was subjected to chromium concentrations of between 0.3-247µg/L in flowing sea-water over a four week period, was between 0.2mg/kg and 16mg/kg approximate equivalent wet weight. Similar tests on *Heterozostera tasmanica* and zinc in sea-water at concentrations between 1.5µg/L and 258µg/L, produced tissue zinc concentrations of between 8 and 140mg/kg wet weight after a four week period (Ahsanullah and Williams, 1991).

The concentration of zinc in the seagrass *Posidonia oceanica* growing in the Antikyra Gulf, Greece, exhibited seasonal variations with maximum mean concentrations of around 5mg/kg dry wt in winter then decreasing to a summer minimum of 4mg/kg dry wt (Malea and Haritonidis, 1989).

2.6.3 Bivalves

Western Australian species of marine mussels *Mytilus edulis* and *Xenostrobus pulex* have been found to spawn between July to November and August to January respectively (Wilson and Hodgkin, 1967). Spawning has a considerable direct impact upon body metal content (Mance, 1987). The faster growing sex (usually the female) can be expected to contain lower concentrations of metals, but not necessarily a smaller total body burden. If the estuarine mussel *Xenostrobus securis* followed a similar reproductive cycle pattern, it would affect the heavy metal content found in the mussels sampled during this survey.

The position of sessile organisms in tidal waters affects the animals exposure to metals, particularly in the intertidal zone. The mussel *Mytilus edulis* found growing in an intertidal region were more contaminated than those found in a sub-tidal region (De Wolf 1975; Phillips 1974; cited in Mance, 1987).

Most surveys on ecological effects are carried out on benthic communities. Because of their relatively sessile lifestyle, they cannot avoid pollution effects by swimming to another area. This makes them vulnerable to the effects of pollution and easy to study (Cooper, 1989).

Selective suspension-feeding organisms may inadvertently ingest metal-binding substrates when heavy concentrations of re-suspended substrates are mixed with phytoplankton (Luoma, 1986).

Direct uptake of some metals trace metals from sediments contributes to metal concentrations in benthic organisms. Metal uptake from the sediment is controlled by the concentration of the exposure,

the partitioning of the metals among components of the sediment and the redox potential of the sediment. (Luoma, 1986).

Mollusc species in polluted systems can accumulate very high levels of zinc. Oysters can accumulate zinc directly from the water and from ingested particulate matter. Mussels can have average concentration factors in their soft parts of 400 for chromium and 11,000 for zinc (Institute of Sanitary Engineering, Polytechnic of Milan, 1982).

The mussel *Xenostrobus securis*, which occurs in the middle to upper Swan River estuary, was analysed for its soft tissue zinc concentration in August 1985. Twelve sites were sampled between the Narrows Bridge and Guildford. Mussels associated with drains from Belmont to Bassendean, had a mean zinc content of 8.3mg/kg. In Perth Water the mean zinc content of *Xenostrobus securis*, was 7.7mg/kg (Blackmore 1985). Blackmore concluded that these drains did not represent a significant source of zinc to the mussels.

Analysis of the chromium and zinc concentrations of the Swan estuarine mussel, *Xenostrobus securis*, which is readily found attached to substrates at the outfalls of the drains in Perth Water was carried out (Hosja; 1987). It was found that the flesh of mussels at the Victoria Avenue Main Drain (VAMD) outfall contained up to 25mg/kg of chromium (wet weight basis). The high chromium content of mussel tissue appeared to be associated with high mean drain chromium concentrations, rather than with total loads.

Bioaccumulation of chromium was demonstrated in the estuarine mussel *Xenostrobus securis* growing at the outfall of the VAMD in the Swan River estuary (Schulz and Hosja, 1988). The highest concentration of chromium in mussels was 64mg/kg wet weight basis. The chromium content of mussels decreased as the distance from the drain outfall increased. The area used as a source of control mussels had the lowest soft tissue chromium content at 0.82mg/kg on a wet weight basis. During the same survey, the zinc concentration in mussels was more uniform between sites. The highest levels of zinc was also at the mouth of the VAMD at 24mg/kg. Mussels from the control site contained the same concentration of tissue zinc (12mg/kg) as those 5-10 metres away from the outfall of the VAMD. A similar zinc trend was demonstrated in mussels from the Swan River estuary (Hosja, 1987).

Xenostrobus securis mussels collected from the Swan River estuary at Bayswater had mean chromium and zinc concentrations of 0.4mg/kg and 15mg/kg respectively (Atkins et al., 1990). Samples of mussels from the same area in October 1990 contained

chromium and zinc concentrations of 0.2-0.4mg/kg and 14-20mg/kg respectively (Klemm and Deeley, 1991).

Chegwidden in 1980-a analysed the edible mussel *Mytilus edulis* from the lower Swan-Canning estuarine system. He found that tissue zinc concentrations ranged between 27.6mg/kg and 76mg/kg on a wet weight basis. Chromium concentrations were all less than 0.5mg/kg.

For a period of 16 months between 1977 and 1979, the mussel *Mytilus edulis* was sampled at stations off the Western Australian coast and analysed for metals. The mean concentrations of zinc in the mussels ranged between 16.7 and 134.8mg/kg (wet weight basis). Mean chromium concentrations in *Mytilus edulis* ranged between 0.2mg/kg and 7.2mg/kg (Chegwidden 1979).

The mussel *Mytilus edulis* from Princess Royal Harbour at Albany, which was contaminated by superphosphate spillages, industrial effluents and hull cleaning operations contained soft tissue chromium concentration ranges of between 0.37mg/kg and 0.76mg/kg. Zinc concentrations ranged between 32.4mg/kg and 69.3mg/kg (Talbot, 1983).

Table 2.16

Wet weight equivalent mean concentrations and ranges of zinc in *Mytilus edulis* from other studies. Where required the factor used for the conversion of dry weight results to wet weight results was 0.17.

Area and source	zinc mean & range (mg/kg-equiv. wet wt)
North and south islands of New Zealand (1975)*	12.6 (3.8-26.01)
Derwent River Estuary, Tasmania (1976)*	85.6 (28.4-224)
Corio Bay Victoria (1976) Smith et. al., 1981	27.3 (17.4-68.1)
Western Port Bay Victoria (Phillips 1976)	22.2 (±5.3) to 41.9 (±9.9)
Port Phillip Bay Victoria (Phillips 1976)	16.4 (±3.3) to 97 (±6.7)

*cited in Chegwidden 1979.

The hairy mussel *Trichomya hirsuta* from Lake Macquarie, had a mean zinc concentration of 14mg/kg converted to wet weight basis using approximately 80% moisture content (Batley, 1987).

The mean zinc concentration in mussels from six areas in Port Phillip Bay in January 1988 was approximately 31mg/kg on a wet weight basis (Arnott et. al., 1988).

Table 2.17

Trace metal concentrations in the soft parts of *Mytilus edulis* from different geographical areas. Mean values and ranges are listed when available. Values given as mg/kg dry wt, were converted to approximate wet weight concentrations (factor used 0.17).

Locations	Authors cited in Knutzen 1981	Zinc (mg/kg wet wt)
Naples Bay Italy	Sheppard and Bellamy 1974	38
Marseille France	Fowler and Gregoini 1976	35-107
North Sea UK	ICES 1974	32
The Netherlands		18
Germany		21
Norway		32
Penang Malaysia	Sivalingam Bhaskaram 1978	13
Tyne UK	Simpson 1979	83
Chao Phraya River mouth Thailand	Knutzen 1981	9

cited in Knutzen, 1981.

Table 2.18

Comparison of mean zinc concentrations in the green mussel *Mytilus viridis*, from four river mouths and Hau Hin intertidal zone, -converted from dry weight to approximate equivalent wet weight concentrations).

River	Zinc (mg/kg)
Mae Klong	12
Ta Chin	12
Chao Phraya	9
Bang Pakong	11
Hua Hin intertidal	8

Knutzen, 1981

The zinc concentrations of mussels from the Baltic sea ranged between 16-110mg/kg as wet weight. Open-sea organisms had the lowest metals (Brugmann, 1981).

Mean zinc concentrations in the mussel *Mytilus edulis* from San Francisco Bay, which had been receiving untreated industrial and domestic waste for 100 years, was below 34mg/kg wet weight. The same species from Tomales Bay, had 0.2mg/kg of chromium and 16.4mg/kg of zinc (Bradford and Luoma, 1980).

2.6.4 Crustacea

Crustacean muscle has concentration factors of 100 for chromium and 2,000 for zinc (Institute of Sanitary Engineering, Polytechnic of Milan, 1982).

Larvae of shrimp can be up to 500 times more sensitive to metal-bearing sewage sludge than adults of the same species. (Franklin, 1983).

Atkins et. al., (1990) found that the estuarine shrimp *Palaemonetes australis* in the Bayswater area had mean tissue chromium and zinc concentrations of 0.4mg/kg and 36mg/kg respectively. Similar results for chromium (0.1-0.2mg/kg) and zinc (12-20mg/kg) were found in shrimp from the same area in October 1990 (Klemm and Deeley, 1991). Shrimp from the up-river control site at Guildford had a marginally lower zinc concentration of 10mg/kg.

Flesh of the Blue swimmer crab species, *Portunus pelagicus*, from Western Australian coastal waters contained concentrations of between 8.6-32.2mg/kg of zinc and 0.8-1.2mg/kg of chromium on a wet weight basis (Chegwiddden, 1979). Crab hepatopancreatic tissue was found to concentrate zinc, when compared to the flesh, with ranges of 22-256mg/kg on a wet weight basis. Chromium in the hepatopancreas of however contained similar chromium concentrations to the crab flesh with ranges of 0.7mg/kg to 1.9mg/kg.

Muscle tissue of the blue crab *Callinectes sapidus* was analysed for zinc from four stations in two South Carolina estuaries. The mean values ranged between 28.5 to 34.3mg/kg wet weight. Blue crab muscle from locations nearest to domestic and industrial activities had the highest zinc values (Sanders, 1984).

Muscle tissue of the yellow crab, *Cancer anthonyi* in the wastewater discharge zone of the Los Angeles County Municipal outfall, was shown to accumulate chromium double that of the control crab at Dana Point. However the zinc concentration was 25% that of the control crab (Young et.al., 1981).

2.6.5 Fish

Fish are a possible source of chromium in the diet for humans. In fish the metals tends to accumulate mainly in the skin, bones, liver and kidneys; parts not generally eaten by humans (Langard in Waldron, 1980).

Determinations of potentially harmful contaminants in fish are considered as a complement to levels in water and sediment, as they provide information on the bio-available portions.

For the intake by fish, trace metals must be in a biologically active form. Fish can take up metals through their gills (Harms and Kerkhoff, 1989), though chromium is not accumulated in gill tissue (Holdway, 1988). The relationship between the trace metal concentrations in fish and the metal burden of the relevant habitat can be complicated by the organism's sexual cycle, age and also the changes in ambient water quality parameters such as salinity, temperature and dissolved oxygen content (Harms and Kerkhoff, 1989).

Temperature may affect the toxicity of heavy metals to fish. Higher water temperature increased sensitivity of mullet to the lethal effects of zinc (Negilski, 1976).

Chromium six is more toxic in sea-water while Cr^{3+} is possibly more toxic in freshwater (Holdway, 1988). By lowering the pH of water by 1-2 pH units the toxicity of chromate increased by two orders of magnitude. Chromate salts readily form CrO_4^{2-} , HCrO_4^- (hydrochromate ion) and $\text{Cr}_2\text{O}_7^{2-}$. Hydrochromate ion formation is favoured at low pH. it crosses biological membranes more readily than the divalent ions. Therefore the toxicity increases with lower pH (Holdway, 1988).

Fish muscle has concentration factors of 70 for chromium and 500 for zinc (Institute of Sanitary Engineering, Polytechnic of Milan, 1982). The fact that most harmful trace metals are found in lowest concentrations in skeletal muscle of fish may be indicative of regulatory, metabolic exclusion mechanisms which prevent enrichment of such metals in muscle tissue (Harms and Kerkhoff, 1989).

Cr^{3+} is thought to be an essential trace element. Fish presumably convert Cr^{6+} to Cr^{3+} . In fish Cr^{3+} is shown to impair glucose transport in the intestine and decrease levels of glucose in the liver. Cr^{3+} acts by altering complex biochemical pathways connecting proteases and glucomogenesis (Holdway, 1988). The levels of chromates and zinc in freshwater associated with fish kills are $>3,300$ - $133,000\mu\text{g/L}$ and >400 - $1,760\mu\text{g/L}$ respectively. The acceptable continuous exposure zinc level in water for fish culture is $<5\mu\text{g/L}$ (Langdon, 1986).

Table 2.19

The wet weight concentrations of chromium and zinc in the muscle of marine fish.

Muscle tissue of five species of fish from the Swan-Avon Estuary was analysed for chromium and zinc concentrations from 1978 to 1979.

Site and species spp	Chromium mg/kg	Zinc mg/kg	Authors
Cape West Coast SA <i>Scomber japonicus</i>	0.65	7.2	(Van As et. al., 1975) *
North Is. NZ <i>Seriola grandis</i>	0.02	9.5-56	(Brooks & Rumsey 1974) *
North Is. NZ <i>Trigla kumu</i>	0.01-0.02	5.5-56	(Brooks & Rumsey 1974) *
LA wastewater outfall zone	0.02-0.09	<1.2-6.6	Young et. al., 1981
LA outside outfall zone various spp	<0.01-0.12	<1.2-6.1	Young et. al., 1981

* cited in Forstner and Wittmann 1979.

The mean concentration for metals were close to minimum levels in all individuals heavier than 50g (Marks et. al., 1980). The smallest fish had the greatest zinc concentrations. Metal concentrations were highest in fish that ingested bottom material rather than in those that fed on mussels, crustacea, polychaetes and plants. The mean muscle concentrations for chromium in sea mullet, yelloweye mullet, yellowtail trumpeter, black bream and Perth herring were between 0.11 and 0.15mg/kg (wet weight basis). The range of zinc concentrations were between 4.0 and 5.8mg/kg (wet weight). Metal concentrations in fish muscle varied in different species in the same environment. The highest individual chromium and zinc concentration in fish muscle was in Perth herring at 0.76mg/kg and 18.6mg/kg respectively.

Table 2.20

A range of zinc concentrations as wet weight in the muscle of marine fish from around the world (various authors).

The zinc concentrations of fish from the Baltic sea ranged between 1.2-32mg/kg as wet weight. Open sea organisms had the lowest metal concentrations when compared to near shore animals (Brugmann, 1981).

Site/Species	Zinc-mg/kg	Authors
Cape West Coast South Africa <i>Seriola pappei</i>	6.7	(Van As et. al., 1975) *
Cape Hatteras, NC USA <i>Pomatomus saltatrix</i>	6.4	(Cross et. al., 1973)*
Sagres, Sth Portugal <i>Solea solea</i>	11.4	(Stenner & Nickless, 1975) *
Sagres, Sth Portugal <i>Raja clavata</i>	10.4	(Stenner & Nickless, 1975) *
Bristol Channel GB <i>Scyliorhinus</i> spp	11.5-13.7	(Peden et. al., 1973) *
Northumberland Power Station <i>Pleuronectes platessa</i>	30.3	(Wright 1976)*
NE Atlantic/ Cornwall GB <i>Belone belone</i>	8.4-10.8	(Stevens Brown, 1974)*
N Atlantic <i>Mugil cephalus</i>	3.4	(Windom et. al., 1973) *
S Baltic <i>Clupea harengus</i>	7.8-27	(Falandysz and Lorenc-Biala, 1984)**
G of Bothnia <i>Macoma baltica</i>	4.0-5.4	(Tervo et. al., 1979) *
N Atlantic-herring	3.3-7.5	(ICES 1977)**

*cited in Forstner and Wittmann 1979

**cited in Samiullah,

Twelve species of teleosts fish from Cockburn Sound had metal values well below National Health and Research Council Standards and the Western Australian Food and Drug Regulations. The levels reflected the relatively low rate at which metals are accumulated in the muscle and also the mobility of fish. The highest mean and individual zinc concentration in fish muscle tissue was 15.1mg/kg. and 21.6mg/kg wet weight basis for tailor and six line trumpeter respectively. The highest mean and

individual chromium concentration in fish muscle tissue was 0.18mg/kg for rock flathead (Plasket and Potter, 1979).

In the Derwent Estuary in Tasmania, sea mullet *Mugil cephalus* was found to contain up to 38.9mg/kg of zinc. Other fish ranged between 4.6 and 13.5mg/kg (Eustace cited in Hart, 1982).

Fish from the Iraja River have chromium concentrations (wet weight) 10 times greater than other polluted areas (Pfeiffer et. al, 1982). Fish had mean chromium concentrations of 1.13mg/kg wet weight. This compared to a mean of 0.12 for carnivorous fish and 0.22mg/kg for omnivorous fish in the Illinois River (Mathis and Cummings, cited in Mance, 1987).

Recent work indicates that the zinc concentration in cod liver was significantly influenced by the fat content of the tissue analysed (Harms and Kerkhoff 1989).

Chromium is more readily accumulated but depurated slowly. The bioconcentration factor of fish kidneys is approximately 10 times water concentrations. Chromium is not biomagnified (Holdway, 1988).

Analyses of metals from the muscles, livers, gills and hearts of many fish in the Andaman Sea revealed the highest concentrations in the liver (Kureihy, Sanzgiry, George and Braganca, 1983 and Kureishy, Sanzgiry and Braganca, 1981, cited in Samiullah, 1990). A similar trend was found in fish from the Great Barrier Reef (Denton and Burdon-Jones 1986, cited in Samiullah, 1990). Fish from polluted environments tend to accumulate zinc in the liver, kidney and digestive tract and not in the muscle (Hart 1982). Zinc concentrations in North Sea fish muscle were reportedly below 10mg/kg wet weight with little variation irrespective of the source of fish (Harms and Kerkhoff, 1989).

Table 2.21

A range of zinc concentrations as wet weight in the livers of marine fish from around the world (various authors).

Site/Species	zinc-mg/kg	Authors
S Baltic <i>Mesaidotea entomon</i>	6.7-14.5	(Tervo et. al., 1979) *
N Atlantic <i>-Pleuronectes platessa</i>	26-40	(ICES 1977) *
N Atlantic-herring	23-25	(ICES 1977) *
N Atlantic-cod	10-36	(ICES 1977) *

* cited in Samiullah, 1990

2.7 Environmental and health criteria

The fate of bio-accumulative pollutants such as heavy metals in the aquatic environment is highly complex and poorly understood. Environmental scientists must determine what levels of such pollutants are able to be assimilated by receiving waterbodies without leading to potential human health risks or adverse environmental impacts. The following section discusses these issues.

Effluent discharge criteria, environmental criteria and human health limits are formulated and applied to industrial effluents, the environment and to potential human food, in order to meet the stated objectives of healthy people and environments. The relationship between the different types of criteria in the context of effluent discharges, dilution factors and mixing zones are often poorly understood. Figure 2 explains the relationship between these factors.

2.7.1 Industrial effluents

Heavy metals may be dissolved in an effluent or adsorbed or incorporated into organic particles or soil particles. This is represented as the shaded rectangles in the hypothetical effluent represented in Figure 2.1. The levels of pollutants in effluents are enforced through appropriate discharge limits (effluent criteria) which should ensure that pollutants in effluents do not cause adverse environmental impacts in receiving water bodies after dilution and mixing have occurred. Discharged effluents may be diluted from between 100 to 1,000 times or more depending on the volume of effluent and drain flow. This is represented by a smaller shaded rectangle in the drain water in Figure 2.

When an effluent is discharged into a drain the reduction in water velocity causes much of the suspended solid load to settle. This means that pollutants adsorbed onto particulates become incorporated into the drain sediments (sedimentation).

2.7.2 Environmental criteria

2.7.2.1 Waters

Similar processes of dilution, mixing and sedimentation occur when drain waters enter riverine systems although dilution factors are often considerably greater (10,000-1,000,000 times). Figure 2 indicates this in terms of very small shaded rectangles in the riverine waters.

Environmental criteria are selected depending on the beneficial use assigned to a particular estuary. In the case of the Swan River estuary, where aquatic animals are harvested and consumed, stringent criteria (Schedule 3 in EPA Bulletin 103, 1981) are appropriate.

Table 2.22

Acceptable concentrations of Cr^{6+} and zinc toxicants for Marine and Estuarine waters.

Metal	Acute Criterion $\mu\text{g/L}$	Chronic criterion- $\mu\text{g/L}$
Cr^{6+}	95	86
Zinc	1100	50

Draft National Water Quality Guidelines ANZEC., 1990.

The river quality standards for the receiving fresh waters in the Thames Region vary depending on the river quality objective. For Class 1A and 1B-High quality waters, the mean chromium and zinc River Quality Standards at various water hardnesses are listed below.

Table 2.23

Mean chromium and zinc concentrations for classes 1A and 1B High quality waters in the Thames Region.

Hardness	chromium- $\mu\text{g/L}$	zinc- $\mu\text{g/L}$
0-50	5	8-16
50-100	10	50-75
100-200	20	75
>200	50	125

Source-National Rivers Authority-Thames Region.

Table 2.24

Annual average dissolved chromium and total zinc Salt Water Environmental Quality Standards for receiving waters in the Thames Region.

The proposed upper guidance limits for heavy metal discharges to receiving waters from specified industrial sources prepared by the Water Quality Branch of the Environment Protection Authority Victoria, 1979 were 300 $\mu\text{g/L}$ for total chromium and 500 $\mu\text{g/L}$ for zinc.

Metal	criterion - µg/L
Chromium	15
Zinc	40

source - National Rivers Authority - Thames Region

2.7.2.2 Biota

Table 2.25

Marine and Estuarine Water Quality Criteria for harvesting of aquatic life (including molluscs for food).

Metal	Single sample criteria - µg/L	6 month median criteria - µg/L
Chromium	no reading to exceed 7	2
Zinc	no reading to exceed 200	20

EPA Bulletin 103, 1981

2.7.2.3 Sediments

Draft Australian guidelines for the assessment of contaminated sites have been used as an indication of the level of contamination of sediments in the Swan River. These guidelines are total chromium 100mg/kg dry basis and 350mg/kg for total zinc.

2.7.3 Human health criteria

Pollutants may be incorporated into the tissues of animals and plants through a number of mechanisms and may ultimately be ingested by humans. Maximum Residue Levels (MRL) and Maximum Permitted Concentrations (MPC) of pollutants in foodstuffs are statutory limits enforced by Health Authorities.

Table 2.26

The Maximum Permitted Concentration (MPC) of chromium in edible tissue as wet weight.

Food	(MPC) - mg/kg
edible tissue	5.5

Food and Drug standards (Amendment No. 14) Regulations 1976. S.R No. 290 Health Act 1958.

Victoria Government Printer, Melbourne (cited in Australian and New Zealand Environment Council, October 1990).

Table 2.27

The Maximum Permitted Concentration (MPC) of zinc in the flesh of mussels, shrimp and fish as wet weight.

Food	Zinc (MPC) - mg/kg
molluscs	1000 *
shrimp	150 *
fish	150 *
oysters	1000 **
fish and crustacea	150 **

*Health Act 1911 Health (foodstuffs) (general) Regulations 1987 Section A12.

**NH&RMC (1987)

The maximum allowable wet weight concentration of chromium is 1mg/kg under the Hong Kong Food Adulteration Regulations (FAR 1978) for metals (Ashton, 1991).

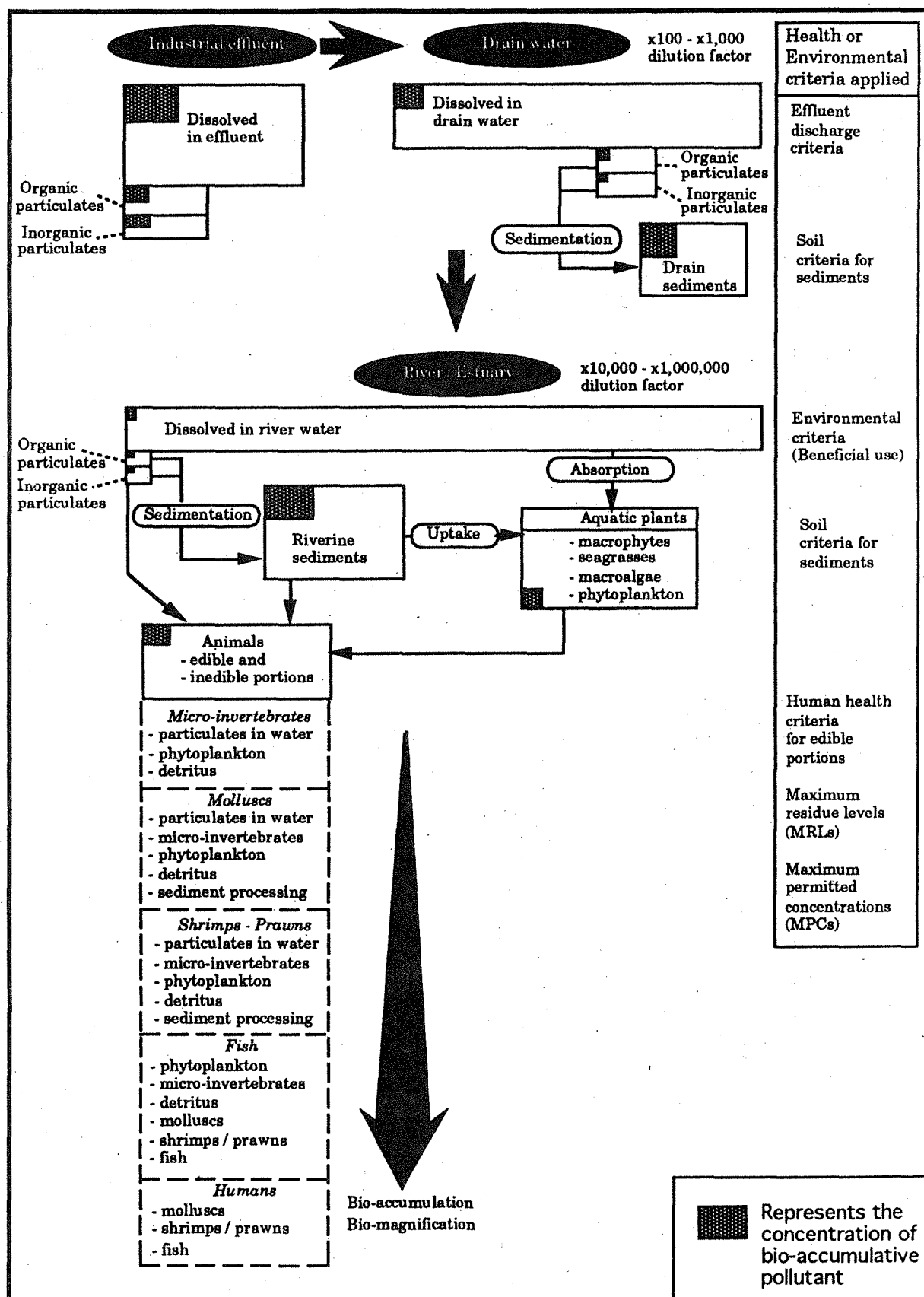


Figure 2.1 Fate of bio-accumulative pollutants in an effluent discharged to a drain flowing into an estuary.

3. Materials and methods

The sampling strategy was to look at and compare metal concentrations of the various components of the estuarine system on two separate occasions at each end of the 1988-89 summer period.

3.1 Physico-chemico

At the time of water sample collection, estuarine salinity, temperature and dissolved oxygen profiles were measured at selected sites along the sampling grid. These were done to assist the explanation of the behaviour and fate of metals in the freshwater from the drains on entering the more saline estuarine waters. of the estuary.

Estuary salinity (parts per thousand-p.p.t.) and temperature was measured using a YeoKal salinity-temperature bridge (Model 602). The meter was calibrated against Standard Sea-water (P-91) Institute of Oceanographic Science, Wormley, Godalming, Surrey, England. The dissolved oxygen concentration, in milligrams per litre (mg/L) was determined using a YeoKal Oxygen/Temperature meter (Model 603), incorporating salinity-temperature compensation.

3.2 Preparation

Sample bottles and containers were prepared at the Chemistry Centre (Western Australia).

3.2.1 Estuary Body

All water samples were kept on ice until delivery to the laboratory-generally within 4-6 hours of collection. At the laboratory the samples were preserved as detailed below in acid cleaned containers for water and sediments. Polythene bags were used for for biota sample collection and storage.

Waters were sampled at 40 sites, on a 400 metre grid pattern on the same day. Sampling was done from one boat taking about 4 hours. There were six sites in Melville Water, 25 sites in Perth Water (approx 3.5km²), and another 7 sites upstream of the Causeway bridges. Other sites were sampled away from the CBD to act as controls. This included the estuary at Mt Henry in the Canning Estuary (SR23A), Armstrong Spit downstream in Melville Water (SR16) and at the Middle Swan Bridge (SR3) upstream in Middle Swan.

During the first attempt to sample all of the estuarine sites on 15 December 1988, a sudden storm which blew up forced the trip to be abandoned after the completion of only 9 sites. All regular estuarine

surface and bottom water grid sites were completely sampled on two occasions (20/12/1988 and 9/3/1989). The bottom 450mm of the water column was sampled using a modified Niskin sampler. Water samples were then transferred to acid-soaked 1 litre polythene bottles. The full bottles were then taken to the Chemistry Centre of Western Australia laboratory where they were acidified with 10mL of concentrated nitric acid (Merck Suprapure M S). Samples were not filtered.

3.2.2 Drain Outfalls

On two separate occasions surface waters were sampled for total chromium and zinc on a smaller grid pattern adjacent to the outfalls of the Mounts Bay Main Drain (21 January; 24 February 1989); and on three occasions in the Claisebrook Main Drain (22 & 23 December 1988; 2 February 1989). All samples were collected near to midday and coincided with the incoming tide. The Mounts Bay Main Drain has two pipe outlets to the Swan Estuary. The water leaving both outlets was sampled on these occasions.

3.2.3 Sediments

Most of the Swan estuary sediments between the Narrows Bridge and Maylands have been disturbed either by dredging or reclamation activities in the period between 1895 and 1976 (Riggert, 1978). This included sites SRE2 to SRQ1 inclusively. The sediment and biota at site SRP1 upstream of the Bunbury rail bridge, appeared to have avoided any disturbance by dredging.

For this survey, sediments were collected from 40 estuarine sites on the regular grid pattern at 400 metre intervals (figure 1.1). The sediment sites were the same as the water sites.

The surface 20mm of sediment was collected by a diver over a period of a week at the grid sites on two occasions (November 1988 and March 1989). Sediments were sampled from a 5 metre radius through and around the grid site. They were collected by scraping a plastic container fitted with an adjustable slot, across the sediment surface. The sediment collected was screened through a 1mm mesh sieve to remove coarse shell and larger debris particles. The sieved material was then transferred into clean 500mL jars. These were stored in the refrigerator prior to trace metal analysis.

Sediment samples were homogenised and dried slowly at 90 °C. The resultant solid cake was ground in an agate mortar, homogenised and stored at ambient temperature in polycarbonate containers until required for analysis.

Previous tests had shown that the above procedure gave comparable results to freeze drying and homogenised wet samples gave excessive and unacceptable variations.

Sediment types varied considerably with depth and distance from the shore. In Melville Water some sites varied from coarse shell grit through to sand. Shallow areas of the Perth basin varied from gritty sand to sandy silt. Deeper areas of Perth Waters were primarily fine muddy to silty sediments which extended into areas upstream of the Causeway Bridges. In the Canning Estuary, at Mt Henry, the sediment was a black-brown loose silty mud.

3.2.4 Fish

Sixteen species of bony fish (teleosts) were collected for trace zinc and chromium analysis. Fish with a variety of diets were selected to determine if concentrations of metals were greater in detritivorous species such as Perth herring than in algal eaters such as Six-lined trumpeter (Loneragan and Potter 1987). Most fish were caught during the day by hand seine at three locations (Figure 1.1). These were adjacent to the outlets of the;

- SRFish 1-Mounts Bay Main Drain in Perth Water
- SRFish 2-Victoria Avenue Main Drain in Perth Water
- SRFish 3-Claisebrook Main Drain upstream of the Causeway at East Perth.

There were fewer species of fish caught in 1988 than in 1989. This was attributed to the salinity of the river being lower at the end of 1988. Nocturnally-active fish such as cobbler (*Cnidogobius macrocephalus*) were either caught by hand-line, cobbler traps or provided by professional net-fishermen. One pair of cobbler were actually trapped in the Mounts Bay Main Drain, behind the weir constructed by the Water Authority of WA.

Fish were sorted then transferred into pre-labelled polythene bags. They were stored on ice and transported to the Murdoch University laboratory for dissection. When available, larger fish were dissected into component flesh, liver, viscera and male or female gonads. These were then blotted dry repacked and deep-frozen until they could be analysed. Prior to analysis, thawed samples were cut into aliquots for analysis. Analyses were carried out on a wet weight basis on composite of tissue from a number of fish of the same species and of the same approximate size range.

Very small fish species caught (eg. hardyheads - *Atherinasoma* spp.), were gutted then bulked for total metal analysis. It was assumed that there would be no significant difference in diet or habitat in those species. However the larger Ogilby's hardyhead (*Pranesus ogilbyi*) was kept separate. Some of the smaller fish were analysed whole while others had their head and viscera removed prior to analysis.

Teleost species collected were cobbler (*Cnidogobius macrocephalus*), Perth herring (*Nematalosa vlaminghi*), six-line trumpeter (*Pelates sexlineatus*), trumpeter whiting (*Sillago maculata*), tailor (*Pomatomus saltator*), blowfish (*Torquigener pleurogramma*), gobbleguts (*Apogon rueppellii*), black bream (*Acanthopagius butcheri*), yellowtail (*Amniataba caudavittatus*), whitebait (*Hyperlophus vittatus*), bridled goby (*Amoya bifrenates*), Ogilby's hardyhead (*Pranesus ogilbyi*), the hardyheads (*Atherinosoma presbyteroides*, *A. wallacei*), sea mullet (*Mugil cephalus*) and yelloweye mullet (*Aldrichetta forsteri*).

3.2.5 Invertebrates

Invertebrates such as gastropod and bivalve molluscs and crustacea were sampled in both 1988 and 1989 when available.

3.2.5.1 Crustacea

Crabs, shrimp and prawns were collected for analysis.

The common estuarine shrimp *Palaemonetes australis* was collected from three locations in the Swan-Canning estuary in, 1990. These were from Perth Water (SRJ3) and the two control sites at the Middle Swan Bridge (SR3) upper Swan estuary and at Mount Henry in the Canning River estuary (SR 23A). Shrimp were collected by scooping into macroalgal (*Gracilaria*) mats with a sieve. The animals were placed in plastic bags and stored deep frozen. Analysis was carried out on a homogenised composite of a number of shelled animals.

Flesh of a single sample of King prawn *Penaeus latisulcatus* caught in the hand seine adjacent to Victoria Avenue Main Drain in 1989 was analysed. Similarly, flesh of a single blue swimmer crab *Portunus pelagicus* caught adjacent to the Claisebrook Main Drain (CMD) outfall in 1989 was used for analysis.

3.2.5.2 Molluscs

Two species of common estuarine bivalves were sampled. The small mussel *Xenostrobus securis*, 20-30mm, was found in the sandy shallows of the Perth

basin and also affixed to firm substrates. This species was growing at most of the drain outfalls except for the Mounts Bay Main Drain. Mussels were harvested by diver and the shells were scrubbed clean with a nylon-bristled brush. The byssus threads removed prior to bagging and freezing. The whole soft internal portion from a number of animals was removed and homogenised and then analysed. There was evidence that *Xenostrobus* is being actively harvested by the local fish population.

Though occasionally very abundant, the recently introduced 'bag' mussel *Musculista senhousia* was sampled (Slack-Smith and Brearley, 1987). Due however to its small size and its delicate shell it proved too time-consuming to clean and too difficult to successfully extract sufficient flesh of the animal without including small pieces of shell, and dirt contamination in the samples. There was no evidence that this species of mussel was part of local fish diets, probably due to the very muddy-slimy nature of its colony growth.

The small white bivalve, *Spisula trigonella*, was more common in the deeper muddy sites. The animals were collected by a diver scraping up the top 50mm of the bottom sediment into a slotted box. All whole animals shells were first rinsed on site through a sieve prior to bagging and freezing.

The bivalves were opened in the laboratory and the whole inner portion removed and combined into a composite sample for each site.

3.2.5.3 Gastropods

Two gastropod species were collected from the surface sediments in Melville Water. These were *Bedevea paiveae* and the whelk *Velacumantis australis*. These species were time-consuming to collect, difficult to process and were largely restricted to the more marine area of Melville Water downstream of the Narrows bridge. Therefore only a few gastropods were collected and analysed.

3.2.6 Macroalgae

The most abundant macroalgal species was the red species *Gracilaria* cf. *verrucosa*. This species was collected by a diver and was generally not very abundant during the 1988-89 survey except at site SRJ3 in Perth Water. The alga was found growing attached to firm substrates such as old shells, retaining walls and rocks next to storm-water drain outlets. The alga was also found in loose unattached clumps on the bottom.

Other species of alga sampled were *Grateloupea*, *Ulva* and *Hypnea*.

All algal samples were rinsed thoroughly to remove entrained biota and sediment, prior to bagging and freezing. Representative sections were cut and analysed as required. One sample of *Gracilaria* collected from Melville Water was contaminated by a quantity of the blue-green alga *Lyngbya* sp.

3.3 Analytical techniques-total metal content

3.3.1 Water Samples

Water samples contained no significant suspended particulate matter and digested and non-digested samples gave the same results indicating no significant complexing with dissolved organic matter, hence most samples were analysed directly.

3.3.1.1 Chromium

Co-precipitation and coagulation with iron and palladium followed by filtration, dissolution of precipitate with nitric acid (Merk Suprapure), made to a small volume and determined by electrothermal AAS.

3.3.1.2 Zinc- (total metal)

Direct determination by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) using long integration times. All low results confirmed by electrothermal Atomic Absorption Spectrometry (AAS).

3.3.2 Sediments- (total metal)

Samples were digested slowly at low temperature with a nitric/hydrochloric acid solution (aqua regia) followed by hydrofluoric acid fusion. This digestion procedure was repeated twice to ensure all chromium was released into solution. Non-volatilised hydrofluoric acid was complexed with borax and the resultant solution made to volume and quantified by flame AAS.

3.3.3 Sediments- (bio-available metals)

Aliquots of homogenised sediment were boiled in 1 molar hydrochloric acid and filtered. The cooled filtrate made to volume and analysed by flame AAS.

3.3.4 Biota

Aliquots were cold-digested overnight in concentrated nitric acid, followed by mild heating and oxidation using hydrogen peroxide. Quantification was by flame AAS.

3.4 Analytical techniques-quality assurance

The following procedures were adopted.

3.4.1 Waters

Approximately ten percent of samples, randomly selected from all areas were re-analysed on a separate day with good agreement of results. Some 5% of the samples randomly selected were spiked for recovery analysis at the 5 and 10µg/L levels; all recoveries were between 95 and 100%.

Electrothermal AAS quantification was by duplicate analysis on each sample and a spiked recovery of each sample. At every 13th sample a digested blank and a standard were treated as samples

All the ICP-AES results for zinc were confirmed by electrothermal AAS on all samples having less than 25µg/L zinc. About 2% of samples having greater than 25µg/L zinc were confirmed by electrothermal AAS (ET AAS) as well as APDC chelation extraction with ET AAS and flame AAS quantification.

Two inter-laboratory comparisons were carried out with the Scientific Services Laboratory of the Water Authority of Western Australia (WAWA) (this lab did all the analyses in the WAWA air-conditioner effluent in-drain study).

Samples from Claisebrook MD and MBMD were used and good agreement was obtained for all results of >50µg/L or > 20µg/L for chromium and zinc respectively which were the detection limits for that laboratory. Lower values by the Chemistry Centre (WA) laboratory could only be confirmed as <50µg/L or <20µg/L respectively by the Scientific Services Laboratory of WAWA.

3.4.2 Sediments

Repeat analyses were carried out on both bio-available and total metal determinations on 3 % of samples. Certified reference material BCSS1 and MESS1 were included in routine batches. Agreement on repeat analyses was generally within 10% for chromium and zinc. Results for certified reference materials was generally within the quoted acceptable range.

3.4.3 Biota

Repeat macroalgal and shrimp analyses were within 10% and a biota certified reference material (DORM1), was within the specified range.

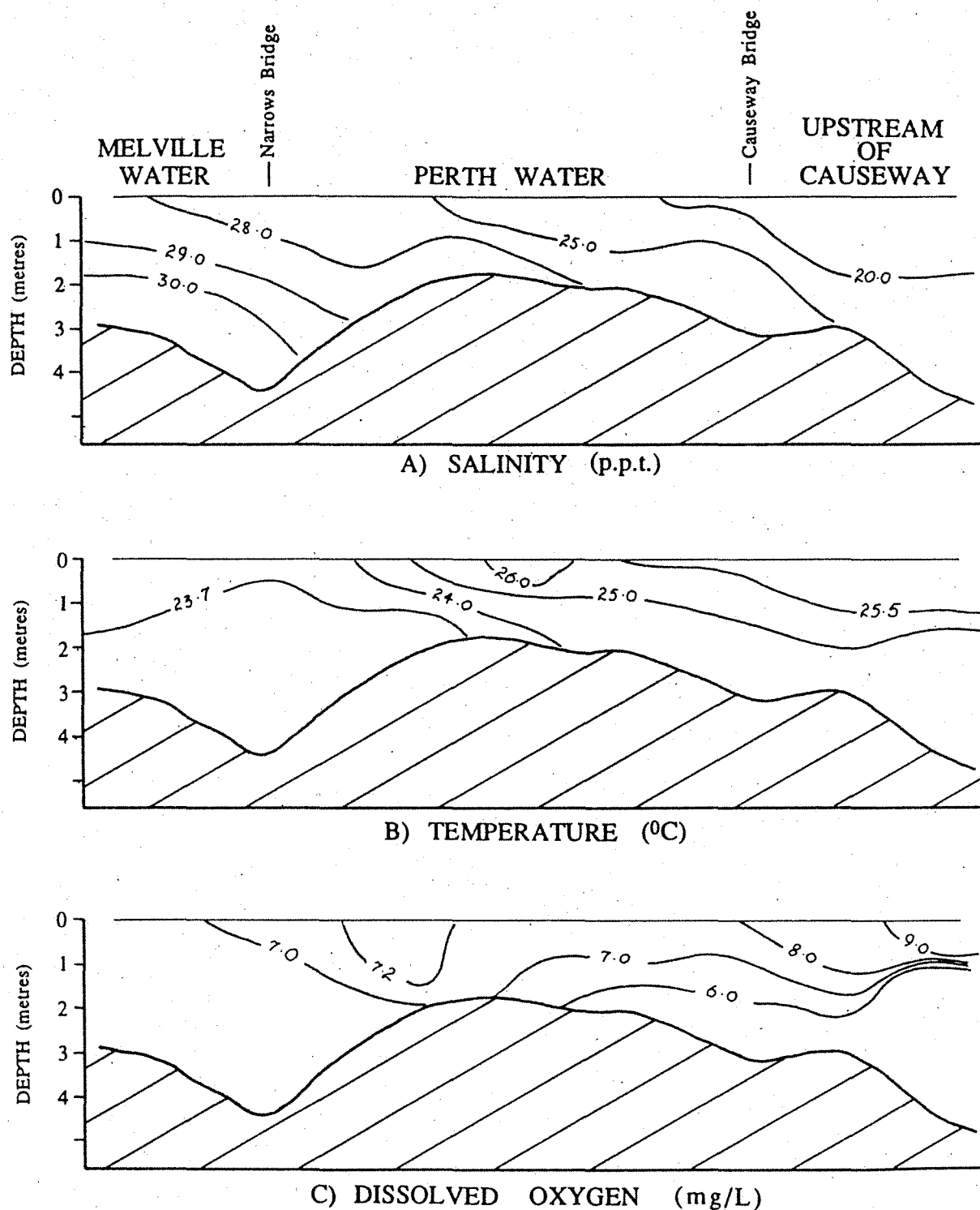
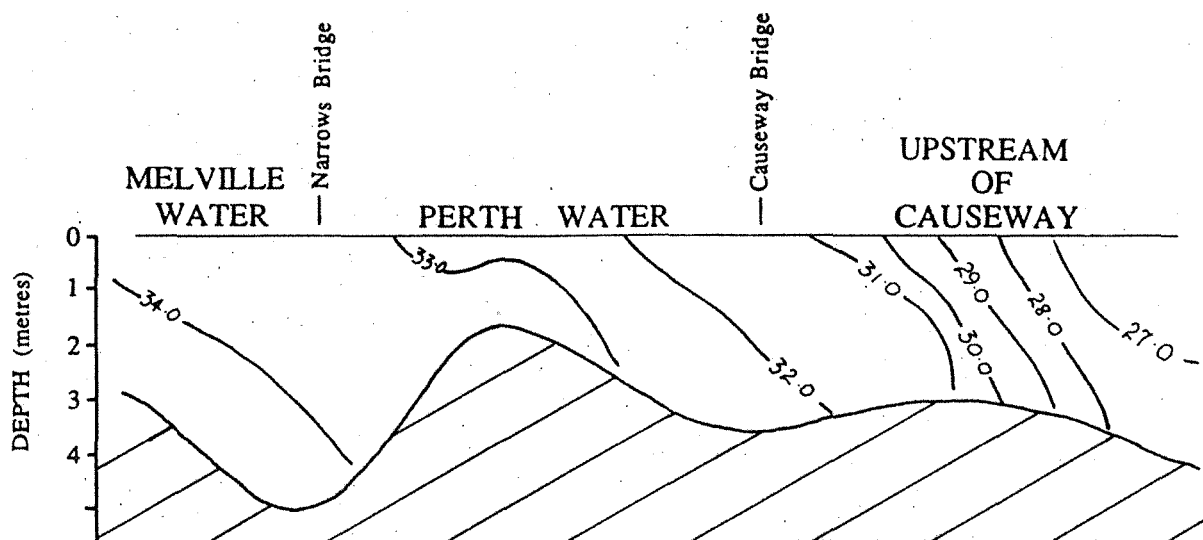
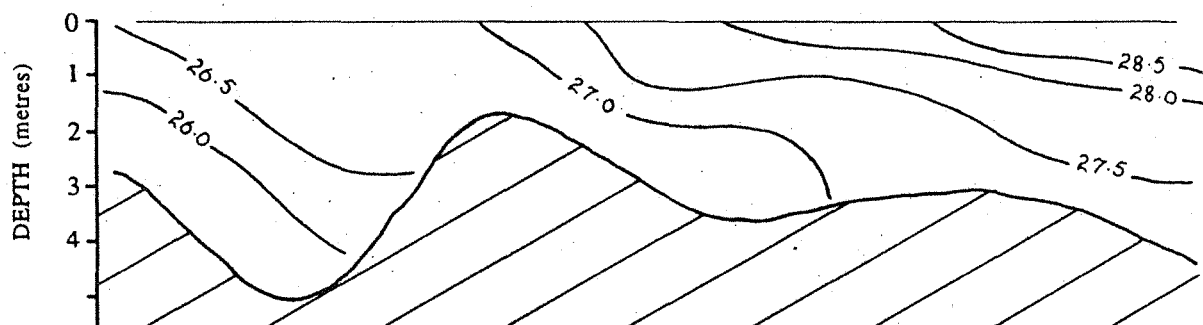


Figure 4.1 Results of physico-chemical monitoring of water quality in the Swan River estuary on 20th December 1988

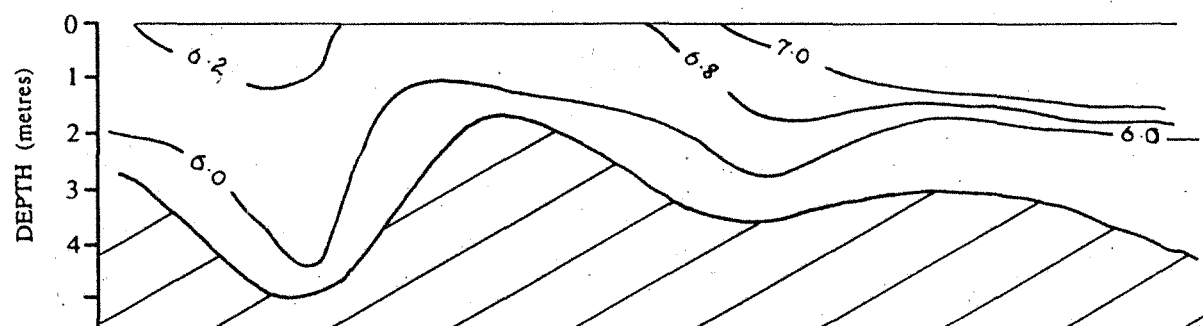
- A) salinity isohalines - p.p.t.
- B) temperature isotherms - $^{\circ}\text{C}$
- C) dissolved oxygen profiles - mg/L



A) SALINITY (p.p.t.)



B) TEMPERATURE (°C)



C) DISSOLVED OXYGEN (mg/L)

Figure 4.2 Results of physical monitoring of water quality in the Swan Estuary on 9th March 1989

- A) salinity isohalines - parts per thousand
- B) temperature isotherms - ° Celsius
- C) dissolved oxygen profiles - mg/Litre

4. Results

4.1 Water quality

4.1.1 Physico-chemical properties

4.1.1.1 Waterbody salinity-p.p.t.

In December 1988, the the Swan River estuary from Melville Water to East Perth waters upstream of the Causeway was marine, ranging in salinity from 30 to 20 parts per thousand (p.p.t.) respectively (Figure 4.1a). By the 9 March 1989, the area had become increasingly more saline (34-27 p.p.t.), as the marine wedge moved further upstream (figure.2,a).

4.1.1.2 Waterbody temperature

In December 1988 the ambient water temperatures ranged from 23.7°C in Melville Water to 25.5°C upstream of the Causeway (Figure 4.1b). On the 9 March 1989 water temperatures were slightly higher, ranging from 26.0°C in Melville Water to 28.5°C upstream of the Causeway (Figure 4.2b).

4.1.1.3 Waterbody dissolved oxygen

In the month prior to this survey, bottom water in the estuary around the Narrows bridge sites was anoxic.

In Melville Water by December 1988, dissolved oxygen levels had returned to normal saturation concentrations at between 7.0mg/L and 7.2mg/L. Upstream of the Causeway bridges, surface water dissolved oxygen was higher at 9.0mg/L (Figure 4.1c), which was likely due to the presence of phytoplankton activity in the area. By March 1989, all estuarine dissolved oxygen concentrations had returned to normal levels, ranging between 6.0mg/L and 7.0mg/L (Figure 4.2 c).

4.2 Chemical

4.2.1 Water- chromium concentrations

None of the water samples were filtered prior to analysis since no sediment or particulate material was visible and digested samples gave the same results as filtered digested samples.

4.2.1.1 Perth CBD drain outfalls

The chromium concentrations in these drains regularly exceeded the Water Quality Criteria for chromium in Marine and Estuarine Waters (DCE, 1981). These criteria are not normally applied to drains.

(a) Claisebrook Main Drain-East Perth

The concentrations of chromium in the Claisebrook Main Drain, (before mixing and dilution by Swan River estuary waters), were 13, 27 and 8.5µg/L on the 22, 23 December 1988 and the 2 February 1989 respectively. These results are similar to the chromium concentration of <50µg/L obtained by Water Authority of WA sampling in their corresponding survey period (WAWA Report 1990; appendices 10.1, & 10.3).

The Water Quality Criteria for Marine and Estuarine Waters for a single sample of 7µg/L, of chromium is normally not applied to the water of drains. It would have been exceeded by all of the drain water samples.

(b) Mounts Bay Main Drain

The Mounts Bay Main Drain empties into the Swan River estuary through dual pipe outlets, downstream of the Barrack Street jetty complex. Twice during this survey the WAWA installed a flow-gauging weir across the downstream pipe while blocking off flow in the upstream outlet.

The concentrations of total chromium in the downstream and upstream pipes of the Mounts Bay Main Drain outfalls on the 27 January 1989, were 6µg/L and 420µg/L respectively. On the 24 February 1989, the chromium concentrations in both the downstream and upstream pipes were higher than in January 1989, at 140 and 780µg/L respectively. Samples taken from the same locations later that day they yielded concentrations of 90 and 840µg/L respectively.

Though not directly applicable to drain waters the concentrations of chromium in Mounts Bay Main Drain waters were well above the estuarine criteria for both a 6-month median and also for a single sample.

4.2.1.2 Waters adjacent to drain outfalls

(a) Swan Estuary adjacent to the Claisebrook Main Drain

Estuary water samples taken immediately adjacent to the Claisebrook Main Drain on the 22, 23 December 1988 and on the 2 February 1989, showed similar distribution patterns of surface total chromium (Figures. 4.3a; 4.3b). The median and mean values for all sites adjacent to drains, during the three sampling periods from December 1988 to February 1989 were 7.5µg/L and 8.7µg/L.

The shallow area of the adjacent estuary (0.3-0.5 metres), partially contained on the upstream side by a sandy spit was subjected to chromium concentrations exceeding the six-monthly median environmental criteria of 2µg/L. This is not unexpected and consistent with a small mixing zone.

On the 22 and 23 December 1988, surface concentrations of chromium were higher than those recorded in February 1989. They ranged between 11.0-0.6µg/L, 23-1.2µg/L, and 4.4-1.3µg/L respectively.

Surface chromium concentrations decreased as the distance from the drain outfall increased. The lowest 1988-89 chromium concentrations adjacent to the drain outfall were similar to the values of chromium recorded at the estuarine grid sites located immediately upstream (site SRO1), and downstream (site SRN1).

Both on the 22 and 23 December 1988, respectively a surface mixing zone area exceeding 700 square metres adjacent to the Claisebrook Main Drain, had concentrations greater than 7µg/L of chromium.

On the 22, 23 December 1988 and on the 2 February 1989, a surface mixing area of approximately 1000 square metres of the Swan River estuary exceeded chromium concentrations of 2µg/L (Figures 4.3.a & 4.3.b).

Schools of juvenile mullet were frequently observed feeding within this shallow mixing zone adjacent to the Claisebrook Main Drain in the Swan River estuary.

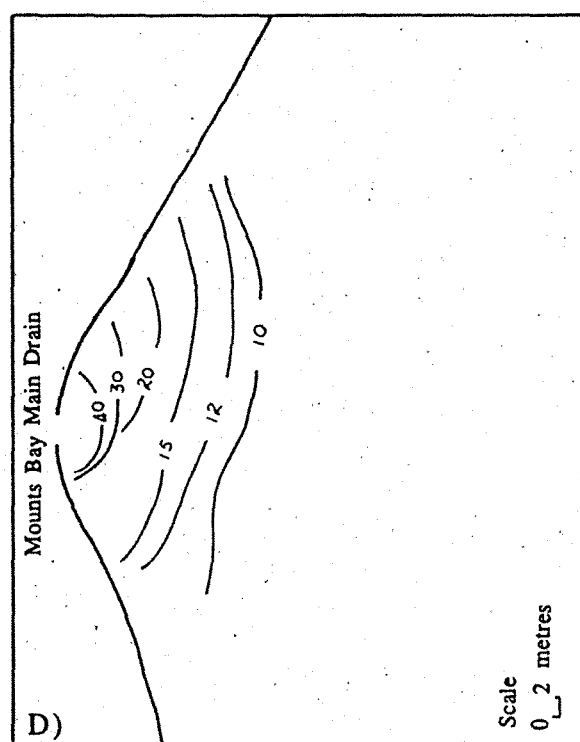
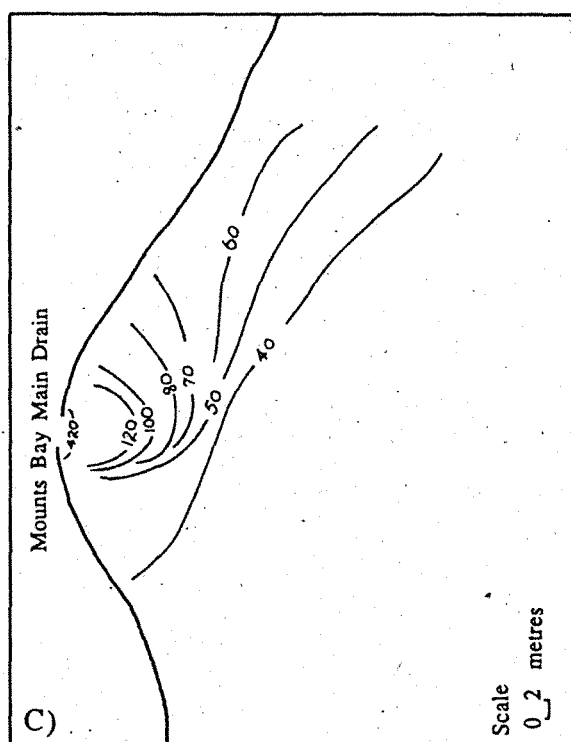
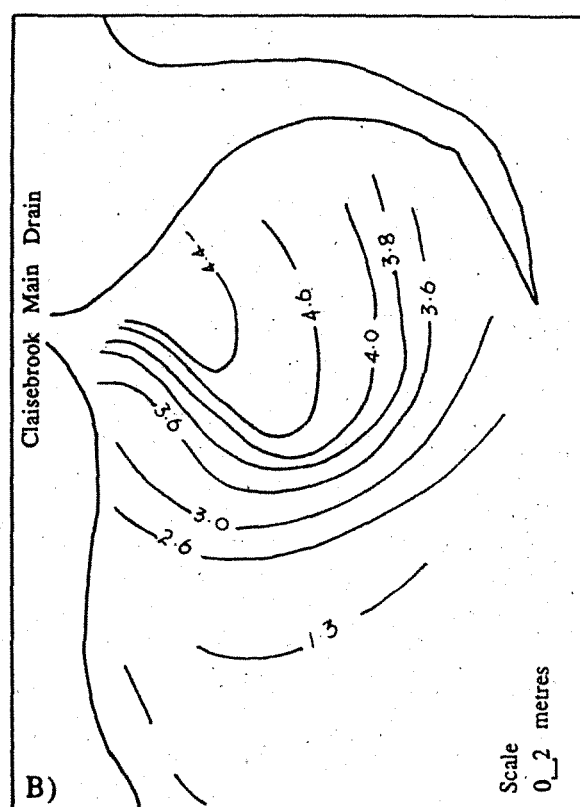
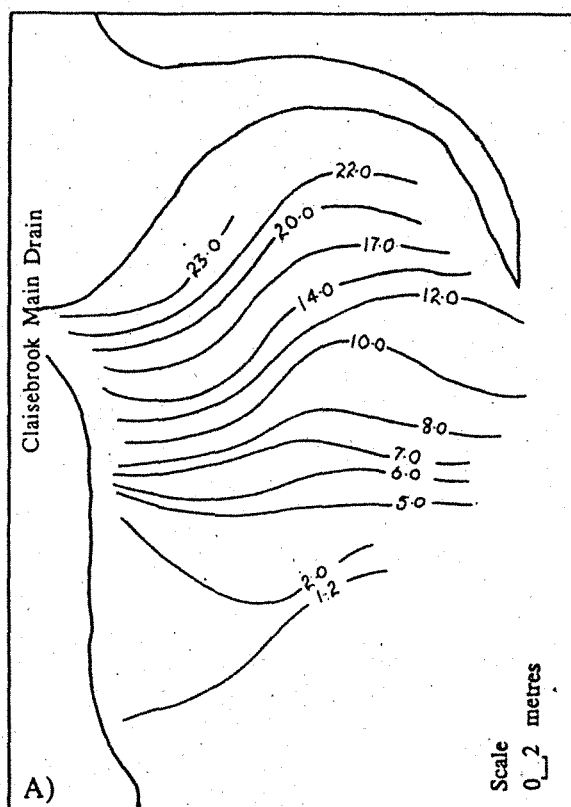


Figure 4.3 Concentration of chomium (Cr) [$\mu\text{g/L}$] in Swan River estuary surface waters adjacent to the mouth of Claisebrook Main Drain (CMD) and the Mounts Bay Main Drain (MBMD)

A) CMD 23/12/1988

B) CMD 2/2/1989

C) MBMD 27/1/1989

D) MBMD 24/2/1989

(b) Swan River Adjacent to the Mounts Bay Main Drain

Adjacent to the dual outlets from the Mounts Bay Main Drain, the drain-water plume on entering the estuary, was being pushed upstream by the incoming tide.

Surface-water chromium concentrations decreased as the distance away from the drain outlet increased. It was observed that the prevailing wind also affected the distribution of the plume. The fresh less dense drain water remained on the estuary surface and thus was affected by wind energy. A similar phenomenon was observed in the Swan River estuary adjacent to the Bayswater Main during an plume-tracing experiment using fluorescein dye by Mollet in 1983 (Swan River Management Authority unpublished data).

Surface water chromium concentrations fell to 40 µg/L within 35 metres of the drain outlets on 27 January 1989 (Figure 4.3.c). This was similar to the chromium concentration of <0.5 µg/L found at the surface of the nearest upstream river site SRF1 in December 1988. The concentration of chromium at the river surface 35 metres away from the drain outlets was 16 µg/L on 2 February 1989 (Figure 4.3.d).

The chromium concentration at all nine surface water sample sites adjacent to the Mounts Bay Main Drain, exceeded both the Water Quality Criteria maximum for a single sample and the 6-month median.

The chromium concentrations in the sites adjacent to the outfall of the Mounts Bay Main Drain were greater than those found adjacent to the Claisebrook Main Drain. The concentrations were however lower than 4-day LC_{50} of chromium for most aquatic phyla (Mance 1989).

4.2.1.3 Estuarine Body-Grid Sites

The chromium concentrations in the Swan River estuary only rarely exceeded the Water Quality Criteria for Marine and Estuarine Waters (DCE 1981) in the mixing zones immediately adjacent to Perth CBD drains.

The highest single chromium concentration of the Perth Water estuary body sites was at the surface of site SRF1 upstream of the Mounts Bay Main Drain. The recorded chromium concentration of 4.5 µg/L on the 9 March 1989 was below the 7 µg/L criterion for a single water sample.

(a) Melville Water

In Melville Water on the 15 December 1988, chromium concentrations in surface and bottom waters were below 1.5 µg/L. Higher chromium concentrations in the range 1.0-1.5 µg/L were found in the bottom water rather than in the surface water. The higher concentration waters appear to have originated from the Perth Water area (Figures 4.4 and 4.5b).

On the 20 December 1988, the distribution of surface chromium was similar to that found on the 15 December 1988 (Figures 4.6a & 4.5a). In the bottom water on the 20 December 1988 however, there was a strong chromium concentration gradient which appeared to originate from outside of the sampling grid (Figure 4.6b). Mean bottom chromium concentrations in Melville Waters immediately downstream of the Narrows Bridge were high on 20 December 1988 (2.12 µg/L). The high mean was unusual, and reflected the effect of a single high value of 6.2 µg/L. This value was near to the criterion for a single water sample. On the 9 March 1989 the surface and bottom chromium concentration ranges were similar (Figures 4.7 a & 4.7 b).

Table 4.1

Mean surface and bottom water chromium concentrations and ranges in Melville Water on the 15 & 20 December 1988 & 9 March 1989

Sample depth	15 Dec. 1988 (µg/L)	20 Dec. 1988 (µg/L)	9 Mar. 1989 (µg/L)
Surface	0.60 (<0.5-1.0)	0.74 (<0.5-1.2)	0.65 (<0.5-1.1)
bottom	0.83 (<0.5-1.4)	2.12 (0.5-6.2)	0.7 (0.5-1.1)

The mean surface chromium concentration was fairly uniform in Melville Water (Table 4.1). The mean chromium concentration was significantly greater in bottom water on 20 December 1988. The overall Melville Water median and mean chromium concentrations of all water samples from surface and bottom sites, from 15 December 1988 to 9 March 1989, were 0.7 µg/L and 0.88 µg/L respectively. These were well below the 2 µg/L six-monthly median criteria for chromium.

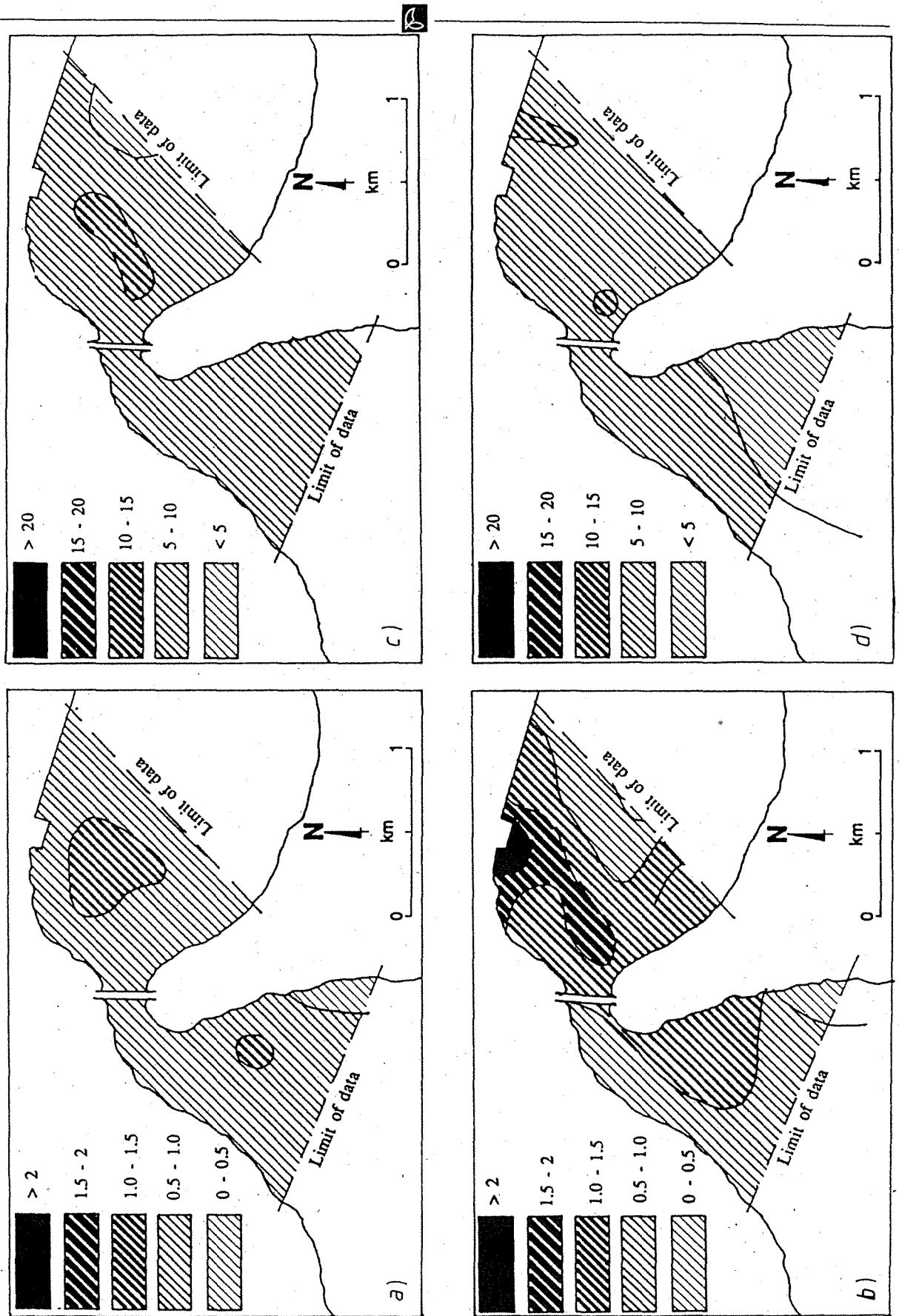


Figure 4.4 Concentration ranges for chromium (Cr) and zinc (Zn) [$\mu\text{g/L}$] in Swan River estuary surface and bottom samples

a) Cr surface 15/12/1988,

b) Cr bottom 15/12/1988,

c) Zn surface 15/12/1988,

d) Zn bottom 15/12/1988

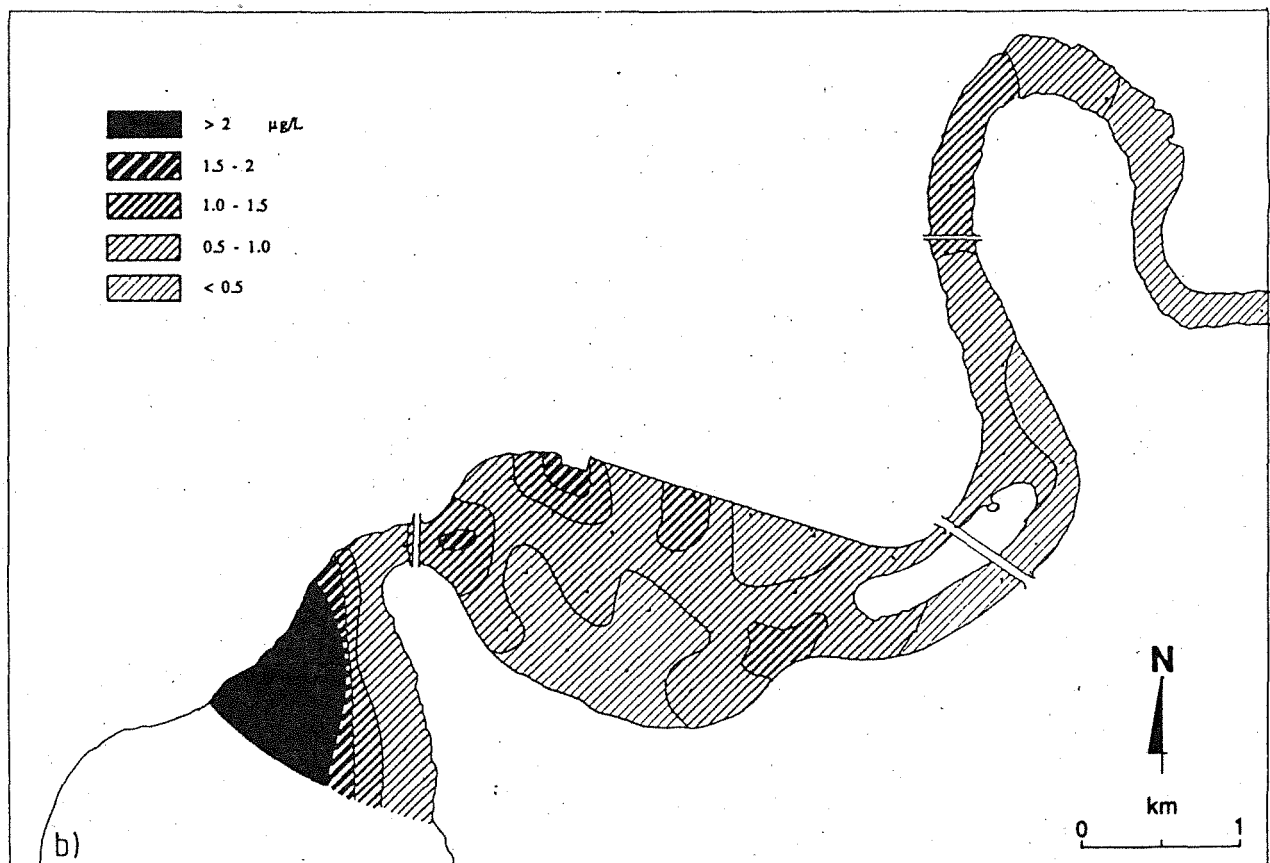
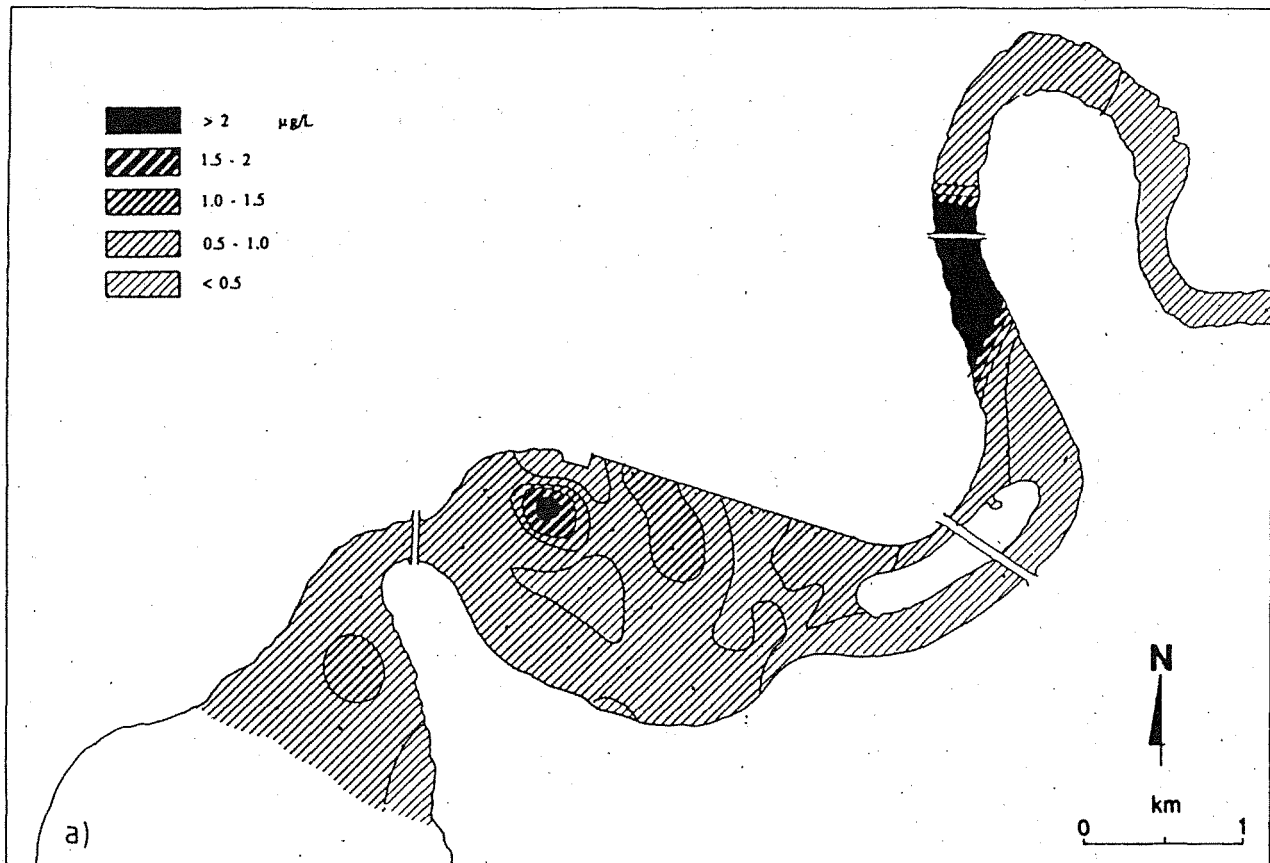


Figure 4.5 Concentration ranges for chromium (Cr) [$\mu\text{g/L}$] in Swan River estuary surface and bottom samples

a) surface 20/12/1988,

b) bottom 20/12/1988,

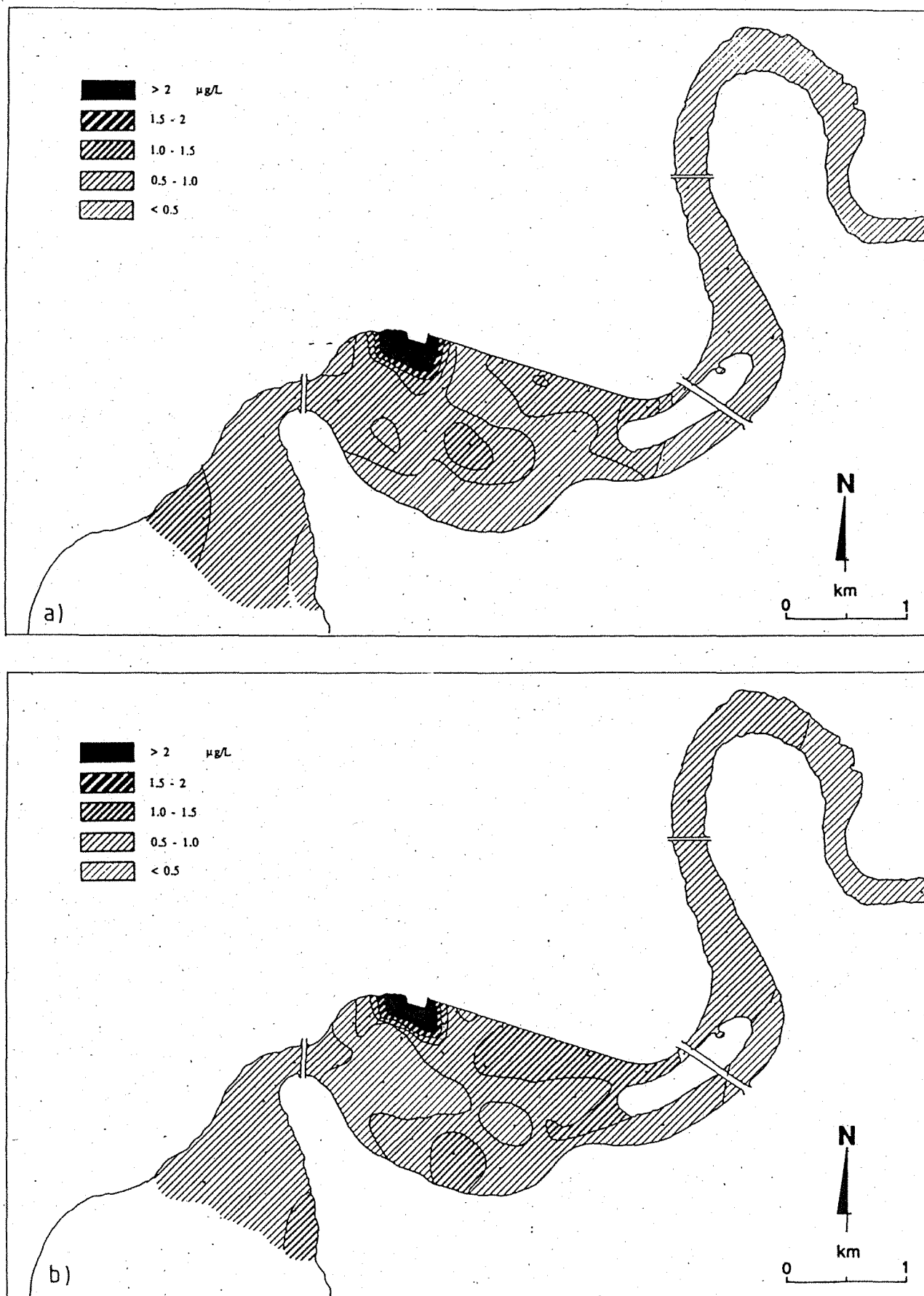


Figure 4.6 Concentration ranges for chromium (Cr) [$\mu\text{g/L}$] in Swan River estuary surface and bottom samples

a) surface 9/3/1989,

b) bottom 9/3/1989,

(b) Perth Water-chromium

In the western portion of Perth Waters on the 15 December 1988, higher chromium concentration gradients were evident in the bottom water (Figures 4.4a, 4.4 b). The higher chromium concentration plume in the bottom water, was adjacent to the outlet of the Mounts Bay Main Drain-MBMD (Figure 1.1). On the 20 December 1988 and also on the 9 March 1989. Similarly higher concentrations were evident in both the surface and bottom waters adjacent to the MBMD (Figures 4.5a & 4.5b, 4.6a & 4.6b).

Table 4.2

The mean, median and range of chromium concentrations in all surface and bottom samples from Perth Water for the period 20 December 1988 to 9 March 1989.

	Chromium (µg/L)	Water Quality Criteria (µg/L)
mean	0.77	n/a
median	0.60	6-month median <2.0
range	<0.5-4.5	single reading <7.0
number of samples	98	n/a

n/a means not applicable

The median and maximum chromium concentrations for Perth Water were both below Water Quality Criteria for Marine and Estuarine Waters (Table 4.2).

Table 4.3

Mean surface and bottom chromium concentrations of grid profiles numbered 1-4 in Perth Water on 20 Dec 1988 and 9 March 1989

Profile	20 Dec 1988 (µg/L)		9 Mar 1989 (µg/L)	
	Surf	Bott	Surf	Bott
1	0.71	0.86	1.24	1.48
2	0.78	0.71	0.56	0.71
3	0.57	0.78	0.75	0.53
4	0.75	0.5	0.45	0.85

On the 20 December 1988 there were similar mean chromium in mean chromium concentrations along the numbered profiles in Perth Water. In March 1989, the mean surface and bottom water chromium concentrations were highest nearer to the Central Business District drain outlets (profile line number 1). These means were also double the concentrations 400 metres away and almost double the means found at the same sites in December 1988.

Table 4.4

The ranges of surface and bottom water chromium concentrations of Perth Waters along profiles 1-4, in 1988 and 1989.

Profile	20 Dec 1988 (µg/L)	9 March 1989 (µg/L)	Criteria (µg/L)
1	<0.5-1.7 (14)	<0.5-4.5 (16)	7
2	<0.5-2.1 (16)	<0.5-1.2 (16)	7
3	<0.5-1.5 (12)	<0.5-1.3 (12)	7
4	<0.5-0.8 (8)	<0.5-1.3 (8)	7

Number of samples in brackets

None of the maximum chromium concentrations in the water, exceeded the Water Quality Criteria for Marine and Estuarine Waters criterion for a single sample of 7 µg/L. The highest chromium concentration of 4.5µg/L, was found at the surface of site SRF1 just upstream of the Mounts Bay Main Drain outlet during an incoming tide. With a median concentration of 2.5µg/L, site SRF1 was also the only individual site in Perth Water to exceed 2µg/L.

Table 4.5

The overall mean surface and bottom chromium concentrations in Perth Water in December 1988 and March 1989.

	20 Dec 1988 (µg/L)	9 Mar 1989 (µg/L)
Surface	0.69	0.78
Bottom	0.68	0.93

There was no significant difference between the mean surface and bottom chromium concentration means in Perth Water in 1988. The mean bottom

water chromium concentration for Perth Water in 1989 was slightly above the surface mean.

Table 4.6

Perth Water median chromium concentrations of both top and bottom water samples for grid profiles 1-4 for the period 1988-89.

Profile number	Median Cr concentration (µg/L)	Six-monthly median criterion (µg/L)
1	0.7 (n=30)	2.0
2	0.55 (n=32)	2.0
3	0.5 (n=24)	2.0
4	0.6 (n=16)	2.0

n=Number of samples in brackets

The highest median chromium concentration was nearest to the Perth CBD drain outfalls and was below the six-monthly criterion.

(c) Upstream of the Causeway-East Perth (Sites M to P)

Upstream of the Causeway Bridges on 20 December 1988, the highest surface and bottom water chromium concentrations were at the sites nearest to the outfall of the Claisebrook Main Drain (Figure 4.5a). The surface and bottom water at the eastern side of the Swan River estuary upstream of the Causeway area had its lowest chromium concentrations in December 1988 and March 1989 (Figures 4.5a & 4.5b, 4.6a & 4.6b).

Table 4.7

Overall median, mean, and range of chromium concentrations (µg/L) of surface and bottom water in the East Perth area, upstream of the Causeway (sites SRM-SRP inclusive), on the 20 December 1988 and the 9 March 1989.

	concentration (µg/L)	criteria (µg/L)
Median	0.5	2.0
Mean	0.81	n/a
Range	(<0.5-5.6)	7

(n=20)

n/a means not applicable

The mean and median chromium concentrations of the Swan River estuary at East Perth were both below the six-month and single sample criteria. The highest individual chromium concentration of 5.6µg/L was at the surface of site SRO1 upstream of the Claisebrook Main Drain sampled during an incoming tide.

Table 4.8

Mean surface and bottom water chromium concentrations in East Perth (sites SRM to SRP inclusive), upstream of the Causeway on the 20 Dec 1988 & 9 March 1989

location	20 Dec 1988 (µg/L)	9 Mar 1989 (µg/L)
Surface	1.54	<0.5
Bottom	0.78	0.6

n=5

On the 20 December 1988, the mean bottom chromium concentrations of the Swan Estuary was slightly higher than on the 9 March 1989. The East Perth waters surface mean was highest in 1988.

(d) Upstream of the Bunbury Bridge (Sites Q and R)

Table 4.9

Mean surface and bottom water chromium concentrations in the Maylands portion of the Swan Estuary upstream of the Bunbury Rail Bridge on the 20 Dec 1988 & 9 March 1989.

	20 Dec 1988 (µg/L)	9 Mar 1989 (µg/L)
Surface	<0.05	<0.05
Bottom	<0.05	<0.05

On 20 December 1988, and on 9 March 1989 the surface and bottom chromium concentrations for the Maylands area were all below the detection level of <0.05µg/L (Figures 5-8).

Table 4.10

Summary of the surface and bottom water mean chromium concentrations on the 20 December 1988 and the 9 March 1989.

Depth	Melville Water ($\mu\text{g/L}$)	Perth Water ($\mu\text{g/L}$)	u/s of Causeway ($\mu\text{g/L}$)	u/s of Bunbury Bridge ($\mu\text{g/L}$)
Surface 1988	0.74	0.69	1.54	<0.05
Bottom 1988	2.12	0.68	0.78	<0.05
Surface 1989	0.65	0.78	<0.5	<0.5
Bottom 1989	0.70	0.93	0.62	<0.5

On the 20 December 1988 and the 9 March 1989 the lowest mean surface and bottom chromium concentrations were in the area upstream of the Bunbury rail bridge (Table 4.10). The highest mean bottom water concentration was in Melville Water in 1988. The highest mean surface chromium concentration was upstream of the Causeway bridges. In March 1989, Perth Water had slightly higher mean surface and bottom water chromium concentrations.

4.2.2 Water-zinc concentrations

4.2.2.1 Drains-zinc concentrations

(a) Claisebrook Main Drain

The concentrations of zinc in the Claisebrook Main Drain were fairly uniform during the survey period. Instantaneous values of 64 and 81 $\mu\text{g/L}$ were measured on the 22 and 23 December 1988 respectively and 58 $\mu\text{g/L}$ on 2 February 1989. These zinc concentrations were similar to those values obtained by the Water Authority (WAWA 1990, appendices 10.1, 10.3).

Though not normally applied to drain water, all zinc values in the Claisebrook Main Drain were below estuarine Water quality criterion for single samples (200 $\mu\text{g/L}$). The median zinc value of 64 $\mu\text{g/L}$ in the drain, for the period December 1988 to February 1989 exceeded the Water Quality Criteria for Marine and Estuarine Waters 6 month median of 20 $\mu\text{g/L}$.

(b) Mounts Bay Main Drain

During both drain-plume sampling exercises in January and February 1989, the concentrations of zinc in the estuary were markedly different immediately in front of each pipe outlet. The concentrations of zinc found in the upstream pipe outlet (250, 250 $\mu\text{g/L}$) were much higher than in the downstream pipe outlet (33, 49 $\mu\text{g/L}$). Zinc values obtained in this survey were similar to those found by Water Authority sampling (WAWA 1990; Appendices 10.5 & 10.6).

(c) Swan Estuary adjacent to the Claisebrook Main Drain East Perth

The Claisebrook Main Drain plume containing zinc and chromium from the Claisebrook Main Drain was dispersed in a similar way on entering the adjacent waters of the Swan River estuary in both December 1988 and in February 1989 (Figures 4.3a & 4.3b).

In December 1988 and February 1989, the measured surface water zinc concentration ranges adjacent to the Claisebrook Main Drain were similar at 70-16 $\mu\text{g/L}$ and 44-20 $\mu\text{g/L}$ respectively. The zinc-bearing drain plume proceeded upstream with the incoming tide and the prevailing breeze. Within 35 metres from the drain outfall, the zinc concentrations had been diluted to values similar to those recorded at the surface of the nearest regular grid sites upstream (SR01) and downstream (SRN1). These data are consistent with a small mixing zone.

(d) Swan River estuary adjacent to the Mounts Bay Main Drain

On both 27 January and 24 February 1989 the Mounts Bay Main Drain plume was forced upstream by an incoming tide. After mixing with Perth Water, the high surface zinc concentrations fell rapidly to 30 and 15 $\mu\text{g/L}$ within 35 metres of the Mounts Bay Main Drain outfall (Figures 4.8 a, & b). The lower concentrations were slightly higher than zinc values recorded upstream at the grid site SRF1 sampled in December 1988 and March 1989.

The median zinc concentrations in the mixing zone adjacent to the dual Mounts Bay Main Drain outlets over the two sampling periods was 32.5 $\mu\text{g/L}$. This would have exceeded the six-monthly median criterion of 20 $\mu\text{g/L}$. The mean zinc concentration in the mixing zone was 57 $\mu\text{g/L}$ over the same period.

Within this area, schools of juvenile fish (especially mullet) have constantly been observed feeding at the drain outlets.

4.2.2.2 Swan Estuary Water Body - Zinc

(a) Melville Water

On the 15 December 1988, surface and bottom water zinc concentrations downstream of the Narrows bridge were low with the lowest readings in bottom water adjacent to the Kwinana Freeway (Figures 4.4c & 4.4d).

Mean and median water zinc concentrations Melville Water were fairly uniform during the 1988-1989 sampling period. The range of zinc concentrations for bottom water in 1989 was <5 to 10µg/L. These values were all below the estuarine criteria for the six-monthly median and for a single sample.

Table 4.11

Mean surface and bottom water zinc concentrations in Melville Water on the 15 Dec, 20 Dec 1988 & 9 March 1989. Maximum values in brackets.

	15 Dec 1988 (µg/L)	20 Dec 1988 (µg/L)	9 Mar 1989 (µg/L)	All 1988-1989 (µg/L)	SQCM & EW DCE 1981 (µg/L)
Surf mean and max	6.0	<5.0	<5.0	<5.0 (7.0)	200
Bot mean and max	5.3	<5.	7.0	6.0 (10.0)	200
Median surf & bot	5.5	<5.0	5.0	5.0 (n=4)	20
mean surf & Bot	5.6	<5.0	5.0	5.0 (n=34)	NA

WQCM & EW = Water Quality Criteria for Marine and Estuarine Waters of Western Australia (DCE, 1981).

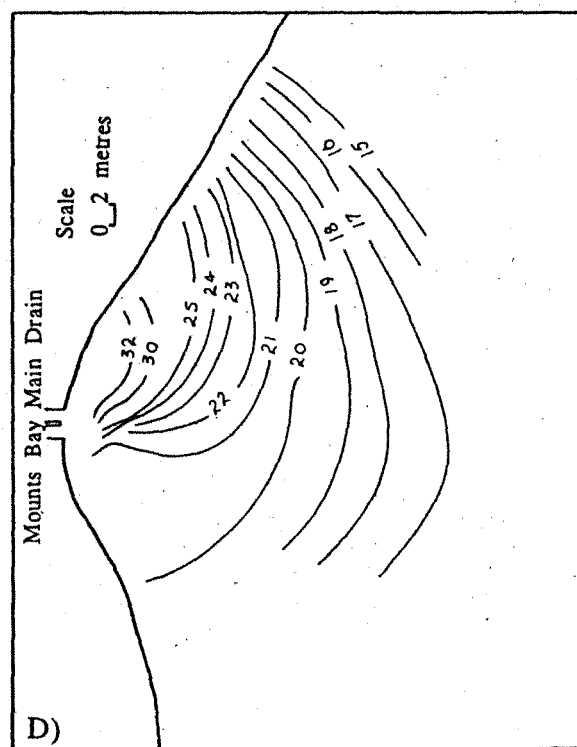
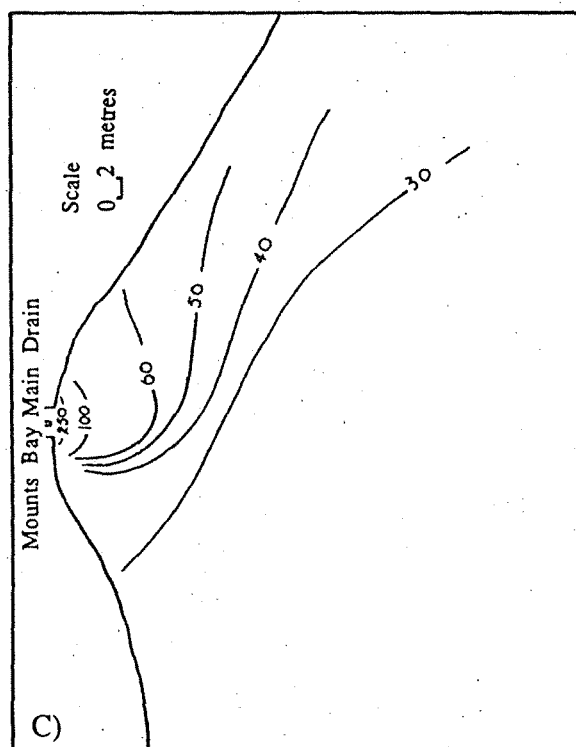
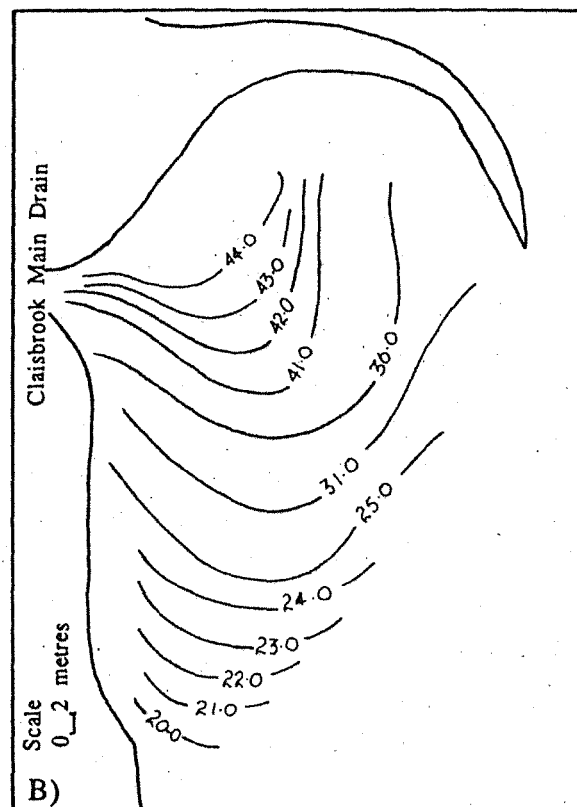
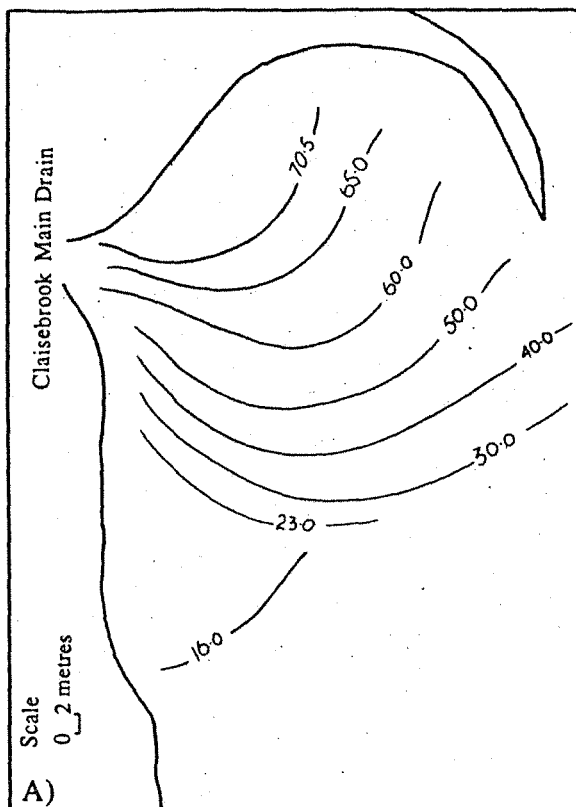


Figure 4.7 Concentrations of zinc (Zn) [$\mu\text{g/L}$] in Swan River estuary waters adjacent to the mouth of Claisebrook Main Drain (CMD) and the Mounts Bay Main Drain (MBMD)

A) CMD 23/12/1988
C) MBMD 27/1/1989

B) CMD 2/2/1989
D) MBMD 24/2/1989



(b) Perth Water

On the 15 December 1988, in the western part of Perth Water, both surface and bottom zinc concentrations were low except for a few isolated patches (Figures 4.5c, 4.5d). On the 20 December 1988 a patch of high zinc concentration was found around Heirisson Island (Figure 4.8). On 9 March 1989 higher zinc concentrations were found at the bottom of a number of sites (Figure 4.9).

Table 4.12

Mean surface and bottom zinc concentrations and ranges of in Perth Water on the 20 December 1988 & 9 March 1989.

	20 Dec 1988 (µg/L)	9 March 1988 (µg/L)	All samples 1988-1989 (µg/L)	MEWQ Criteria 1981 (µg/L)
Surface mean	7.3 (<5.0-16)	8.7 (<5.0-20)	8.0 (n=49)	200
Bottom mean	8.1 (<5.0-16)	12.1 (<5.0-57)	10.18 (n=49)	200
Median all samples	NA	NA	9.1 (n=198)	20
Mean all sites	NA	NA	8.0 (n=198)	n/a

NA denotes not available

n/a means not applicable.

The 1988 and 1989 surface and bottom mean zinc concentrations in Perth Water were similar. The highest zinc concentration of 57µg/L at the bottom of grid site SRG4, was approximately a quarter of the criterion for a single sample. The median zinc concentration was less than a half of the six-monthly median Water Quality Criteria for Marine and Estuarine Waters of 20µg/L.

Table 4.13

Mean surface and bottom water zinc concentrations of numbered profiles 1 to 4 in Perth Water on the 20 December 1988 and 9 March 1989.

The mean surface and bottom zinc concentrations on 9 March 1989 were higher than in December 1988. The surface mean zinc concentration was lowest at the sites most remote from the CBD drain outfalls (grid line 4). The

highest 1989 bottom water mean zinc value was at the South Perth side of the waters.

	20 Dec 1988	9 Mar 1988	1988	1988
Profile number	surface (µg/L)	bottom (µg/L)	surface (µg/L)	bottom (µg/L)
1	8.0	8.14	11.0	11.25
2	8.1	6.33	9.13	10.0
3	8.29	7.8	8.2	9.5
4	5.5	8.5	5.5	22.5

(c) Upstream of the Causeway

Generally zinc concentrations found upstream of the Causeway bridges in East Perth water in both December 1988 and March 1989 were moderate (Figures 4.8 & 4.9). One area of elevated zinc concentrations was found at the surface of the eastern Swan on the 9 March 1989 (Figure 4.9b).

Table 4.14

Mean surface and bottom zinc concentrations and overall mean and median concentrations in East Perth water between the Causeway and just upstream of the Bunbury Rail Bridge, sites SRM to SRP inclusive, on 20 Dec 1988 & 9 March 1989.

	20 Dec 1988 (µg/L)	9 Mar 1989 (µg/L)	1988-89 mean (µg/L)	1988-89 median (µg/L)
Surface mean	12.2	10.4	NA	NA
Bottom mean	10.2	9.0	NA	NA
all samples	NA	NA	10.6	10.5

NA means not available.

The surface and bottom water mean zinc concentrations upstream of the Causeway East Perth, were all similar on the 20 December 1988 and the 9 March 1989. The highest zinc concentration was 17µg/L which was well below the single sample water quality criteria of 200µg/L zinc. The median value for 1988-89 was half the six-monthly water quality criterion.

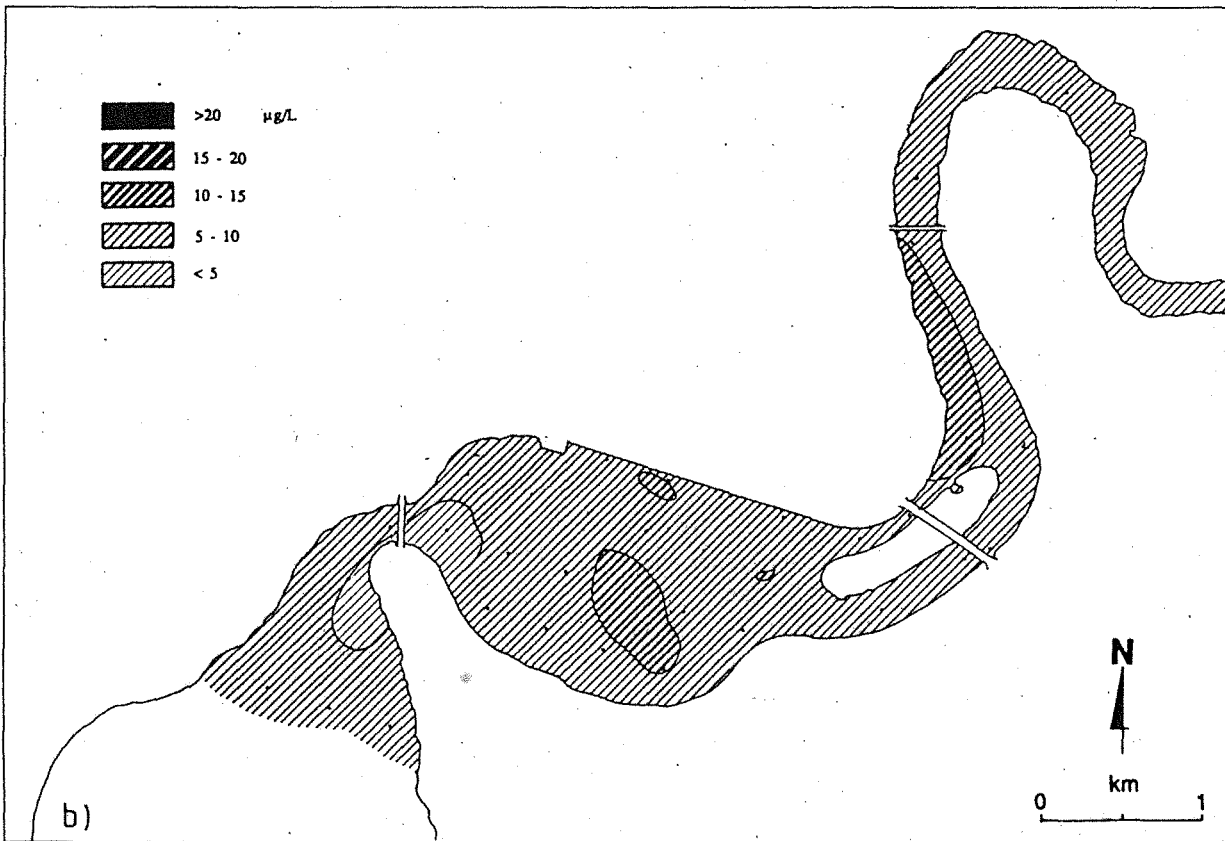
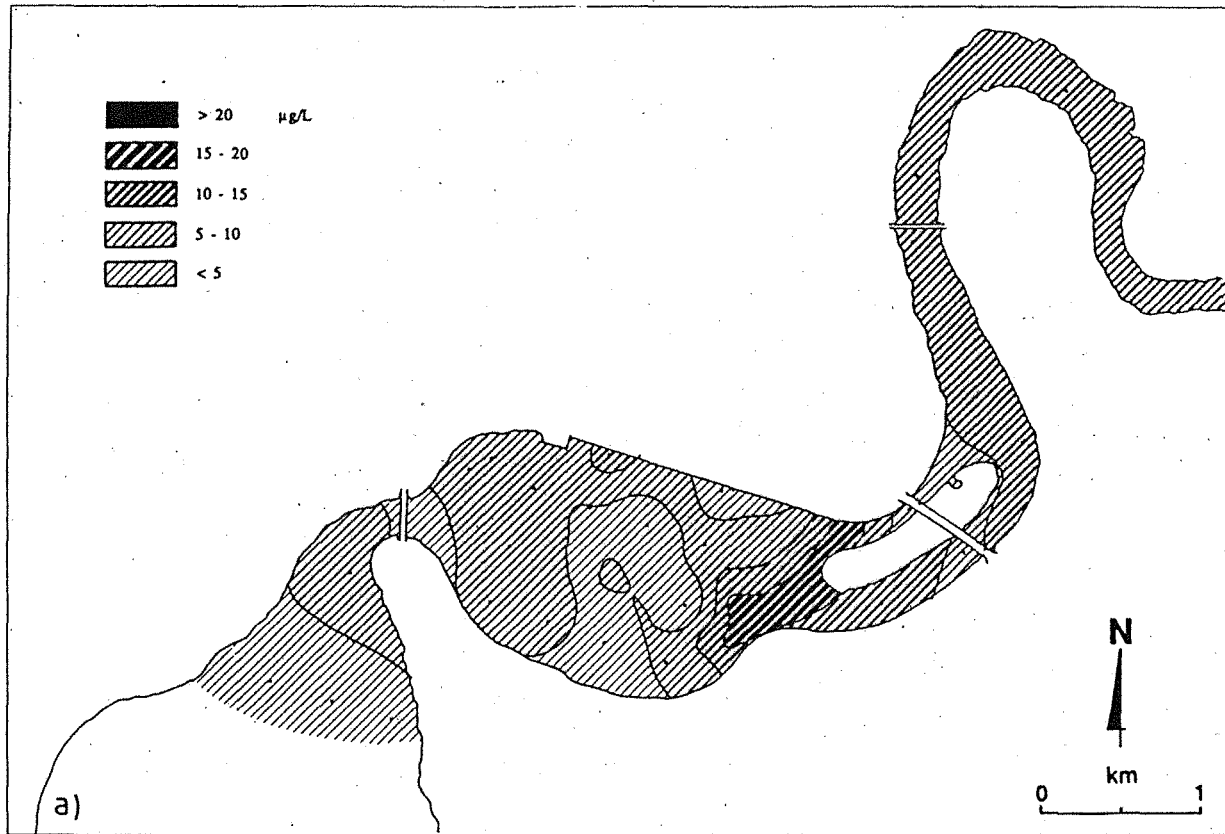


Figure 4.8 Concentration ranges for zinc (Zn) [$\mu\text{g/L}$] in Swan River estuary surface and bottom samples

a) surface 20/12/1988,

b) bottom 20/12/1988,

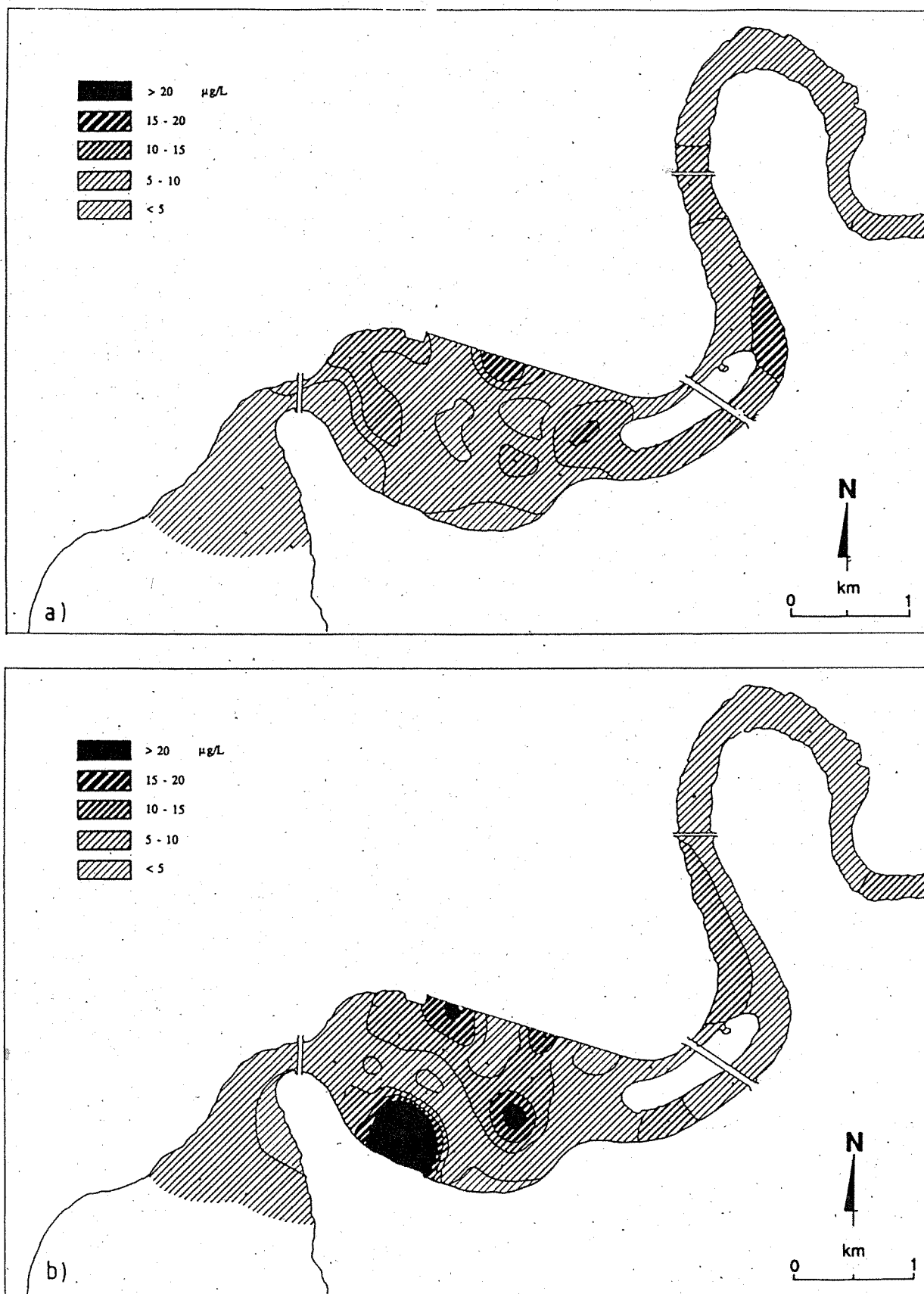


Figure 4.9 Concentration ranges for zinc (Zn) [$\mu\text{g/L}$] in Swan River estuary surface and bottom samples

a) surface 9/3/1989,

b) bottom 9/3/1989

(d) Upstream of the Bunbury Bridge -(Sites Q and R)

The Maylands area of the Swan River estuary upstream of the Bunbury rail bridge had surface and bottom zinc concentrations similar to those found upstream of the Causeway in east Perth waters (Figures 4.8-4.9).

Zinc concentrations in the Maylands water area were higher in December 1988 than in March 1989. The maximum and median zinc concentrations were below the environmental single criterion

Table 4.15

Mean surface and bottom zinc concentrations in the Swan River estuary, upstream of the Bunbury Rail Bridge on 20 Dec 1988 & 9 March 1989.

	20 Dec 88 (µg/L)	9 Mar 89 (µg/L)	1988-89 (µg/L)
Surface	13.0	9.5	NA
Bottom	12.0	9.0	NA
Mean surface & bottom	NA	NA	10
Median all samples	NA	NA	11

NA means not available.

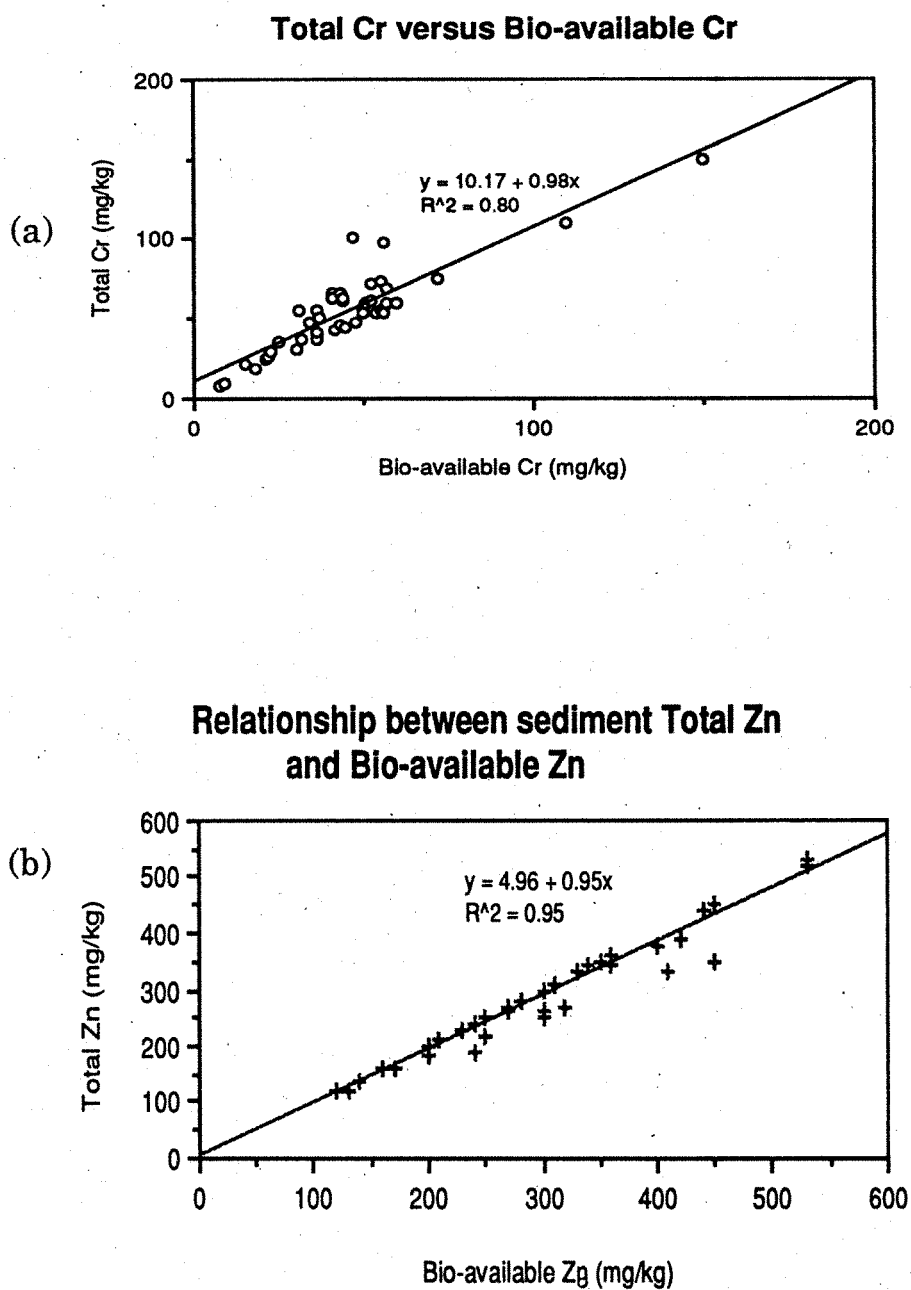


Figure 4.10

The relationship between total and bio-available metals in sediments.

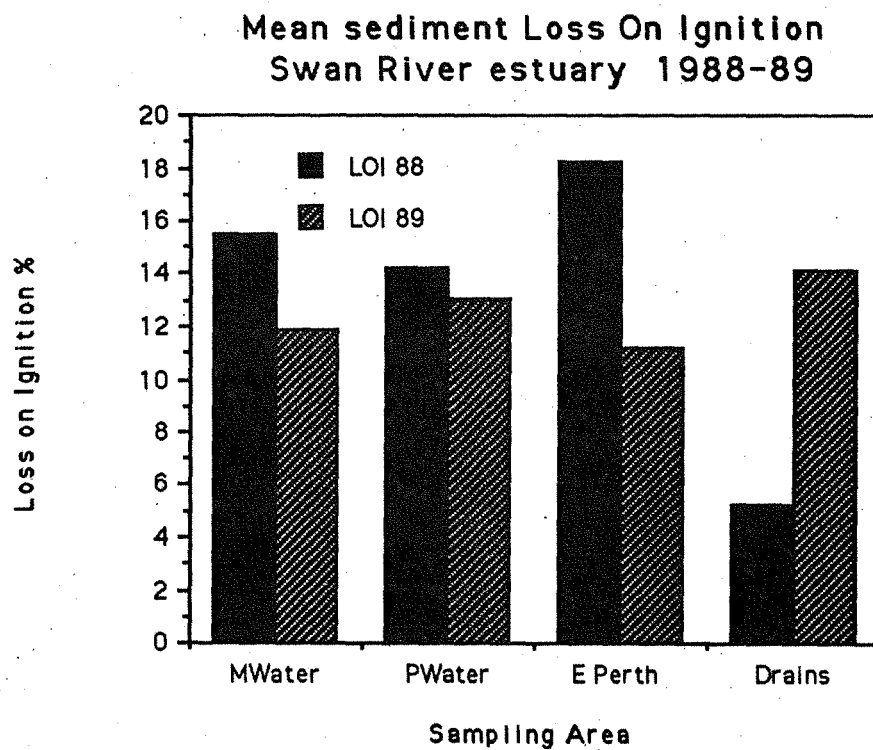
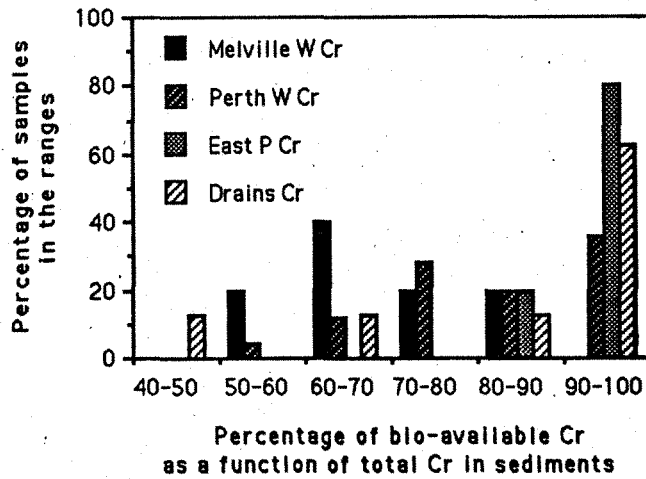


Figure 4.11

The Mean Loss on Ignition of Swan River estuary sediments in 1988 and 1989.

The relative bio-availability as a function of Total Chromium in the sediments of the Swan River Estuary and associated drains 1989.



The relative bio-availability as a function of Total Zinc in the sediments of the Swan River Estuary and associated drains

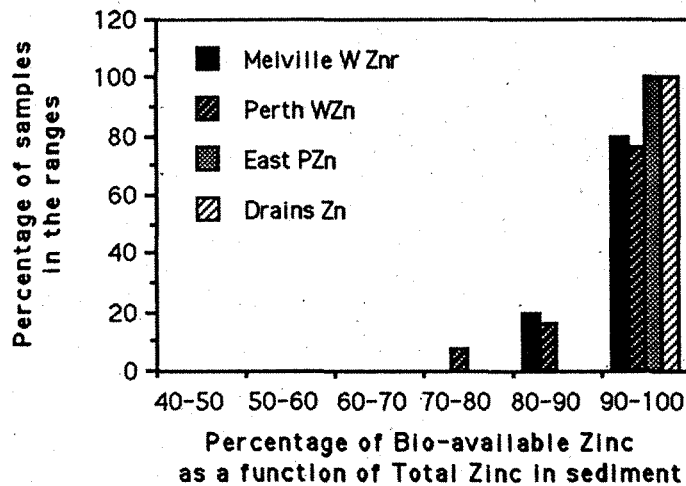


Figure 4.12

The relative bio-availability of total metals in the Swan River Sediments in 1989

4.3 Estuary sediments

The strong correlation between estuarine sediment bio-available and total metals suggests that the method of boiling in 1 molar HCl released most of the available the metal. (Figures 4.10a & 4.10b).

Both due to the absence of bio-available analyses in 1988 and the strong correlations between the bio-available metals and the total metal content of sediments, the majority of results discussed will be on the total metal fractions to enable comparisons to be made.

4.3.1 Loss On Ignition

The mean 1988 Loss on Ignition (LOI), in estuarine sediments was highest in east Perth waters, upstream of the Causeway (Figure 4.11). This mean was higher than that of both Melville and Perth Water sediments. The LOI means in Melville and Perth Waters were similar in 1989 and slightly lower than found in 1988.

4.3.2 Sediment- chromium

Lower relative percentages of the availability of chromium, as a function of total chromium in sediments, were found in the Melville Water area, when compared with sediments associated with the CBD and drains (Figure 4.12a).

4.3.2.1 Melville Water

The distribution of chromium in Melville water sediments was similar in December 1988 and March 1989 (Figures 4.12a & 4.12b). Areas of sediment furthestmost from Perth Water had the lowest chromium values.

Table 4.16

Mean chromium concentrations and ranges in the sediments of Melville Water in 1988 and 1989 as dry weight.

	1988 (mg/kg)	1989 (mg/kg)	1988-89 (mg/kg)	criteria for soils (mg/kg)
mean all sites	52	45	58/0 (n=12)	n/a
range	21-74	9.2-65	9.2-74	100

n/a means not applicable.

The maximum chromium concentrations in the sediments of Melville Water were less than the criteria for contaminated terrestrial soils, which are used by way of comparison.

The range in sediment chromium concentrations for Melville Water were similar to the ranges Chegwiddden found at Chidley Point in July 1980, and in the Cockburn Sound Study of 1979. Sites SRD3, SRD5 and SRD6 in Melville Water, had higher metal levels as determined in the Cockburn Sound Study of 1979 (at or equal to 40mg/kg on a dry weight basis).

There was a strong relationship between the sediment chromium concentration and its organic content (LOI) in Melville Water (Figure 4.16a). This suggests an affinity between metals and organic matter in sediments. This is similar to that observed for terrestrial soils where increased organic matter levels produce a greater cation exchange complex hence an affinity for metal cations. This relationship was strongest in Melville Water. It is probably related to the less turbulent nature of the waterbody when compared to the upstream sites in which sediments are readily disturbed and redistributed by wind-induced waves and tidal movement.

4.3.2.2 Perth Water- chromium in sediments

In 1988, in Perth Water the sediments adjacent to the MBMD, the Coode St Jetty and the west of Heirisson Island had elevated chromium concentrations (Figure 4.12a). In 1989 the area of Perth adjacent to the eastern end of the CBD had elevated sediment chromium concentrations (Figure 4.12b). The other two previously high concentration areas retained moderately high chromium concentrations.

Table 4.17

Mean chromium concentrations and ranges in the sediments of Perth Water in 1988 and 1989.

	1988 (mg/kg)	1989 (mg/kg)	1988-89 (mg/kg)	criteria for contam- inated soils (mg/kg)
mean of all sites	48	55	52.2 (n=48)	n/a
Median	45.5 (n=24)	55 (n=24)	51.5 (n=48)	n/a
Range	8.2-100	29-98	8.2-100	<=100

n/a means not applicable

Two samples of sediment from the Perth Water area (excluding drain outfalls), were at-or-near to the chromium criteria for contaminated soils. The 1989 mean chromium concentration in Perth Water sediments was higher than the 1988 mean. In 1988 and 1989, 71% and 83% respectively, of Perth Water sediment sample sites fell into the category of 'significantly greater metal content' of around 40mg/kg chromium, as indicated by the results of Cockburn Sound Study of 1979.

Table 4.18

Mean sediment chromium concentrations in numbered profiles 1 to 4 in Perth Water in November-December 1988 and March-April 1989.

Profile	20 Dec 1988 (mg/kg)	9 March 1989 (mg/kg)
1	47.4	61.3
2	56.5	49.9
3	39.3	53.5
4	28.75	55.76

In December 1988, the highest mean chromium level of 56.5mg/kg was along the second grid line away from the CBD. In 1989 the highest mean chromium concentration at 61.6mg/kg was nearest to the CBD foreshore. In 1989, most of the mean chromium concentrations of Perth Water sediments, along grid lines 1 to 4, were greater than 1988 values. The lowest mean sediment chromium concentrations during this study was found in 1988, along the grid line 4, nearest to the South Perth foreshore.

There was a positive relationship between the organic content and chromium concentration in sediments of Perth Waters (Figure 4.16b). The relationship was not as good as that found in Melville Water sediments. This is believed to be related to the nature of and the constant mobility of shallow estuary sediments by the prevailing winds.

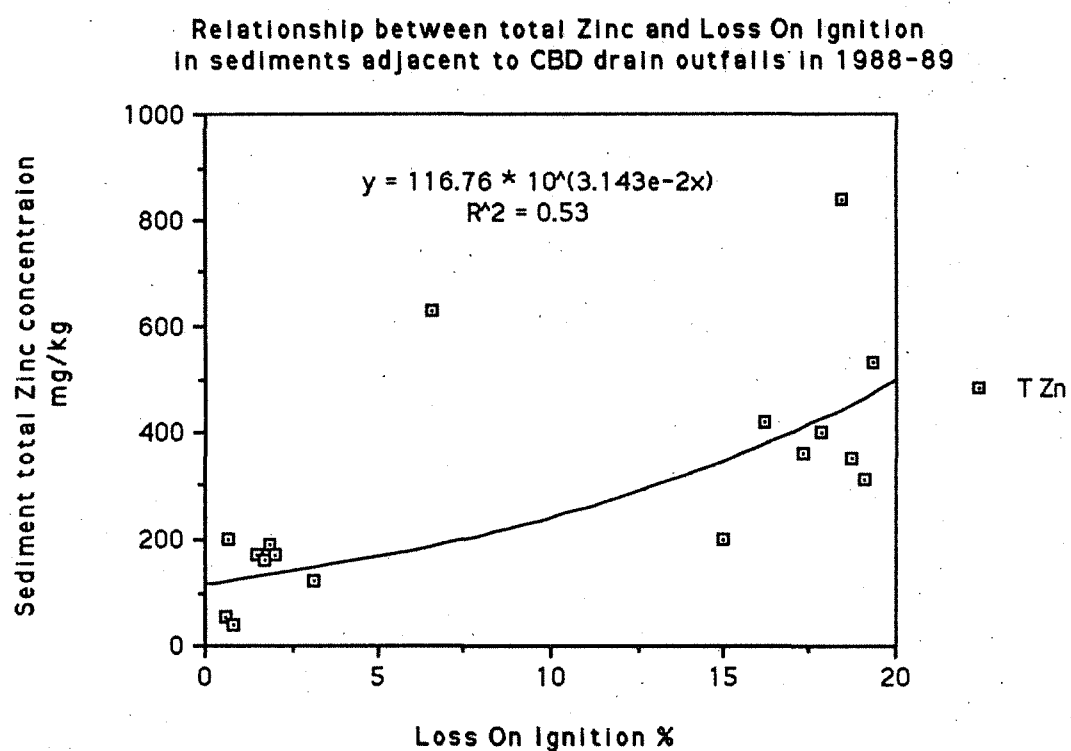
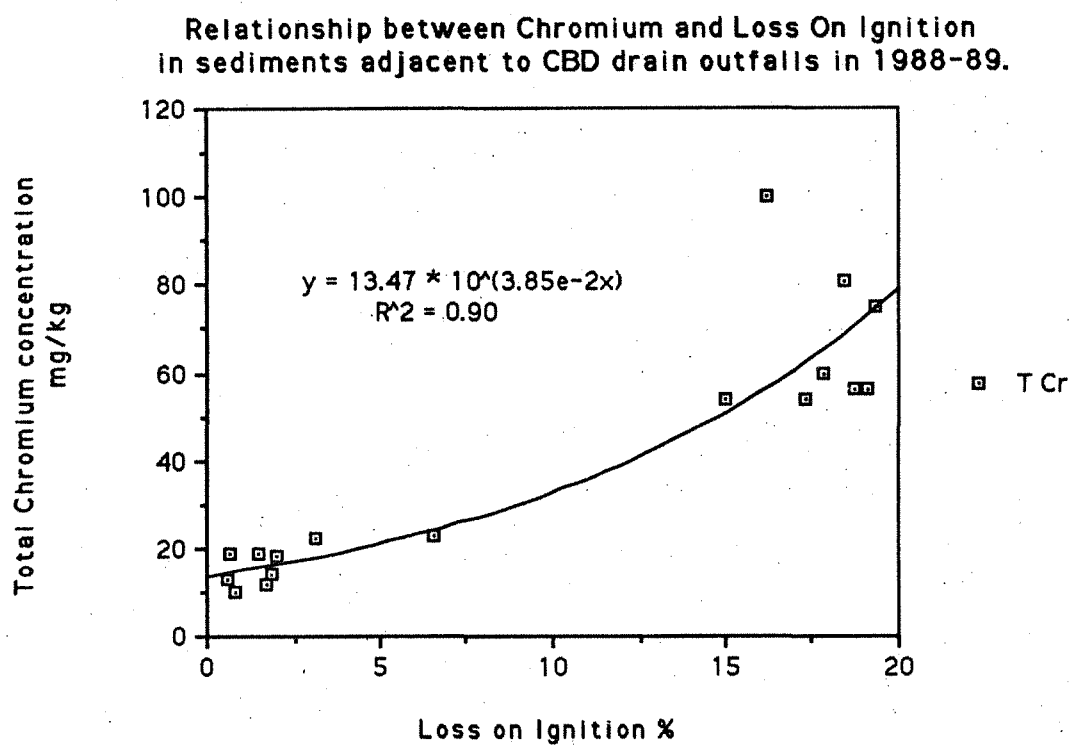


Figure 4.13

Relationships between the sediment metals and Organic content in the Swan River estuary immediately adjacent to the outfalls of Drains from the CBD.

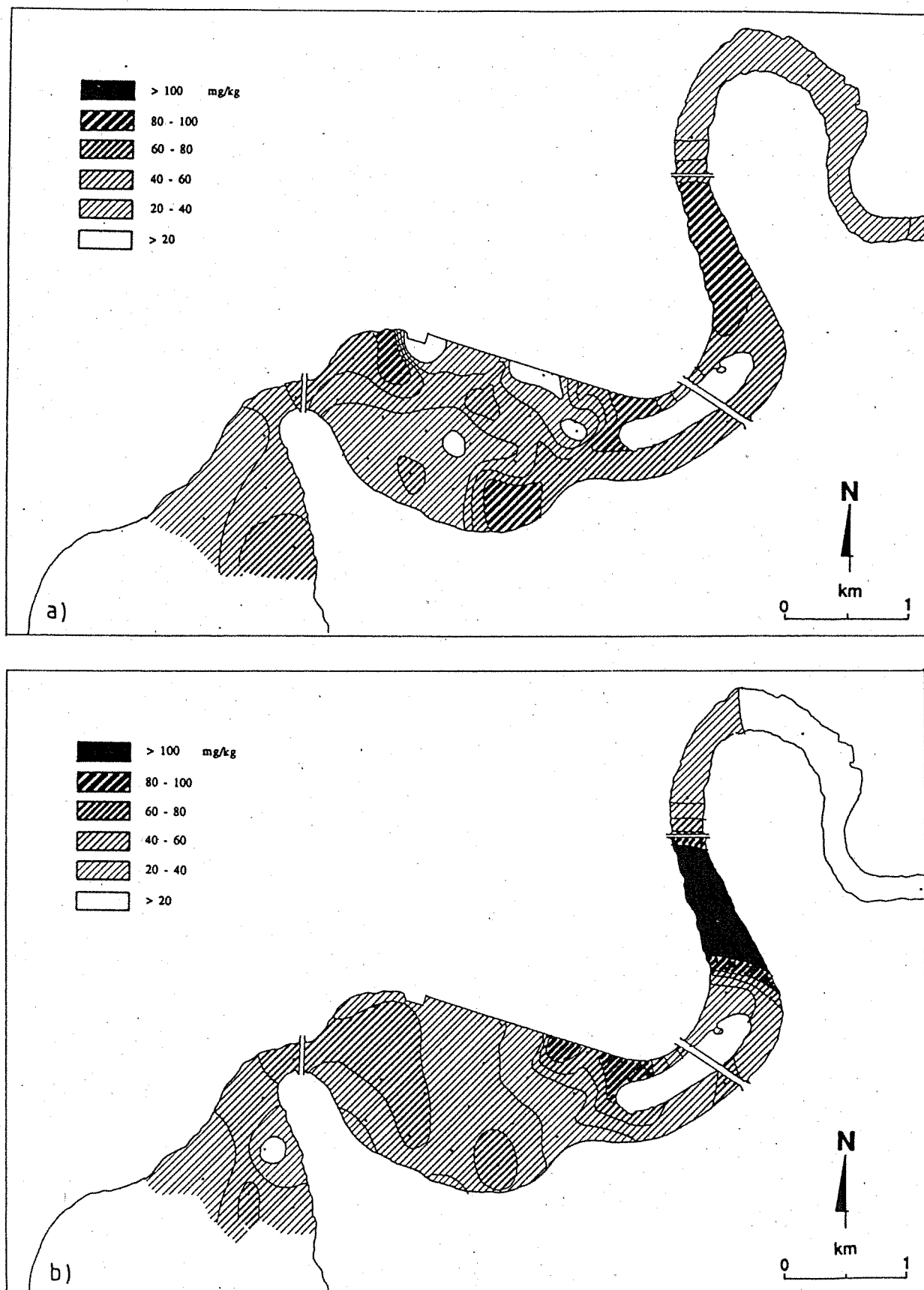


Figure 4.14 Concentration ranges of chromium in Swan River estuary sediments

a) November 1988

b) March-April 1989

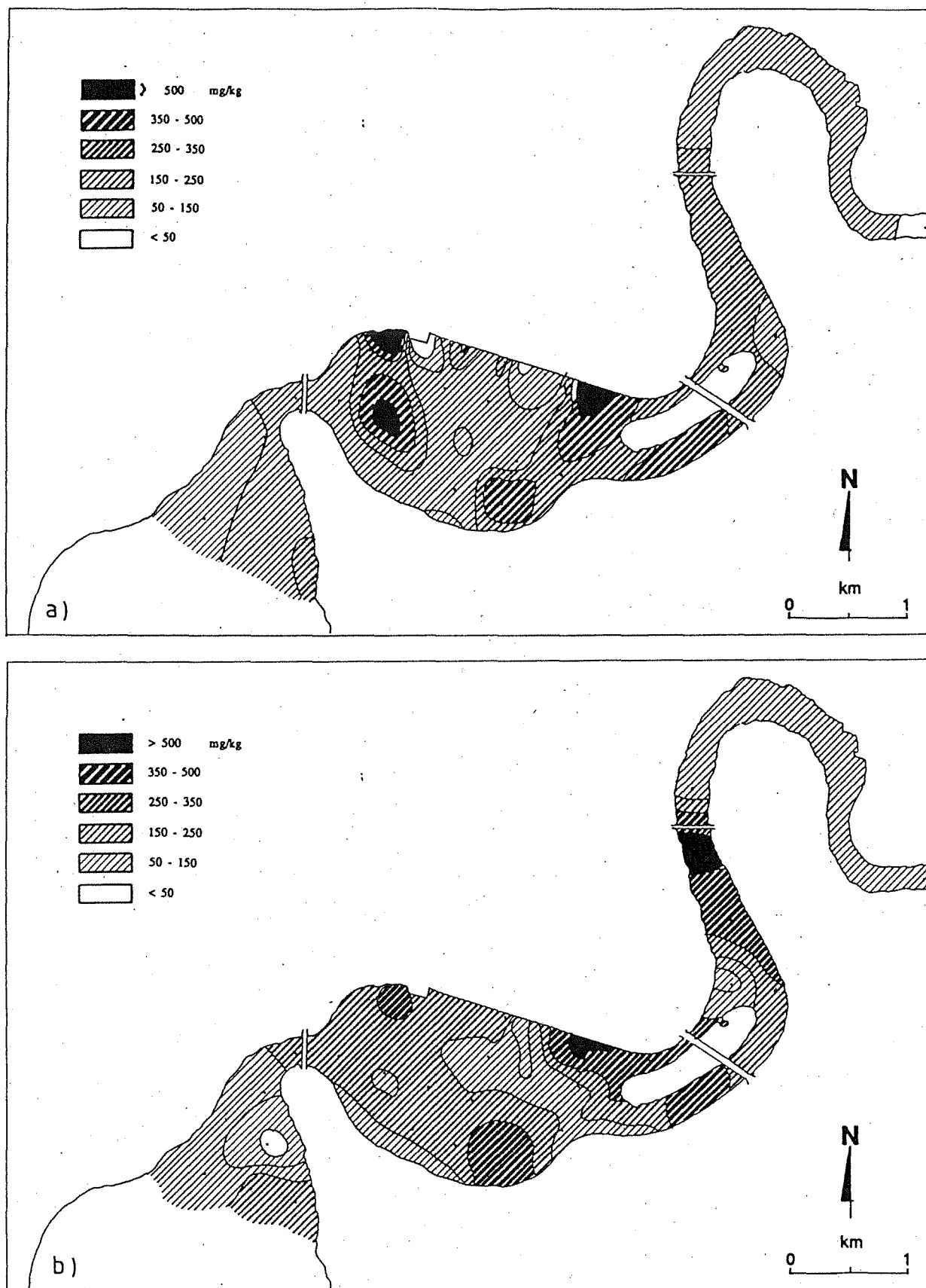


Figure 4.15 Concentration ranges of zinc in Swan River estuary sediments

a) November 1988

b) March-April 1989

4.3.2.3 Upstream of the Causeway-East Perth (Sites M to P inclusive)

Upstream of the Causeway, the area immediately downstream of the Bunbury Rail Bridge had high sediment chromium concentrations in both 1988 and 1989 (Figures 4.14a & 4.14b). These chromium concentrations were also higher than those found in sediment at the mouth of the Claisebrook Main Drain.

The highest mean sediment concentrations of all water areas in this study were found upstream of the Causeway. The overall mean concentrations for the area were similar at 73.0mg/kg and 73.2mg/kg for 1988 and 1989 respectively. The ranges of sediment chromium were 40-88mg/kg and 25-150mg/kg for 1988 and 1989 respectively.

In 1989, two sites upstream of the Causeway bridges (SRN1 and SRO1), exceeded the criterion of 100mg/kg of chromium above which further investigations should be initiated in contaminated soils.

4.3.2.4 Upstream of the Bunbury Bridge (Sites SRQ-SRR)

In both 1988 and 1989, the chromium concentrations in estuary sediments from the Maylands area, upstream of the Bunbury rail bridge were low at less than 50mg/kg (Figures 4.10a & 4.10b).

4.3.2.5 Control sites (Sites SR16, SR9, SR5 and Canning River SR23A)

Table 4.19

The concentrations of total chromium in the sediments of the Swan and Canning River estuary control sampling sites in 1988 and 1989 as dry weight.

Sediment Control Sites	1988 mg/kg	1989 mg/kg	Soil Cr guidelines mg/kg
SR16 Armstrong Spit	23	55	100
SRQ1 Maylands	23	7.5	100
SR9 Rivervale	41	ND	100
SR5 Guildford	31	9	100
SR23A Canning	49	30	100
Mean of all control sites	33.4	25.3	100

ND means not done

The 1989 chromium concentrations in the sediments of the Swan-Canning Estuary sites upstream of the Perth Central Business District, and in the Canning River at Mount Henry, were generally lower than the 1988 concentrations.

At site SR16 (Armstrong Spit) sediment at 14 metres depth site in lower Melville Waters, the 1989 chromium concentrations had doubled those of 1988. This though was still half the upper limit recommended in Australian Guidelines for management of contaminated terrestrial soils. Low bottom water dissolved oxygen concentrations, noted during the previous spring, may have released and thus reduced the bio-available fractions of sediment metals. This therefore would have depressed the December 1988 sediment chromium concentration.

Melville Water bottom water on the 20 December was high in chromium which may have originated from these sediments.

4.3.2.6 Chromium in sediments adjacent to CBD drains

In 1988, the lowest chromium concentration found in sediments adjacent to any Perth CBD drain outfall was 10mg/kg at the mouth of the Hill Street Main Drain. The highest concentration was 81mg/kg at the Mounts Bay Main Drain dual outlets.

In 1989 the highest chromium levels were 100mg/kg at the Bennett Street Main Drain. The lowest concentrations were 18 and 22mg/kg at the Claisebrook and Hill Street Main Drains respectively.

(a) Loss On Ignition (LOI) versus chromium in the surface sediments adjacent to drain outfalls

In the sediments adjacent to drain outfalls, there was a strong correlation ($R^2=0.9$) between the organic content (LOI %) and its chromium content (Figure 4.13 a).

4.3.3 Sediment - zinc

In more than 80% of the sediment sites in the Swan River estuary and adjacent to the drain outfalls, over 90% of the total zinc concentrations was bio-available (Figure 4.12b). This may reflect the settling out of the fine organic particles which have complexed the metals.

4.3.3.1 Melville Water

In both 1988 and 1989, the concentration distribution pattern of sediment zinc in Melville Water sediment sites was similar to that of chromium for the same period (Figures 4.14a & 4.14b and 4.15a & 4.15b).

Table 4.20

Mean, median and ranges of zinc concentrations in the sediments of Melville Water in 1988 and 1989.

	1988 (mg/kg)	1989 (mg/kg)	1988-89 inclusive (mg/kg)	max criterion (mg/kg)
mean all sites	176.8	205.5	191.2 (n=12)	n/a
range	91-260	33-300	33-300	<350
median	NA	NA	180	n/a

n/a means not applicable

NA means not available

The December 1988, mean zinc concentration in the sediment of Melville Water was the lowest mean value for any of the Estuary body sites at 176.8mg/kg. By early 1989 the mean sediment zinc concentration was 100mg/kg less than the mean for Perth Water sites upstream. The highest individual zinc concentration in sediments was at SRE6. These were below the upper limits suggested in Australian Guidelines for management of contaminated soils above which investigations should be initiated. (ANZEC & NH & MRC, 1990).

The zinc concentration in sediments were however higher than those encountered by Chegwidien in the Cockburn Sound Study of 1979. The values were similar to those in the sediments at Chidley Point in the Swan River Study (Chegwidien, 1980-a & 1980-b). This indicates that there is probably no significant metal increase over the past 8 to 9 years.

In Melville Water there was a good correlation ($R^2=0.9$) between sediment zinc concentration and its organic content with the organic content (Figure 4.16 a).

4.3.3.2 Perth Water

In both 1988 and 1989, Perth Water sediments contained high to very high concentrations of zinc. This was adjacent to the MBMD, the Plain Street Main Drain and the Coode Street jetty in Perth Water (Figures 4.15a & 4.15b).

Table 4.21

Means and ranges of zinc concentrations in Perth Water sediments in 1988 and 1989.

	1988 (mg/kg)	1989 (mg/kg)	1988-89 (mg/kg)	criteria (mg/kg)
mean	290 (n=23)	308 (n=24)	299 (n=47)	n/a
median	250	300	NA	n/a
range	70-640	160-450	70-640	350
%> criteria	26.1	29.2	NA	n/a

n/a means not applicable; NA means not available

In 1988 the mean sediment zinc concentration was 290mg/kg in Perth Water. In 1989 the mean for Perth Water sites was similar at 308mg/kg. The overall mean zinc concentration for Perth Water sediments were 33% greater than those found in Melville Water.

The highest zinc concentration for any individual Perth Water sampling site was 640mg/kg recorded in November 1988 at station SRJ1 (Figure 4.13 a) which is 84 % higher than the criterion for contaminated soils.

Other sites exceeding the criterion of 350mg/kg were; SRF3, SRJ2, SRK2, SRL2, only 1988 and sites SRF1, SRG1, SRH1, SRK1 only in 1989. Sites SRI4, SRJ1 and SRL2. exceeded the criterion in both years.

Table 4.22

Mean sediment zinc concentrations of numbered grid profiles 1-4 in Perth Water in November-December 1988 and March-April 1989 (dry weight).

Profile number	Nov-Dec 1988	March - April 1989	criteria (mg/kg)
1	320	370	350
2	290	270	350
3	280	270	350
4	260	320	350

In both 1988 and 1989 the highest mean sediment zinc concentrations were at the sites nearest to the drain outfalls from the CBD. The mean in profile 1 in

1989 was above the upper limits suggested in Australian Guidelines for management of contaminated soils above which investigations should be initiated. (ANZEC & NH& MRC, 1990). The mean zinc concentrations decreased in the profiles away from the CBD. in 1988.

The high mean zinc concentration at site SRI4, at the Coode Street Jetty on the South Perth side of the estuary was attributed to the accumulation of the redistributed of organic-rich sediments into an old dredged ferry channel at that site.

4.3.3.3 Upstream of the Causeway- (Sites M to P)

In 1988 most of the area upstream of the Causeway bridges had high levels of sediment zinc (Figure 4.15a). In 1989 the area of very high to excessively high levels of sediment zinc covered an estimated half of the area upstream of the East Perth water (Figure 4.15b).

The mean sediment zinc concentration in 1989, upstream of the Causeway was slightly higher than that of 1988. The overall mean zinc concentration in the sediments was slightly higher than that of Perth Water. The highest individual sediment zinc concentration was recorded in 1989 at site SRO1, upstream of the Claisebrook Main Drain outlet.

The area means were below the upper limits suggested in Australian Guidelines for management of contaminated soils above which investigations should be initiated. (ANZEC & NH& MRC, 1990). The highest value was well above the 350mg/kg guideline.

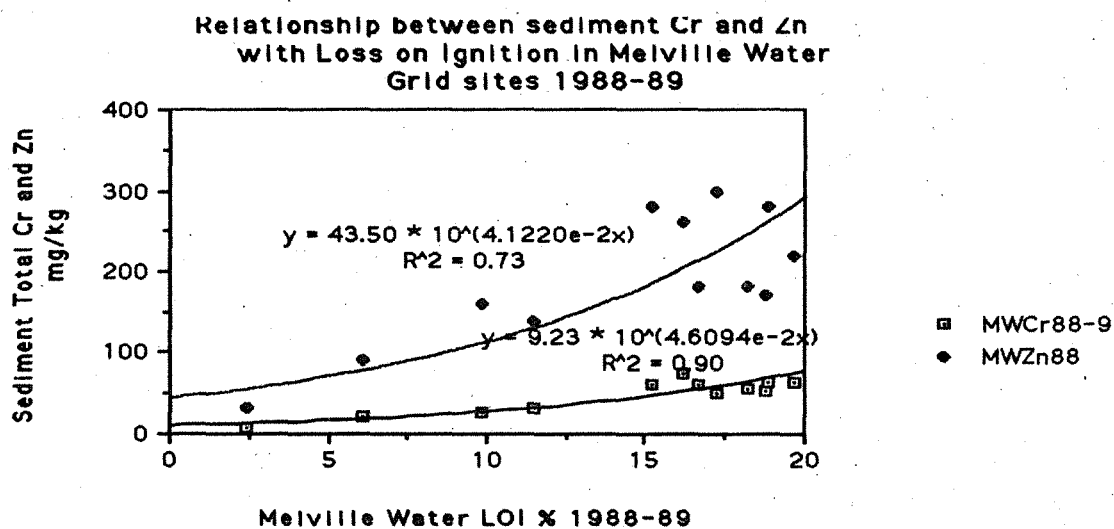
Table 4.23

Means and ranges of zinc concentrations in the Swan River estuary sediments, upstream of the Causeway Bridges to Maylands (sites M-P inclusive) in 1988 and 1989.

	1988 (mg/kg)	1989 (mg/kg)	1988-89 (mg/kg)	criteria (mg/kg)
mean	282 (n=5)	326 (n=5)	304 (n=10)	n/a
median	310	330	NA	n/a
range	200-340	130-530	130-530	350 max
%> criteria	0	40	NA	n/a

n/a means not applicable; NA means not available

(a)



(b)

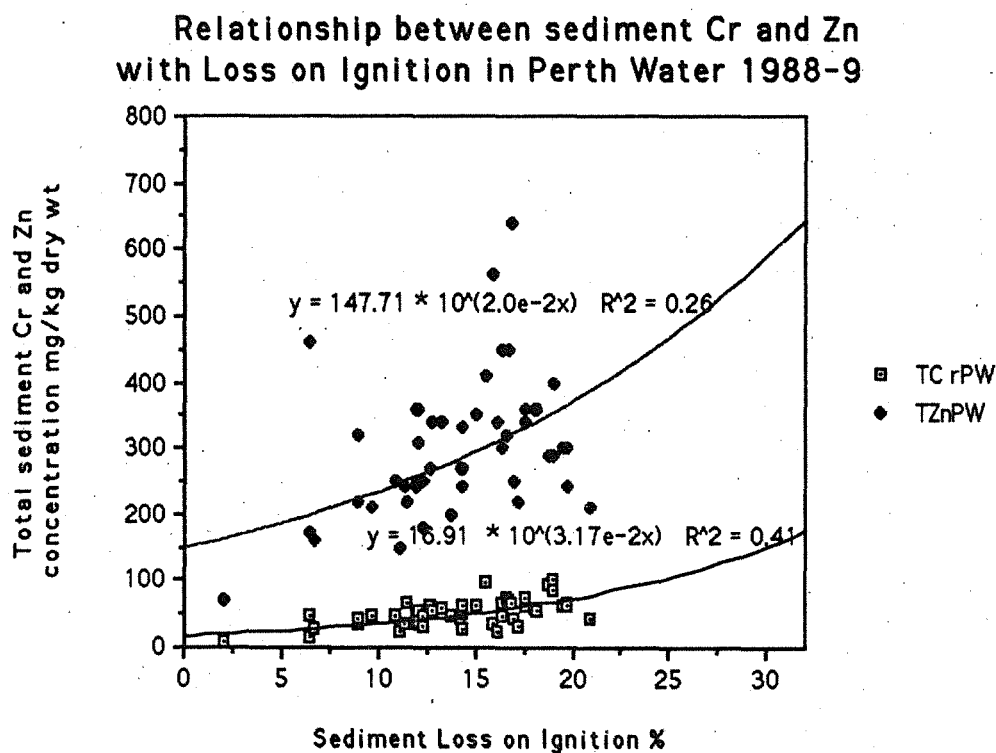


Figure 4.16 Relationship between sediment total chromium and zinc with Loss On Ignition in Melville and Perth Water.

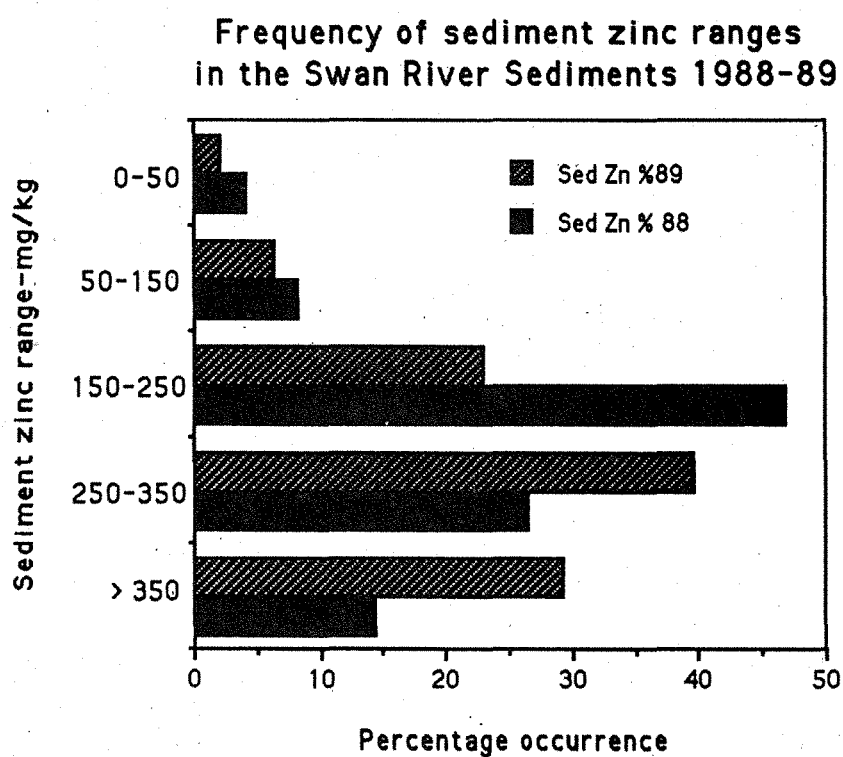
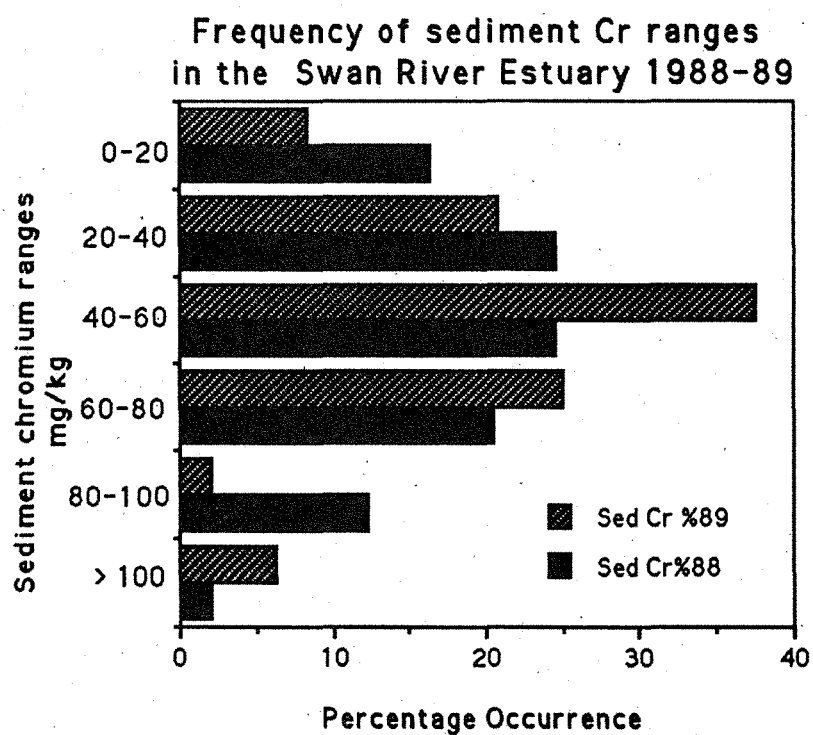


Figure 4.17 Frequency of sediment chromium and zinc ranges in the Swan River estuary.

4.3.3.4 Upstream of the Bunbury Bridge - (Sites Q and R)

Some of the lower sediment zinc concentrations that were recorded were in the Maylands area upstream of the Bunbury rail bridge in both 1988 and 1989, at 210 and 160mg/kg respectively (Figures 15a & 15.b).

4.3.3.5 Control sites - (Sites SR16, SR9, SR 5 and Canning River SR23A) - Zinc

Table 4.24

Sediment zinc concentrations from Swan/Canning estuary control sites in 1988-89.

Site	1988 (mg/kg)	1989 (mg/kg)	Soil criterion (mg/kg)
SR16	230	140	350
SRQ1	210	160	350
SR9/SRR1	260	NA	350
SR5	45	200	350
SR23A	210	230	350

NA means not available

The lowest sediment zinc concentration of control sites was in the Swan River at Guildford (SR5) in 1988. Other control sites had zinc ranges of between 140-260mg/kg. These were below the upper limits suggested in Australian Guidelines for management of contaminated soils above which investigations should be initiated. (ANZEC & NH& MRC, 1990).

4.3.3.6 Sediments adjacent to CBD drains

Table 4.25

Chromium concentrations of sediments adjacent to drain outfalls in 1988-1989.

The only sediment to reach the contaminated soil criterion for chromium was adjacent to the Bennett Street Main Drain in Perth Waters (Table 4.25). Most sediments adjacent to drains increased in chromium concentrations in the period between the 1988 and 1989 sampling occasions.

Drain	1988 (mg/kg)	1989 (mg/kg)
MBMD	54-81	54-56
VAMD	19	56
HSMD	10	22
BSMD	13	100
PSMD	12-19	60-75
CMD	23	18
criterion for soils	100	100

Table 4.26

Zinc concentrations of sediments adjacent to drain outfalls in 1988-1989.

Drain	1988 (mg/kg)	1989 (mg/kg)
MBMD	200-840	350-360
VAMD	200	310
HSMD	38	120
BSMD	53	420
PSMD	160-190	400-530
CMD	630	170
criteria for soils	350	350

In both 1988 and 1989, the lowest zinc concentration was in the sediments adjacent to CBD drain outlets at the Hill Street Main Drain. The contaminated criteria for zinc concentration in soils was exceeded adjacent to the Mounts Bay Main Drain outlet (840mg/kg) and that of the Claisebrook Main Drain (630mg/kg) in 1988. Sediment zinc concentrations adjacent to the MBMD and the PSMD both exceeded the criteria for soils of 350mg/kg in 1989.

The sediment adjacent to drain outfalls had lower mean chromium and zinc to LOI ratios in 1989. This could have been due an unseasonal rainstorm which occurred between the 1988 and 1989 sediment surveys. This may have altered the distribution of fines and organic sediments adjacent to the drain outlets.

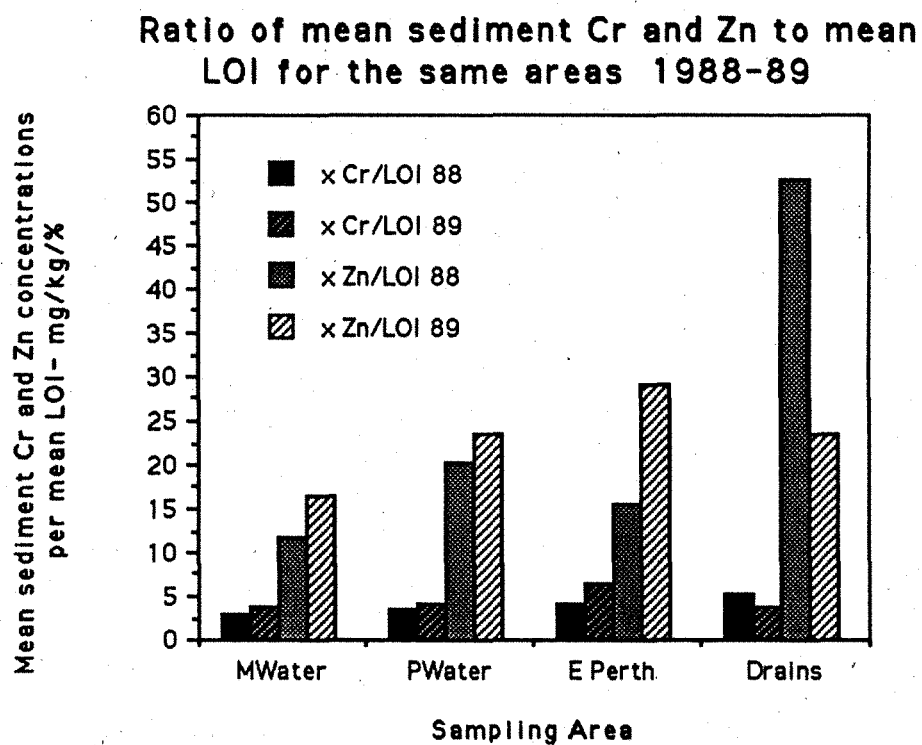


Figure 4.18

Ratio of mean sediment chromium and zinc to mean Loss On Ignition.



Figure 4.19a
Relationship between the chromium content
of sediment adjacent to drains and the Loss on Ignition

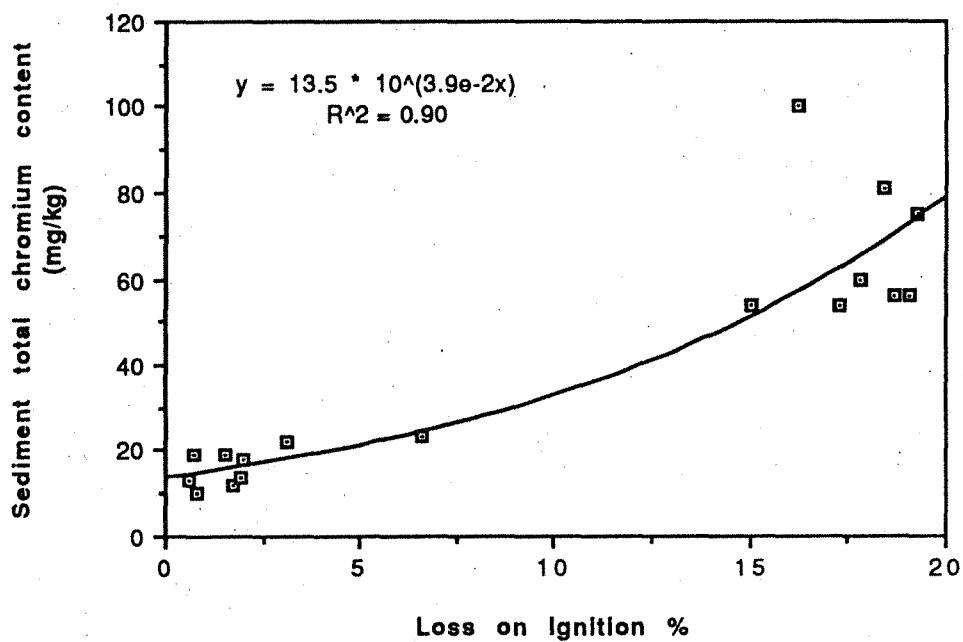


Figure 4.19b
Relationship between the zinc content
of sediment adjacent to drains and the Loss on Ignition

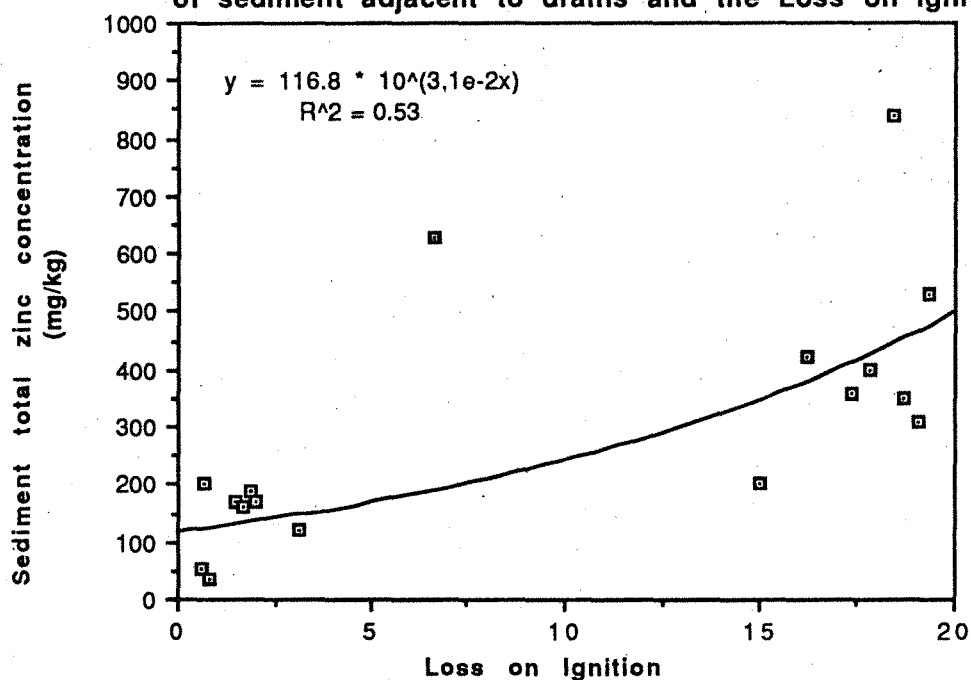


Figure 4.19 Relationship between total chromium and zinc and Loss On Ignition.

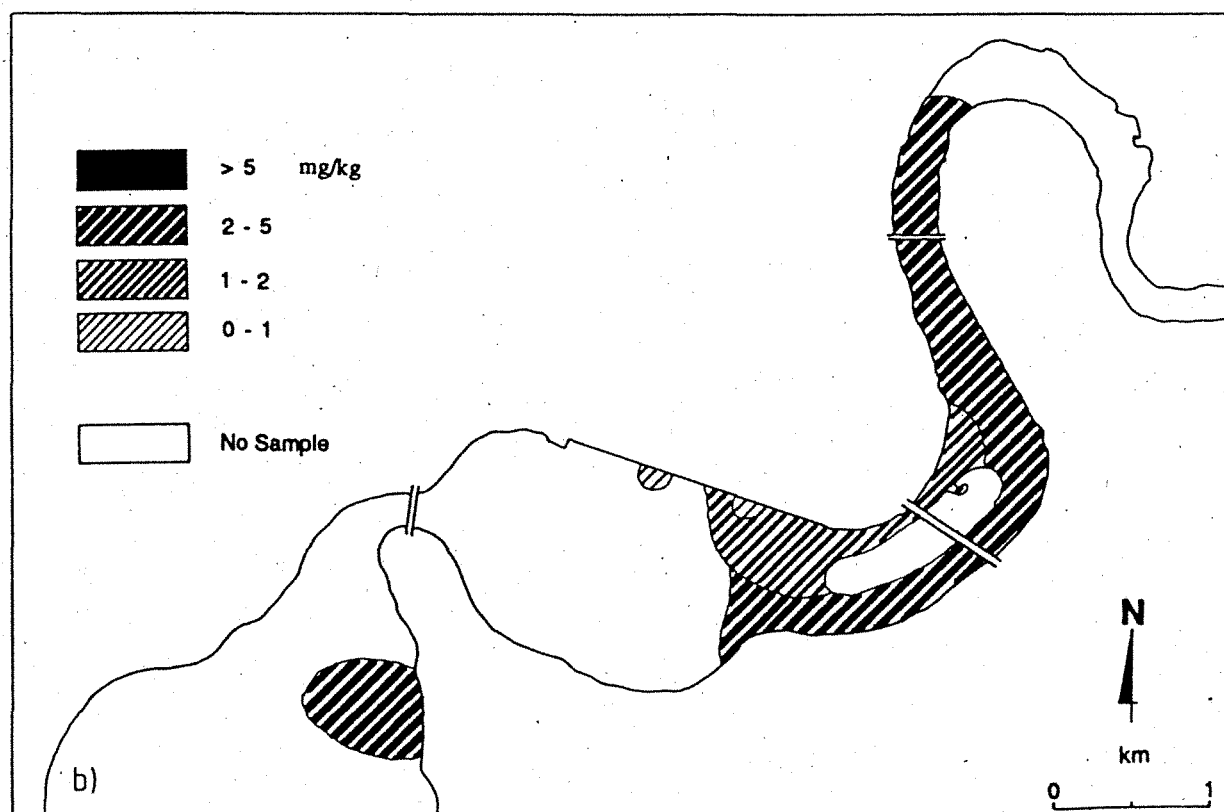
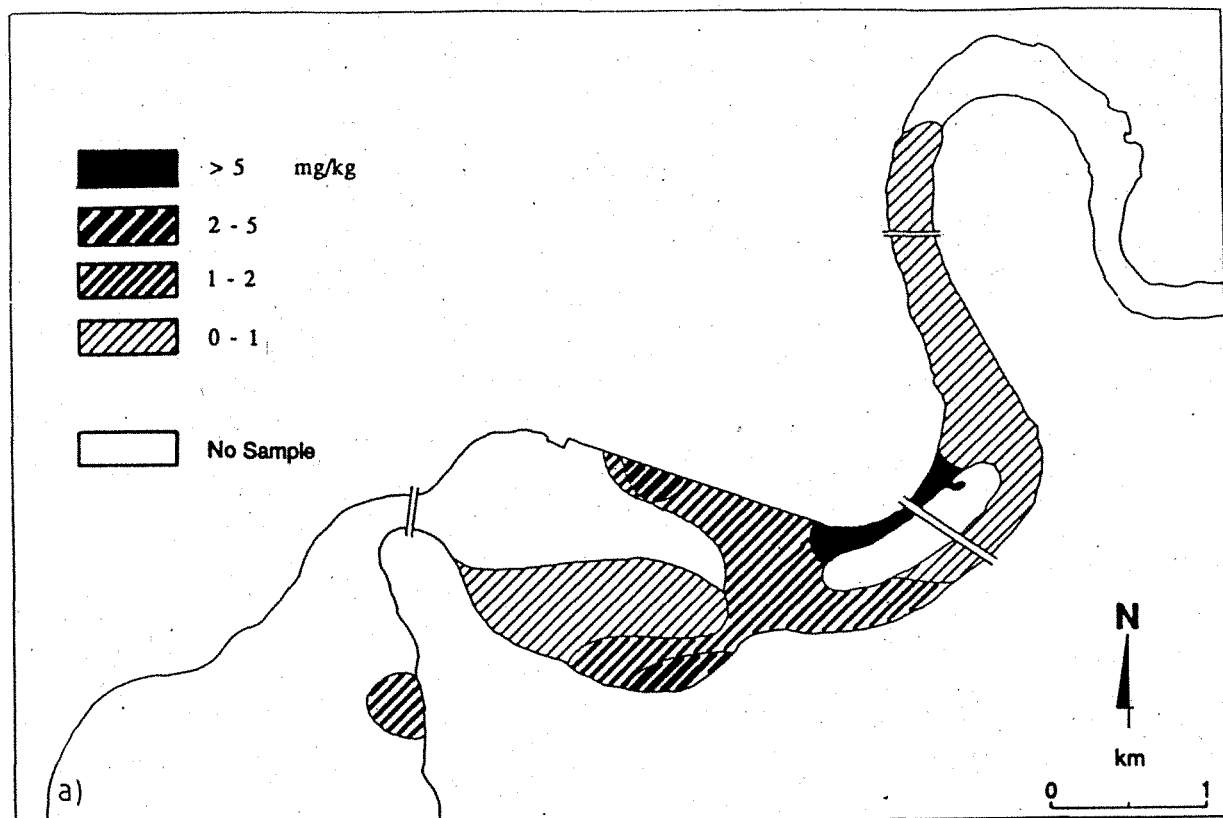


Figure 4.20 Concentration ranges of chromium in Swan River estuary red algae *Gracilaria*
a) November 1988 b) March-April 1989

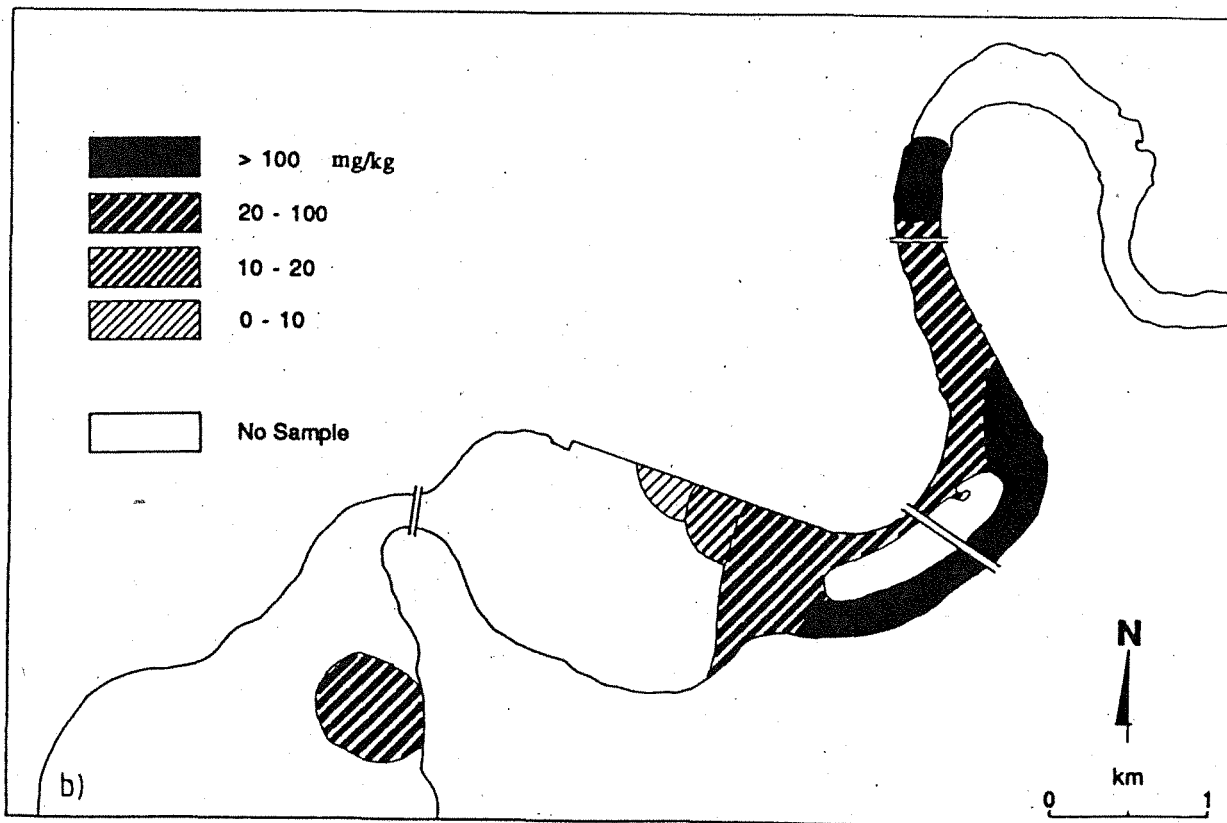
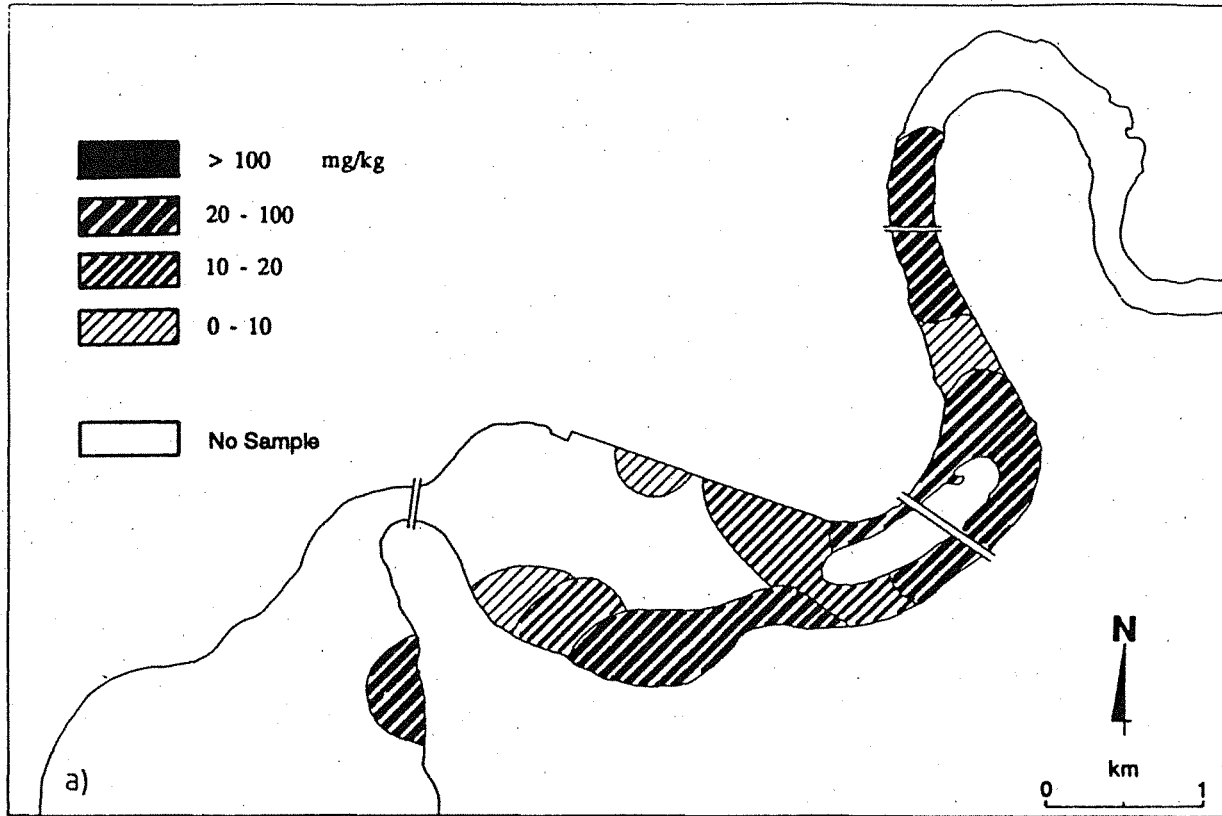


Figure 4.21 Concentration ranges of zinc in Swan River estuary red algae *Gracilaria*

a) November 1988

b) March-April 1989

4.4 Plants and Animals

Immediately adjacent to the Mounts Bay Main Drain outfall benthic plants and animals were relatively scarce.

4.4.1 Metal concentrations in macroalgae

The species of red algae *Gracilaria* was found in both loose-lying and attached habit. It was the most abundant macroalgal species of alga present in the study area. The unattached algal clumps could be transported over large distances in the shallow and frequently wind-stirred waters which complicated an assessment of metal distribution in algae for different sites.

4.4.1.1 Chromium concentrations in *Gracilaria*

In 1988 the chromium concentrations in *Gracilaria* was highest (5.3mg/kg), in algae to the west of Heirisson Island, adjacent to the Plain Street Main Drain. Other high chromium concentrations were found south in the Coode Street area (Figure 4.20a).

By 1989 the area of *Gracilaria* in the 2-5mg/kg concentration range exceeded that of 1988 (Figures 4.20a & 4.20b). In 1989, tissue chromium concentrations in *Gracilaria* growing next to the Kwinana Freeway increased.

The 1989 *Gracilaria* mean chromium concentrations were almost double those of 1988.

Table 4.27

The mean wet weight chromium concentrations and ranges in *Gracilaria* from the Swan Estuary in November-December 1988 and March-April 1989.

In 1989 the mean concentrations of chromium in the red alga *Gracilaria* were greater than the 1988 means for Melville Water, Perth Waters and upstream of the Causeway. The 1989 values for *Gracilaria* in the Canning River and at the Middle Swan Bridge site, were similar to those of the sites upstream of the Causeway in 1988.

Location	1988 (mg/kg)	1989 (mg/kg)
Melville Water	104 n=1	3.65 n=1
Perth Water	1.28 (0.3-5.3) n=12	2.02 (1.3-3.0) n=5
upstream Causeway	0.5 (0.2-0.8) n=3	2.28 (1.0-3.0) n=4
Mt Henry-Canning estuary	NA	0.5 n=1
Middle Swan Bridge	NA	0.5 n=1

concentration ranges in (brackets) NA means not available

(a) Melville Water

Gracilaria collected from Melville Water in 1989 contained the highest concentration of chromium at 3.7mg/kg. In 1989 *Gracilaria* samples collected from Melville Water were heavily contaminated by the blue-green alga, *Lyngbya* sp, which is known to incorporate iron into its sheath layers. This may have influenced the chromium content of the Melville Water *Gracilaria* sample if *Lyngbya* had a similar affinity for chromium.

(b) Perth Water

In Perth Water the highest alga chromium concentration at an individual site was 5.3mg/kg at site SRK1 in 1988. The mean concentration of chromium in *Gracilaria* almost doubled the 1988 mean to 2.0mg/kg by 1989.

(c) Upstream of the Causeway

Gracilaria from upstream of the Causeway bridges at East Perth had a mean concentration of 0.5mg/kg. in 1988 and 2.3mg/kg by 1989.

(d) Control samples

In the areas selected as control sites at Middle Swan bridge site and at Mt Henry in the Canning River estuary, *Gracilaria* samples contained background concentrations of chromium (0.5mg/kg) in April 1989.

(e) Drains

Table 4.28

Concentrations of chromium in *Gracilaria* growing adjacent to drains (wet weight basis).

Drain (MD)	198 (mg/kg)
Victoria Avenue	4.1
Bennett Street	1.3
Plain Street	1.3
Claisebrook	0.3

In November 1988, the highest chromium concentration in *Gracilaria* adjacent to CBD drain outfalls was in algae growing adjacent to the Victoria Avenue Main Drain outfall.

(f) Comparison species of alga

Table 4.29

A comparison of the chromium concentrations of *Gracilaria* from the Victoria Avenue Main Drain in 1988 with other species of algae from the same outfall in 1989 (wet weight).

RHODOPHYTES	Chromium (mg/kg)
<i>Gracilaria</i> (1988)	4.1
<i>Hypnea</i>	2.5
<i>Grateloupea</i>	0.3
CHLOROPHYTES	Chromium (mg/kg)
<i>Ulva</i>	1.6

In the vicinity of the Victoria Avenue main drain in 1989, *Grateloupea* had the lowest chromium concentration. At the same site the other red alga *Hypnea* contained a higher concentration of tissue chromium.

The other species from the VAMD had lower concentrations of chromium in 1989 than *Gracilaria* from the same site in 1988.

(g) Sea Grasses

Potamogeton from the mouth of the Claisebrook Main Drain had a zinc concentration of 13mg/kg in the above-ground portion in 1988.

4.4.1.2 *Gracilaria* - zinc concentrations

In 1989, the number of sites in the Swan River containing *Gracilaria* with tissue zinc greater than 100mg/kg was greater than in 1988. (Figures 4.15 a & b).

The mean 1989 zinc concentration in *Gracilaria* from the Swan River estuary, showed slight to significant increases over the 1988 values.

Table 4.30

The mean concentration of zinc in *Gracilaria* from the Swan River estuary in November-December 1988 and March-April 1989 (weight basis).

Grid sites	1988 (mg/kg)	1989 (mg/kg)
Melville Water	34 n=1	40 n=1
Perth Water	30.8 (9.1-83) n=12	70.4 (17-210) n=5
Upstream Causeway	26.2 (6.6-47) n=3	115.3 (43-180) n=4
Control sites		
Mt Henry-Canning Estuary	NA	17 (n=1)
Middle Swan Bridge	NA	15 (n=1)

NA means not available

(a) Melville Water

The tissue zinc concentration of *Gracilaria* in Melville Water in 1989 was slightly higher than that found in the 1988 survey.

(b) Perth Water

In 1989, the mean concentration of zinc in *Gracilaria* collected from Perth Water, was double the mean 1988 value. In 1988 the Perth Water *Gracilaria* tissue zinc concentration ranged between 9.1 and 83mg/kg. In 1989 the tissue zinc range was 17-210mg/kg.

(c) Upstream of the Causeway

The mean zinc concentration of *Gracilaria* upstream of the Causeway was the highest recorded at 115.25mg/kg in 1989, which was 400 % higher than the 1988 mean.

(d) Controls

In 1989, concentrations of zinc in *Gracilaria* at in the Swan and Canning Estuary control sites, were the lowest of all sites measured. The zinc concentrations in *Gracilaria* tissue at the river-body control sites, were half the mean concentrations found in Melville Water and less than 14 % that of the algae in Perth Water.

(e) Drains

Table 4.31

Concentrations of zinc in *Gracilaria* growing adjacent to drains (wet weight basis).

Main Drain (MD)	1988 (mg/kg)
Victoria Avenue	44
Bennett Street	11
Plain Street	12
Claisebrook	13

Gracilaria growing adjacent to the Victoria Avenue Main Drain had the greatest wet weight concentration of zinc. This was also the drain with the highest water zinc concentration.

(f) Other Species of Alga

Table 4.32

Comparison of zinc concentrations in various algae growing adjacent to the Victoria Avenue Main Drain outfall (wet weight).

Rhodophytes	Chromium (mg/kg)
<i>Hypnea</i>	12
<i>Grateloupea</i>	4.9

Chlorophytes	Chromium (mg/kg)
<i>Ulva</i>	6.7

Grateloupea in the vicinity of the Victoria Avenue main drain had the lowest zinc concentrations in 1989. The other rhodophyte *Hypnea*, had the greatest concentration of chromium from the same location. The chlorophyte *Ulva* had a low zinc concentration (Table 4.35).

The ratio of chromium-to-zinc concentrations in *Gracilaria* tissue from the Swan River estuary better correlated in 1988 than in 1989 (Figure 4.22). In 1989 the zinc concentrations in *Gracilaria* from the eastern portion of the estuary were much higher and therefore less well correlated. *Gracilaria* appeared to take up differing ratios of chromium and zinc over the summer period, especially at sites SRK2, SRM2 and SRP1.

(g) Seagrasses

The ephemeral freshwater aquatic macrophyte *Potamogeton* sp. growing in the freshwater plume adjacent to the mouth of the Claisebrook Main Drain had a chromium concentration of 0.3mg/kg and a zinc concentration of 13mg/kg in the above ground portion in 1988. This freshwater species was not found in the river in the summer 1989 because it is intolerant of the

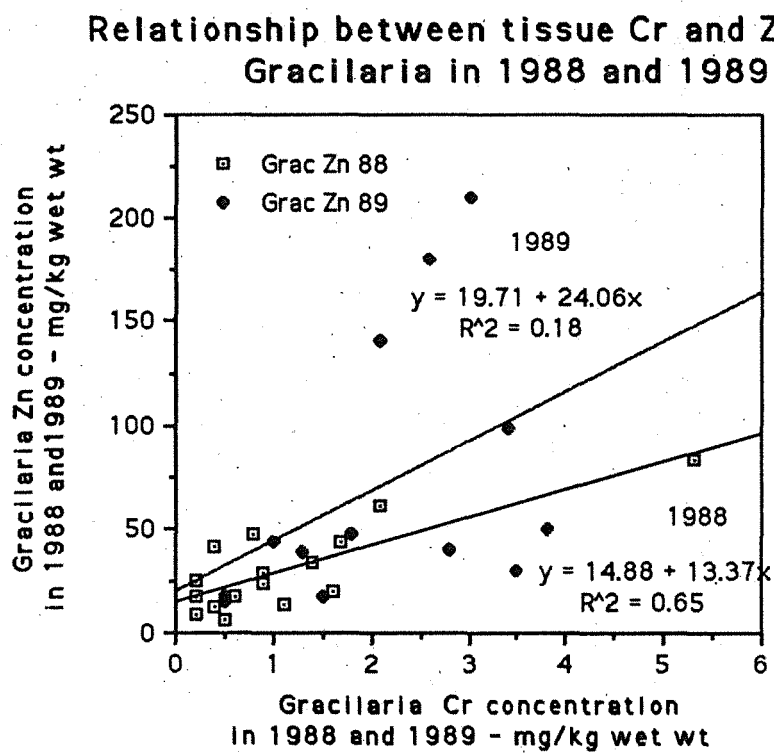


Figure 4.22

Relationship between tissue chromium and zinc in *Gracilaria*

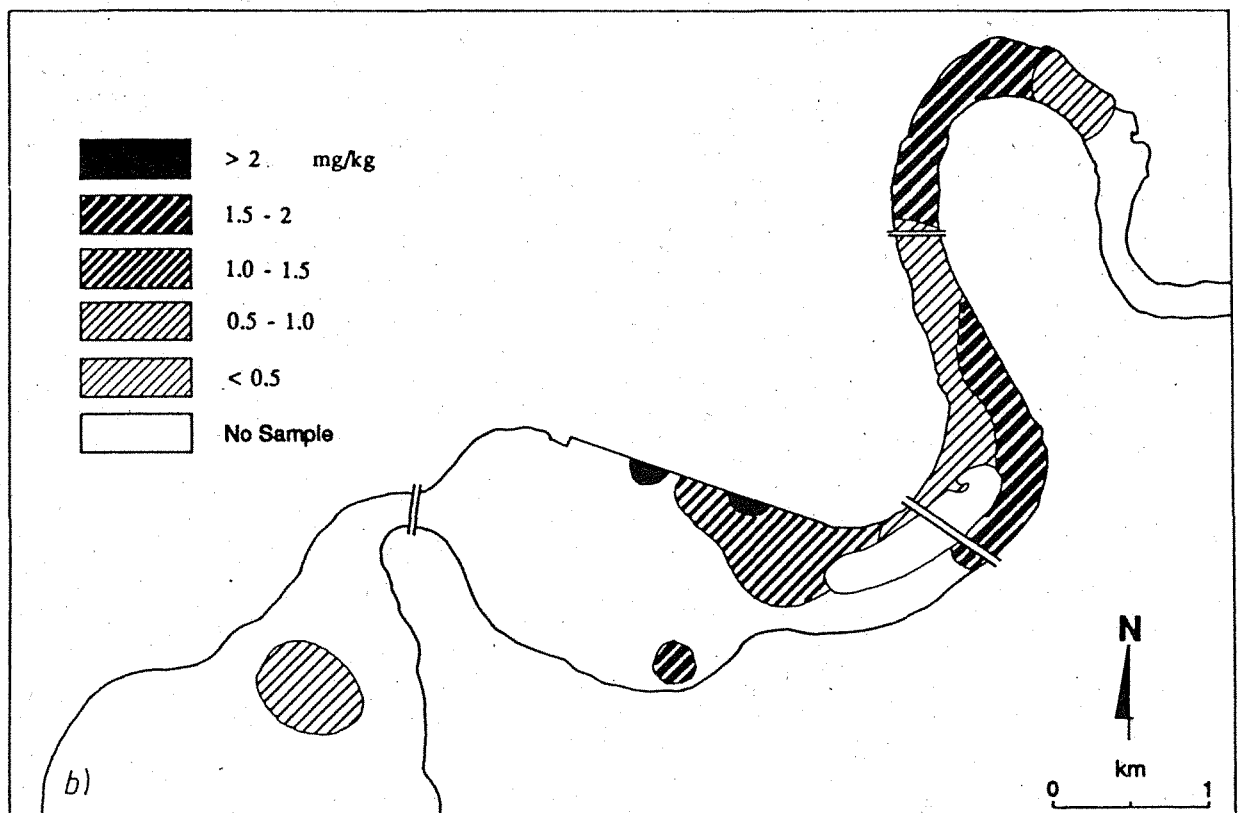
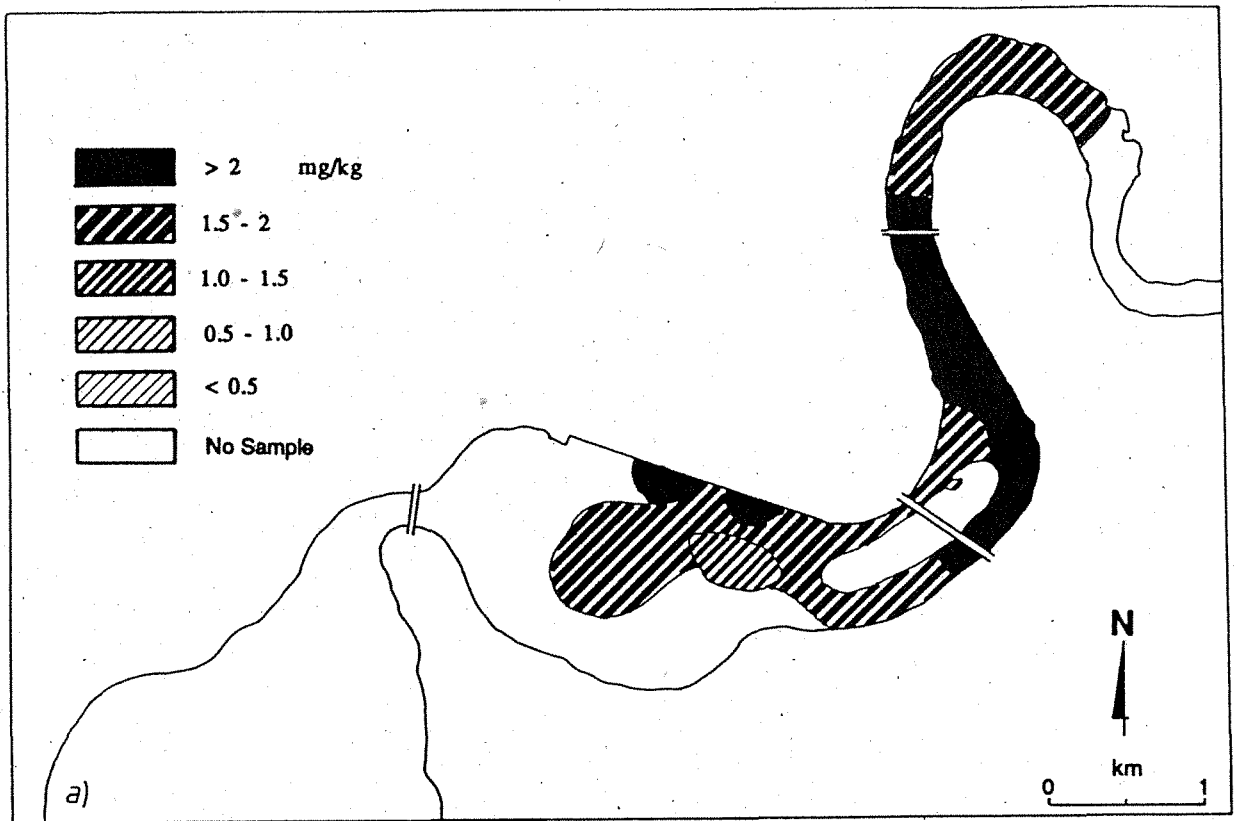


Figure 4.23 Concentration ranges of chromium in Swan River estuary mussels *Xenostrobus*

a) November 1988

b) March-April 1989

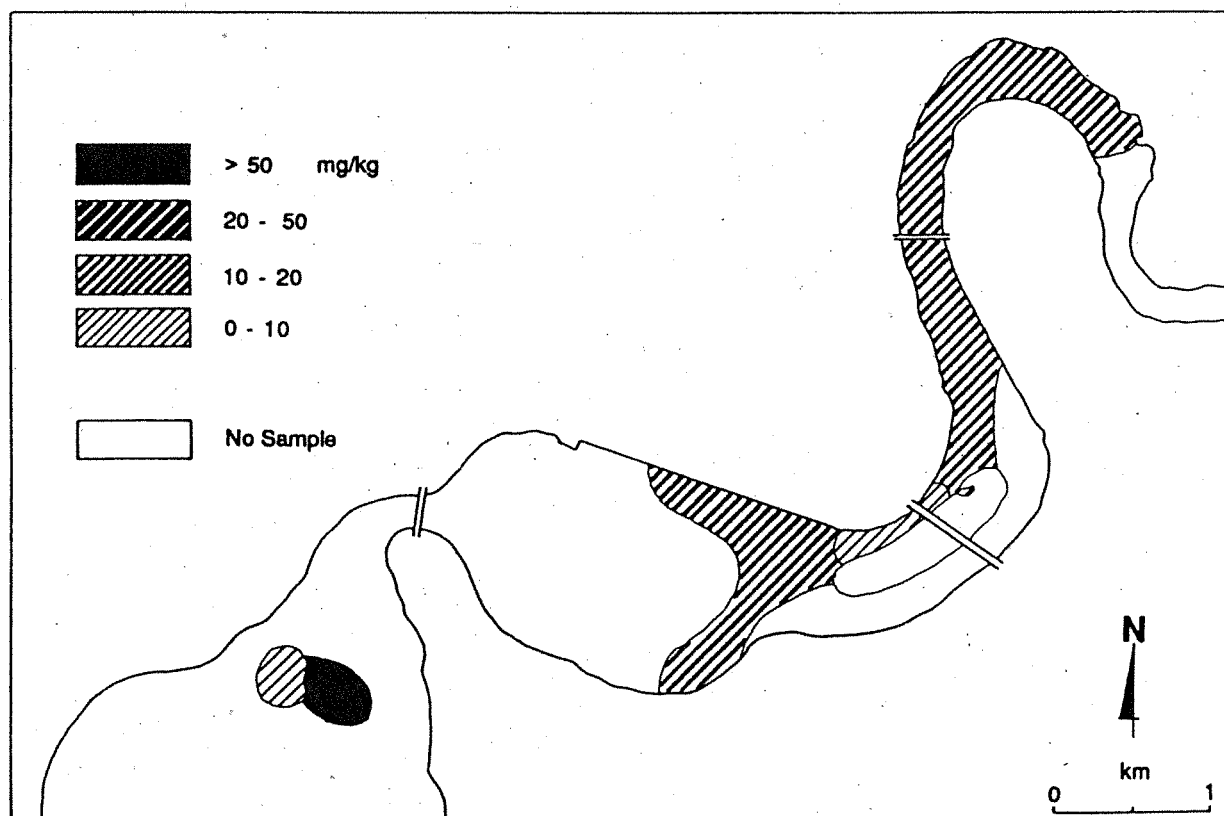
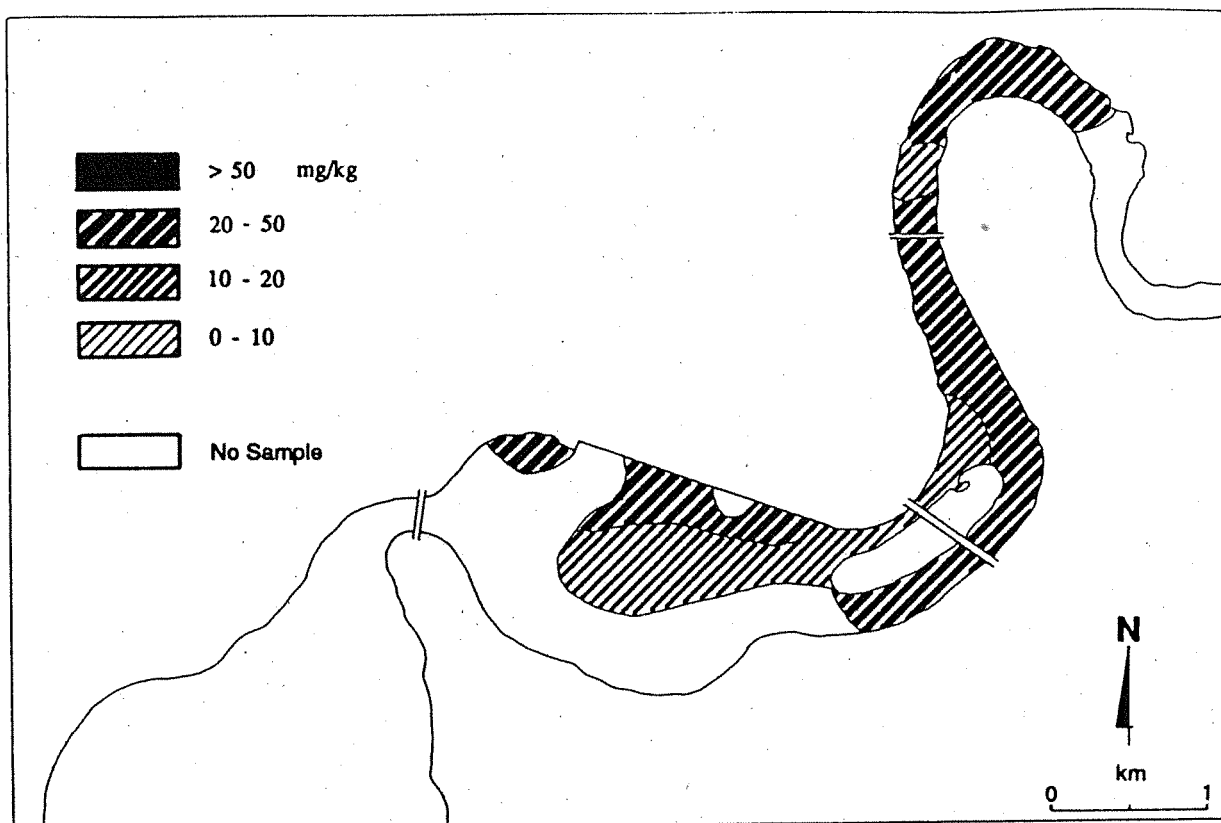


Figure 4.24 Concentration ranges of zinc in Swan River estuary mussels *Xenostrobus*

a) November 1988

b) March-April 1989

4.4.2 Metal concentrations in bivalves and gastropods

The mussel *Xenostrobus securis* and the white bivalve *Spisula trigonella*, were the most abundant and common of the bivalve molluscs sampled. A few estuarine gastropods *Bedeva paivae* and *Velacumantis australis* were also sampled and analysed.

4.4.2.1 Mussels *Xenostrobus* — chromium

Table 4.33

Means and ranges of chromium concentrations in the tissue of the mussel *Xenostrobus securis* from the Swan River estuary in 1988 and 1989 (wet weight basis).

Water-body site	mean & range 89 (mg/kg)	mean & range (mg/kg)
Melville Water	NA	0.4 (<0.5-0.5) n=2
Perth Water	1.34 (0.5-2.6) n=16	0.85 (<0.5-1.9) n=6
upstream Causeway	2.3 (1.1-4.7) n=4	0.7 (<0.5-1.2) n=4
Maylands	1.0 n=1	0.3 n=1

NA means not available

Generally, mean trace metal concentrations in the estuarine mussel *Xenostrobus securis* were higher in the 1988 sampling period than was found in 1989. This might be attributed to factors such as the differences in sex ratio, reproductive and growth stages of the species at the time of sampling.

(a) Melville Water

No samples of *Xenostrobus securis* were collected from Melville Water grid sites in the 1988 survey. In 1989 chromium concentrations in Melville Water mussels were low (Figure 4.23b). The mean chromium concentration in mussels from Melville Water sites was the lowest for any of the waterbody mussels.

(b) Perth Water

Most of the mussel chromium concentrations in Perth Waters were in the 1-2mg/kg range (Figures 4.23a & 4.23b). The highest chromium concentrations were in the mussels growing along the northern (CBD) boundary of Perth Waters. In 1988 the highest individual chromium value in Perth Water (excluding drain associated) mussels, was 2.6mg/kg at site SRH1 and 2.2mg/kg at site SRL2 at the eastern end of the Causeway bridges (Figure 4.23a).

The highest chromium value in Perth Water mussels in 1989 was 1.9mg/kg at site SRI4 at the southern side.

(c) Upstream of the Causeway-East Perth Water

In 1988 most of the mussels growing in the East Perth area of the Swan River estuary contained in excess of 2mg/kg of tissue chromium on a wet weight basis (Figure 4.23a). The mean chromium concentration in *Xenostrobus securis* sampled upstream of the Causeway bridges was 2.3mg/kg in 1988 and 0.7mg/kg in 1989. In 1988 the highest individual chromium level was 4.7mg/kg at site SRO1, just upstream of the Claisebrook Main Drain outlet.

(d) Upstream of the Bunbury Rail Bridge-Maylands control sites

Mussels growing at site SRQ1 upstream of the Bunbury rail bridge had tissue chromium concentrations at 1.0mg/kg in 1988 and <0.5mg/kg in 1989. These were similar to the values obtained in the same species of mussels both upstream and downstream of the Bayswater Main Drain (Atkins et al; 1990).

(e) Drains

Table 4.34

Chromium concentrations in the tissue of the mussel *Xenostrobus securis* growing next to the outfalls of CBD drains (wet weight basis).

Main Drain	1988 (mg/kg)	1989 (mg/kg)
Bennett St	5.3	3.9
Plain St	4.0	1.1
Victoria Ave	17.0	13.0
Claisebrook	NA	0.4

NA means not available

In 1988 and 1989 the highest concentration of chromium in *Xenostrobus* mussels, adjacent to drains, was at the outfall of the Victoria Avenue Main Drain (Table 4.34). Mussels growing adjacent to the Victoria Avenue Main Drain had chromium concentrations exceeding those growing in the the main water body sites.

The maximum chromium concentration in *Xenostrobus* mussels from the Victoria Avenue Main Drain in this survey was lower than maximum levels found by Hosja in 1987, and Schulz and Hosja in 1988.

There is no Western Australian health limit set for chromium concentrations in mussels.

4.4.2.2 Mussels *Xenostrobus securis* - zinc

In 1988 the zinc concentrations of *Xenostrobus securis* mussels were higher than in 1989 (Figures 4.26a & 4.26b).

Table 4.35

Means and ranges of zinc concentrations in the tissue of the mussel *Xenostrobus securis* from the Swan River estuary in 1988 and 1989 (wet weight basis).

Water-body	mean & range 1988 (mg/kg)	mean & range 1989 (mg/kg)
Melville Water	NA	41.0 (10-72 n=2)
Perth Water	21.4 (12-49) n=16	11.6 (8.8-13.0) n=6
u/s Causeway East Perth waters	28.0 (14-45) n=4	10.9 (12-17) n=4
Maylands	40.0 n=1	13.0 n=1

NA means not available

Mean and maximum zinc concentrations in the flesh of *X securis* from the Swan River estuary sites were generally higher in 1988 than in 1989.

(a) Melville Water

In 1989 mean zinc concentrations of Melville Water mussels was 41mg/kg. The highest zinc concentration for the mussels at any individual site was 72mg/kg at site SRD6, adjacent to the Kwinana Freeway in Melville Water which was also the highest individual tissue zinc value recorded in this survey.

(b) Perth Water

Mussels growing near to the CBD and east of the Causeway in 1988, had the highest zinc concentrations (Figure 4.17 a). In 1989 zinc ranges were low adjacent to the CBD (Figure 4.17b). The highest concentration of mussel zinc for Perth Water sites in 1988-89 survey was 49mg/kg at site SRK2.

(c) Upstream of the Causeway

Most of the mussels sampled between the Causeway bridges and the Bunbury rail bridge were within the 20-50mg/kg zinc concentration range in 1988 and less at 10-20mg/kg in 1989 (Figures 4.24a & 4.24b). The mean concentration of zinc in *Xenostrobus* upstream of the Causeway bridges, was 25.8mg/kg in 1988 and 13mg/kg in 1989. The highest individual result was at site SRO1 just upstream of the Claisebrook Main Drain, being 45mg/kg in 1988.

(d) Mussels upstream of the Bunbury rail bridge - Maylands area-zinc

(e) Drains

Table 4.36

Zinc concentrations in the mussel *Xenostrobus securis* growing next to the outfalls of CBD drains.-(wet weight basis).

Main Drain	1988 (mg/kg)	1989 (mg/kg)
Bennett St	13	16
Plain St	23	14
Victoria Ave	31	15
Claisebrook	n/a	12

Generally, the zinc concentrations in mussels growing adjacent to Main Drain outfalls were lower in 1989 than in 1988. Mussels growing adjacent to the Victoria Avenue Main Drain, had the highest zinc concentrations in 1988 but this value however, was lower than mussel samples from three Perth

Water grid sites (SRK2, SRO1 and SRQ1).

The 1988 zinc concentration in mussels growing at the VAMD drain outfall exceeded previous values found in *X. securis* from the same drain (Blackmore;1985, Hosja;1987, Schulz and Hosja; 1988). The levels of zinc in the mussels found growing next to the outfalls of CBD drains were well below the health limits (Maximum permitted Concentration-MPC) of 1000mg/kg. These mussels are not known to be consumed by humans.

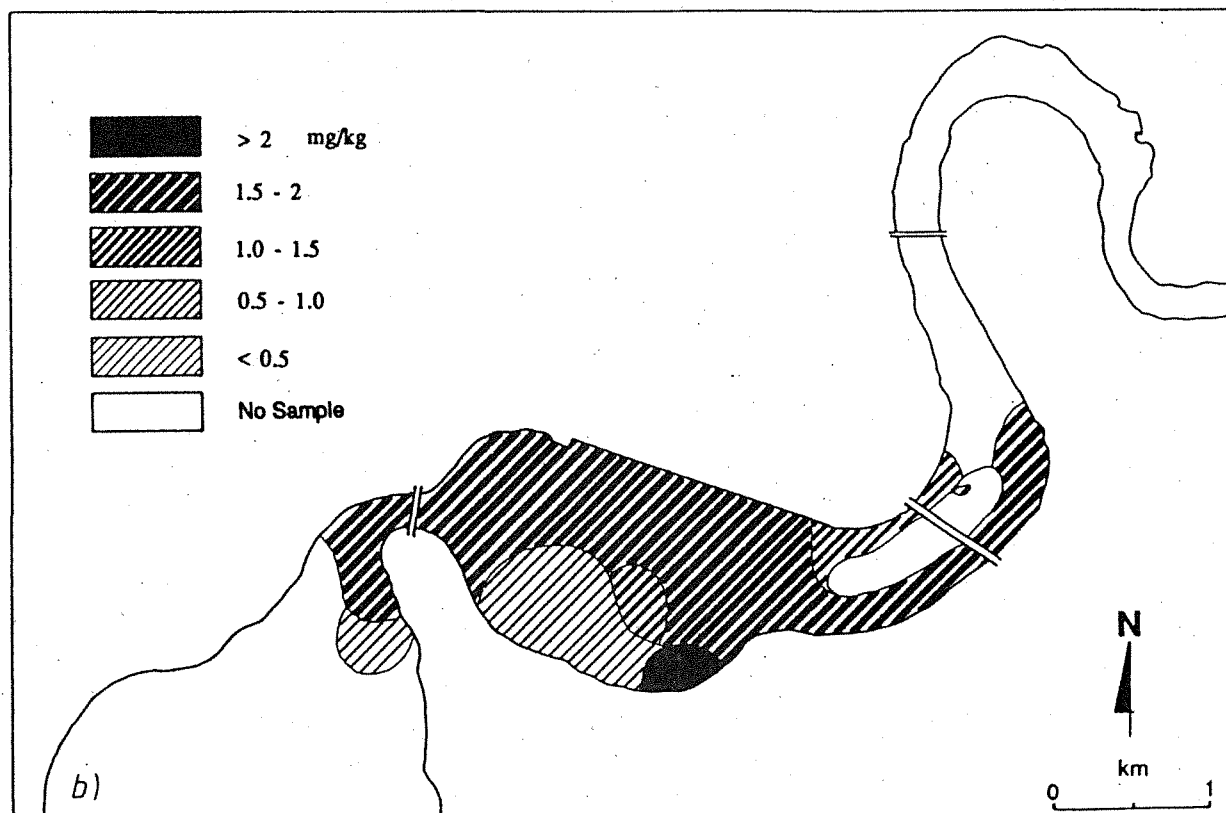
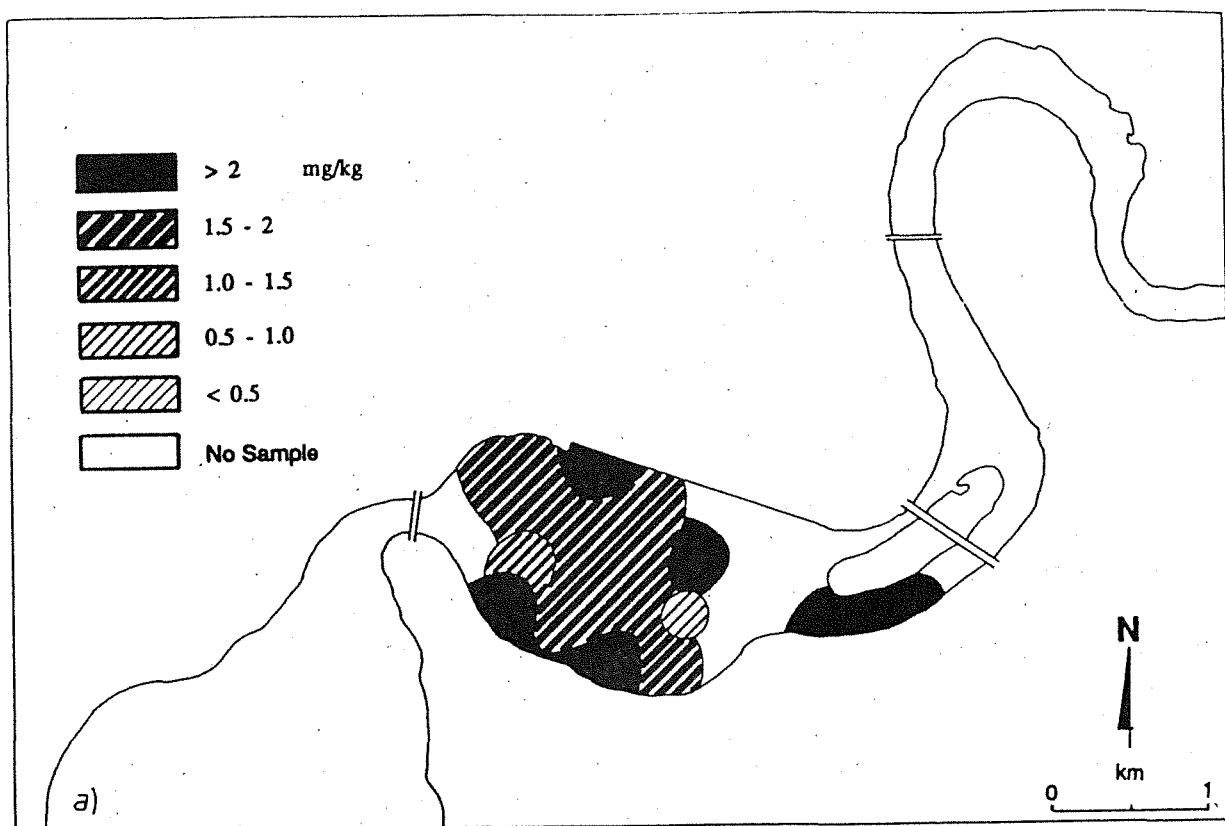


Figure 4.25 Concentration ranges of chromium in Swan River estuary bivalves *Spisula*

a) November 1988

b) March-April 1989

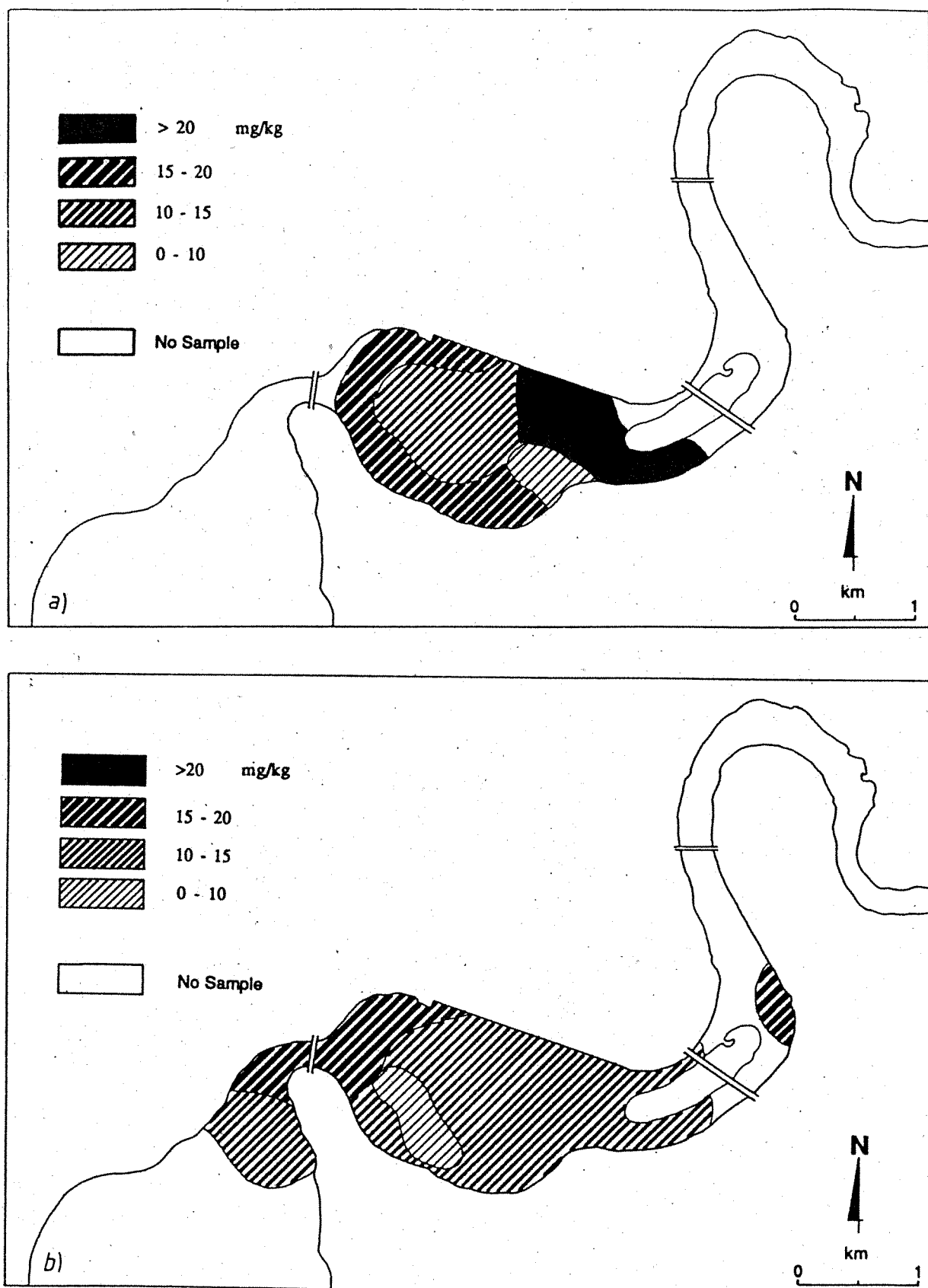


Figure 4.26 Concentration ranges of Zinc in Swan River estuary bivalves *Spisula*
a) November 1988 b) March-April 1989

4.4.2.3 Bivalves - *Spisula trigonella*

The benthic white bivalve *Spisula trigonella* was more abundant in the deeper, siltier parts of Perth Water than was the mussel *Xenostrobus securis*.

(a) Melville Water - *Spisula* - Chromium

The chromium concentration in the white bivalve *Spisula* in Melville Water in 1989 was highest in animals living near to the Narrows Bridge (Figure 4.25b).

(b) Perth Water - *Spisula* - chromium

In 1988 the chromium concentration in the white bivalve *Spisula* was greater than 2mg/kg in five of the sampled areas (Figure 4.25a). By 1989, most of the *Spisula* tissue chromium concentrations were less than 2mg/kg (Figure 4.25b).

Table 4.37

Mean concentrations of chromium in the flesh of the bivalve *Spisula trigonella* along profiles numbered 1 to 4 in Perth Water in November-December 1988 and March-April 1989 (wet weight).

Profile number	Nov-Dec 1988 (mg/kg)	Mar-Apr 1989 (mg/kg)
1	1.9	1.31
2	2.25	1.5
3	0.97	1.06
4	2.08	0.75

Chromium concentrations in *Spisula* from Perth Water in 1988 showed no obvious trends in distribution (Table, Fig 4.18 a). In 1989 however the higher chromium concentrations in *Spisula* were nearer to the CBD area, except for a single high tissue concentration from this bivalve at the Coode Street Jetty area (Figure 4.25b).

(c) Upstream of the Causeway East Perth - *Spisula* - chromium

Insufficient *Spisula* samples were collected from the area upstream of the Causeway bridges to form sufficient sample biomass for analysis.

4.4.2.4 Bivalve - *Spisula* - Zinc

Generally the greater concentrations of zinc in *Spisula* tissue was in 1988 (Figures 4.26a & 4.26b).

(a) Melville Water *Spisula* - zinc

The zinc concentrations in the white bivalve *Spisula* in 1989 were greatest near to the Narrows Bridge, (Figure 4.19b).

(b) Perth Water *Spisula* - zinc

The highest zinc concentration in *Spisula* in 1988, was at the eastern end of Perth Water (Figure 4.26a). In 1989, the zinc concentrations in *Spisula* from Perth Water had fallen (Figure 4.26b).

Table 4.38

Mean concentrations of zinc in the flesh of the bivalve *Spisula trigonella* along grid profiles numbered 1 to 4 in Perth Water in November-December 1988 and March-April 1989 (wet weight).

Profile number	Nov-Dec 1988 (mg/kg)	Mar-Apr 1989 (mg/kg)
1	15.5	13.9
2	17.3	14.4
3	11.8	13.2
4	16.8	9.6

There was no distinct trend evident in zinc concentrations in *Spisula* tissue with respect to the CBD outfalls in Perth Water (Table 4.38).

4.4.2.5 Relationship between bivalve tissue chromium and zinc

There was a poor correlation between the chromium and zinc uptake for *Xenostrobus* and *Spisula* growing at the same sites (Figures 4.27a & 4.27b). This has important implications when comparing toxicity data from the literature which may not cover a specific local aquatic animal.

There was however, a fairly good correlation between the tissue chromium-to-zinc ratios in both *Xenostrobus* and *Spisula* growing in the same location. Both species appear to take up the metals in the same proportions but at differing rates (Figure 4.28).

(a) Gastropods *Bedeve* and *Velacumantis* - chromium and zinc

The estuarine gastropod *Bedeve paivae* was sampled in Melville water in 1988 and 1989, while *Velacumantis australis* was sampled in 1988 only.

Table 4.39

Mean concentrations of chromium and zinc in the flesh of the gastropods *Bedeve* in 1988 and 1989 and *Velacumantis* in 1988 (wet weight).

species	Chromium (mg/kg)	Zinc (mg/kg)
<i>Bedeve</i> (1988)	0.7	85
<i>Bedeve</i> (1989)	0.2	63
<i>Velacumantis</i> (1988)	0.7	39

Relationship between zinc concentrations in *Spisula* and *Xenostrobus* growing at the same sites and at the same time 1988-89

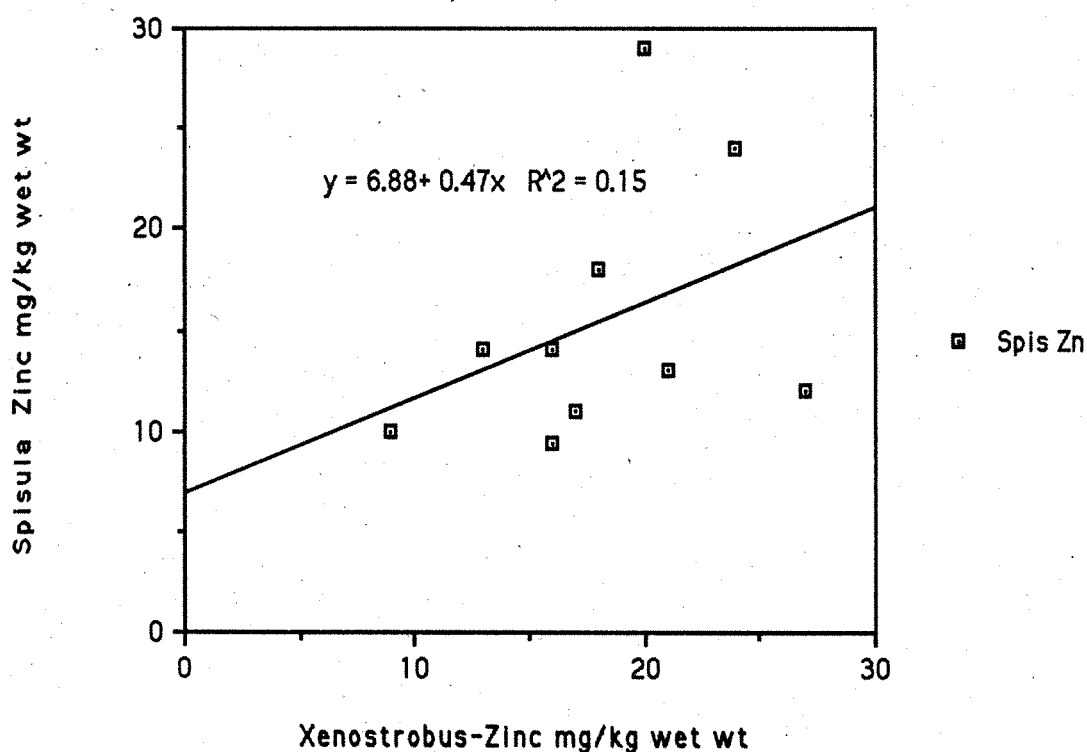


Figure 4.27 Relationship between tissue zinc in *Spisula* and *Xenostrobus*.

Relationship between chromium in *Spisula* and *Xenostrobus* growing in the same sites at the same time 1988-89

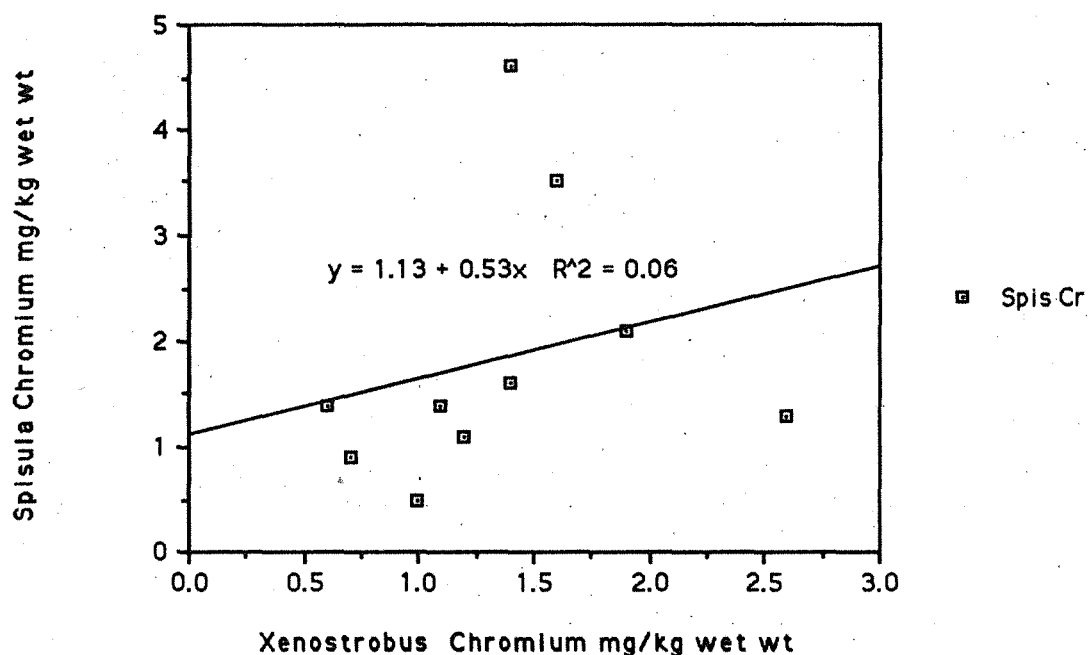


Figure 4.27 Relationship between tissue chromium in *Spisula* and *Xenostrobus*.

Relationship between Chromium and Zinc in *Xenostrobus* and *Spisula* tissue growing at the same locations in 1988-89

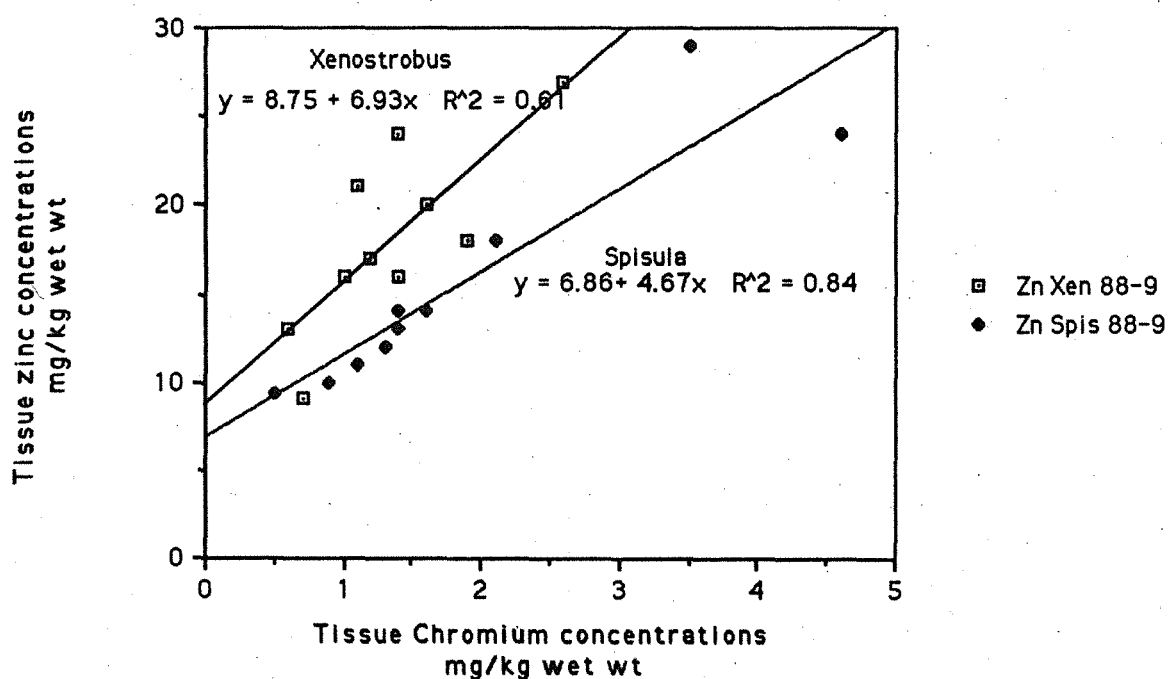


Figure 4.28 Relationship between tissue chromium and zinc in *Spisula* and *Xenostrobus*.

4.4.3 Metal concentrations in Crustacea

The common estuarine shrimp *Palaemonetes australis* remains in the same area over a large range of salinities. The presence of school and king prawns and the Blue manna crabs is more seasonal upstream of Melville Water.

4.4.3.1 Estuarine Shrimp- *Palaemonetes australis*

Table 4.40

Chromium and zinc concentrations (wet weight basis) of *Palaemonetes australis* flesh from the Swan River estuary in 1989 (wet wt).

Site	Chromium (mg/kg)	Zinc (mg/kg)
Perth Water	<0.1	28
Middle Swan	0.2	21
BridgeCanning Estuary	0.2	25
MPC	nl	150

nl indicates not limit.; MPC means Maximum Permissible Concentration.

The concentrations of chromium and zinc in the small estuarine shrimp *Palaemonetes australis* in 1989 were similar in both control and the Perth Water sites (Table 4.40)

(a) Chromium

In April 1988, the concentration of chromium in the flesh of the shrimp *Palaemonetes australis* from site SRJ3 in Perth Water was similar to concentrations in the control shrimp samples. This chromium concentration was also less than values of shrimp from the Swan River estuary at Bayswater (Atkins et al., 1990).

(b) Zinc

Zinc levels in the shrimp *P. australis* in April 1989 were highest in at site SRJ3 in Perth Water (28mg/kg). These values are less than those recorded from the same species at the outfall of the Bayswater Main Drain in 1990 (Atkins et al., 1990). The levels of zinc in the tissue of *P. australis* were well below the Maximum Permitted Concentration of 150mg/kg.

4.4.3.2 Crab - *Portunus pelagicus*

A flesh sample of the blue swimmer crab *Portunus pelagicus* from the vicinity of the Mounts Bay Main Drain contained 0.1mg/kg of chromium and 34mg/kg of zinc on a wet weight basis.

The chromium value of *P. pelagicus* from the vicinity of the CBD was lower than values found in the same species of crab from the Cockburn Sound Study (Chegwidden, 1979). The zinc concentration in Perth Water crab was above the highest value found in Jervoise Bay (Chegwidden, 1979). None of the crab tissue zinc concentrations posed a health threat.

4.4.3.3 Prawns - *Penaeus* - metals

One king prawn (*Penaeus latisulcatus*) sample, fortuitously taken from fish sample area 2 in Perth water in March 1989, contained less than 0.1mg/kg of chromium and 15mg/kg of zinc.

The level of chromium and zinc in the king prawn flesh was below health criteria. A single sample has only limited value as the prawn migrates in and out of the estuary.

4.4.5 Metal concentrations in fish

In 1988 fish were collected from two areas of the Swan River estuary and from all three areas in 1989. Both table and non-table species were collected for analysis.

4.4.5.1 Chromium - Flesh

Unlike benthic bivalves, there was no correlation between the chromium and zinc concentrations in fish flesh.

(a) Table species of fish

The highest concentration of chromium in flesh of edible species was 0.3mg/kg in cobbler from the vicinity of the Victoria Avenue M.D (fish area 2) in 1989. All chromium concentrations in the flesh from edible fish were low.

The levels of chromium in edible fish flesh from this survey were similar to values from the Cockburn Sound Study (Chegwidden, 1979) and The Swan Avon Estuarine Study (Marks, et. al., 1980). Table fish from this survey had lower chromium concentrations than fish from the polluted Iruja River (Pfeiffer et. al., 1982).

Table 4.41

Means and ranges of chromium concentration in the edible fish species caught from the Swan River estuary adjacent to the CBD in 1988 and 1989 (wet weight basis).

Fish type	1988 (mg/kg)	1989 (mg/kg)
Cobbler	<0.1	0.2 (0.1-0.3)
six line trumpeter	0.1	0.1
sea mullet	n/a	<0.1
trumpeter whiting	n/a	0.1
black bream	0.1	NA
tailor	NA	0.1
yellow tail	NA	0.1
MPC	nl	nl

NA means not available. nl means no limit

(b) Chromium in non-table flesh

The flesh of fish not normally consumed by humans contained slightly more chromium than the edible species with both blowfish and one sample of Perth herring at 0.5mg/kg (wet basis). In 1989 the flesh of Ogilby's hardyhead contained <0.1mg/kg of chromium.

Table 4.42

Mean concentration of chromium (wet weight basis) from the flesh of blowfish, Perth herring and Ogilby's hardy head from the Swan Estuary adjacent to the Perth CBD in 1988 and 1989.

Fish type	1988 (mg/kg)	1989 (mg/kg)
blowfish	n/a	0.3 (0.1-0.5)
Perth herring	0.1	0.3 (<0.1-0.5)
Ogilby's hardyhead	NA	<0.1
MPC	NA	NA

NA means not available

The levels of chromium in fish muscle from a variety of both table species of fish and fish which were normally not consumed by humans, were similar.

4.4.5.2 Zinc-Flesh

(a) Table species of fish-flesh.

Table 4.43

Mean concentration of zinc in the edible species cobbler, six line trumpeter, sea mullet, tailor, trumpeter whiting, and yellow tail from the Swan River estuary in 1988 and 1989 (wet wt).

Fish type	1988 (mg/kg)	1989 (mg/kg)
Cobbler	22.1 (5.2-55)	5.0 (0.3-7.6)
six line trumpeter	11.0	15.6 (7.8-20.0)
sea mullet	NA	11.5 (3.0-20.0)
trumpeter whiting	NA	15.0 (12.0-18.0)
black bream	7.0	NA
tailor	NA	20.0
yellowtail	NA	3.8
MPC	150	150

NA means not available

The highest concentration of zinc in the flesh of an edible species of fish was 55mg/kg found in a sample of cobbler in November 1988. Cobbler caught in Perth Water in 1988, would have spent most of the previous winter-spring in the marine waters downstream (J Woods pers comm). 1989, cobbler flesh samples had lower zinc concentrations than in 1988.

All zinc concentrations in fish muscle flesh were well below the health limits of 150mg/kg wet weight basis. In 1989 cobbler and yellowtail had the lowest concentration of zinc in their flesh (Table 4.43). Apart from yellowtail and cobbler, 1989 mean zinc concentrations in table flesh were higher than in found in fish from the Bayswater Main Drain study (Atkins et al., 1990). The zinc concentrations were similar to

values found in fish from the the Swan-Avon study of 1978-1979 (Marks, et. al., 1980) and also in the Cockburn Sound Study (Plaskett and Potter, 1979).

(b) Non-table species of fish-flesh

Table 4.44

Mean (and ranges) of zinc concentrations (wet weight basis) from the flesh of blowfish, Perth herring and Ogilby's hardyhead from the Swan Estuary adjacent to the Perth CBD in 1988 and 1989.

Species	1988 (mg/kg)	1989 (mg/kg)
blowfish	NA	7.3 (6.7-8.0)
Perth herring	8.4	10.7 (5.4-16.0)
Ogilby's hardyhead	NA	34
MPC	150	150

MPC means maximum permissible concentration.

The concentration of zinc in the flesh of non-table fish from the Swan River estuary in this study were similar to levels in edible species and therefore would have conformed to health criteria. The levels of zinc in Perth herring was similar in both 1988 and 1989 (Table 4.44).

4.4.5.3 Fish organs

There was no correlation between the chromium and zinc concentrations in fish organs.

(a) Liver

• *Chromium*

The concentration of chromium in the liver of edible fish were low and ranged from 0.1mg/kg in cobbler, 0.3mg/kg in sea mullet to 0.4mg/kg in yellowtail.

in the livers of non-edible species of fish chromium concentrations were highest in Perth herring, in 1988 (4.9mg/kg) and in 1989 (4.5mg/kg). All other fish livers contained chromium concentrations of less than 7mg/kg on a wet weight basis.

• *Zinc*

Table 4.45

Zinc concentrations (wet weight basis) in livers of fish from the Swan River estuary adjacent to the CBD in March and April 1989.

Non-edible Fish type	zinc (mg/kg)
blowfish	23
cobbler	30
Perth herring	31
mullet-sea	150
six-line trumpeter	43
yellowtail	14
MPC	150

MPC means maximum permissible concentration

The zinc concentration in the livers of fish were variable. The highest concentration was 150mg/kg in sea mullet from fish caught adjacent to the Claisebrook Main Drain at East Perth in 1989. The concentration of zinc in the livers of cobbler from all three sample areas adjacent to the CBD were similar in 1989.

(b) Viscera

• *Viscera-chromium*

In 1988, the viscera of Perth herring from Perth Water contained 3.1mg/kg of chromium on a wet weight basis. This was the highest concentration for chromium of any fish viscera in the survey.

In 1989 the concentrations of chromium in fish viscera were all lower than that in Perth herring in 1988, which was the highest concentration recorded for any of the fish viscera in the 1988-89 survey.

Table 4.46

Mean chromium concentrations (wet weight basis) in viscera of fish from the Swan River estuary adjacent to the CBD in March and April 1989.

Fish type	Chromium (mg/kg)
Cobbler	0.2
six line trumpeter	0.7
trumpeter whiting	0.8
sea mullet	2.3
Ogilby's hardyhead	0.6

• Viscera-zinc

The zinc concentration in Perth herring viscera from Perth Water in 1988 was 26mg/kg on a wet weight basis.

Table 4.47

Mean zinc concentrations (wet weight basis) in viscera of fish from the Swan River estuary adjacent to the CBD in March and April 1989.

Fish type	Zinc (mg/kg)
Cobbler	23
Ogilby's hardyhead	23
sea mullet	35
six line trumpeter	16
trumpeter whiting	13

Sea mullet viscera had the highest concentrations of zinc during the 1988-89 survey (Table 4.47). The lowest concentrations were in trumpeter whiting and six-line trumpeter viscera.

(c) Gonads

Generally the gonads contained the highest chromium and zinc concentrations of any fish parts analysed.

• Gonads-chromium

The male blowfish and the female yellowtail gonads had the highest chromium concentrations in 1989 (Table 4.48). The male gonads from blowfish had higher chromium levels than the female gonads of the same species. The reverse applied to Perth herring.

Table 4.48

Mean chromium concentrations (wet weight basis) in the gonads of fish from the Swan Estuary adjacent to the CBD in March and April 1989.

Fish type	Male mg/kg	Female mg/kg
Cobbler	0.1	<0.1
six line trumpeter	NA	0.3
blowfish	2.1	<0.1
Perth herring	0.9	1.4
Yellowtail	0.3	NA

NA means not available

• Gonads-zinc

Table 4.49

Mean zinc concentrations (wet weight basis) in the gonads of fish from the Swan Estuary adjacent to the CBD in March and April 1989.

Fish type	Male mg/kg	Female mg/kg
Cobbler	11	22
six line trumpeter	NA	250
blowfish	76	37
Perth herring	66	890
Yellowtail	210	NA

The female gonads of six-line trumpeter and Perth herring contained very high levels of zinc, as did the male gonads of yellowtail (Table 4.49). As for chromium the zinc concentrations in male blowfish were higher than concentrations of the female blowfish. Cobbler gonads contained the lowest zinc and chromium concentrations.

• Comparison of all portions

Generally the liver, viscera and gonads of fish contained higher concentrations of chromium than the muscle flesh.

Table 4.50

Comparison between the mean chromium concentration within adult fish species from the Swan-River estuary in 1988-89 (wet weight basis).

Fish spp	Flesh	Liver	Visc- era	male gonad	female gonad
Cobbler 1988	0.04	0.2	NA	0.1	0.04
Cobbler 1989	0.2	0.11	0.15	NA	NA
Perth herring 1988	0.1	3.0	3.1	0.85	NA
Perth herring 1989	0.27	3.75	NA	NA	1.4
Mullet sea	0.04	0.3	2.25	NA	NA
6-line trump- eter 1988	0.1	0.04	NA	NA	NA
6-line trump- eter 1989	0.11	NA	1.2	NA	0.3

NA means not available

Table 4.51

Comparison between the mean zinc concentration (mg/kg) within adult fish species from the Swan River estuary in 1988 to 1989 (wet weight basis).

Fish spp	Flesh	Liver	Viscera	male gonad	female gonad
Cobbler 1988	22.1	15	NA	11	22
Cobbler 1989	5.6	29.3	23	NA	NA
Perth herring 1988	8.4	29.5	26	66	NA
Perth herring 1989	10.7	30.9	NA	NA	890
Mullet	11.5	150	34.5	NA	NA
6-line trum- peter 1988	11	24	NA	NA	NA
6-line trum- peter 1989	15.9	NA	16	NA	250

NA means not available

Generally, the liver, viscera and gonads of fish contained higher concentrations of zinc than did the flesh of the same species (Table 4.51).

4.4.5.4 Whole Fish

(a) Chromium

Table 4.52

Mean chromium concentrations in the whole fish and whole fish minus head and viscera in small and juvenile fish between 1988 and 1989 (wet weight).

Fish type	Year	whole fish (mg/kg)	whole fish minus head and viscera (mg/kg)
gobbleguts	1988	NA	0.1
gobbleguts	1989	0.04	NA
goby	1988	0.1	NA
goby	1989	0.55	NA
hardyhead	1989	NA	0.04
mullet yellow-eye	1989	0.04	NA
Ogilby's hardyhead	1989	0.7	0.04
Perth herring	1989	NA	0.17
six-line trumpeter	1989	NA	0.1
tailor	1989	NA	0.1
white bait	1989	0.04	NA

NA means not available

Hardyhead species with the head and viscera removed contained lower concentrations of chromium than whole intact fish (Table 4.52). In 1989 whole gobies contained higher concentrations of chromium than in 1988 samples. In 1989, whole Ogilby's hardyheads contained the highest chromium concentrations.

(b) Zinc

Hardyhead species with the head and viscera removed contained lower concentrations of zinc than whole intact fish (Table 4.53). In 1989, whole gobies contained higher concentrations of zinc than in 1988. In 1989 whole hardyheads contained the highest concentrations of zinc.

Table 4.53

Zinc concentrations in whole and whole minus head and viscera in the small and juvenile fish between 1988 and 1989 (wet weight basis)

Fish	Year	whole fish (mg/kg)	whole fish minus head and viscera (mg/kg)
gobbleguts	1988	NA	19
gobbleguts	1989	13	NA
goby	1988	26.5	NA
goby	1989	33.5	NA
hardyheads	1989	55.5	39
mullet sea	1989	NA	11
mullet yelloweye	1989	15	NA
Ogilby's hardyhead	1989	42	24
Perth herring	1989	NA	15.5
six-line trumpeter	1989	NA	25
tailor	1989	NA	10
white bait	1989	27	NA

NA means not available

4.4.5.5 Comparison between adult and small fish of the same species

(a) Chromium

The adult flesh of Perth herring contained higher concentrations than juvenile fish of the same species minus the head and viscera (Table 4.54). In all other fish species sampled, both the adult and juvenile, had similar chromium concentrations.

Table 4.54

A comparison between chromium concentration (wet weight) in small fish (minus the head and viscera) with adult fish flesh of the same species in 1989.

Fish spp	adult fish flesh (mg/kg)	juvenile minus head and viscera (mg/kg)
tailor	0.1	0.1
Perth herring 1989	0.27	0.17
sea mullet	0.04	0.04
6-line trumpeter 1989	0.11	0.10

(b) Zinc

Table 4.55

Comparison between zinc concentration (wet weight) in juvenile fish (minus the head and viscera) with adult fish flesh of the same species in 1989.

Fish species	adult fish flesh (mg/kg)	juvenile minus head and viscera (mg/kg)
tailor	20	10.0
Perth herring 1989	10.7	15.5
Mullet sea	11.5	9.9
6-line trumpeter 1989	15.9	25

Small Perth herring, and six-line trumpeter (minus head and viscera), contained higher concentrations of zinc than adult fish of the same species (Table 4.55). Adult tailor had higher zinc concentrations than juvenile tailor.

4.4.5.6 *Scyphomedusae* - jellyfish

Table 4.56

A comparison between mean chromium and zinc concentrations in the various parts of the jellyfish *Phyllorhiza punctata* in 1989 (wet weight).

Portion	Chromium concentration (mg/kg)	Zinc concentration (mg/kg)
Mouthparts	0.04	15
Medusae	0.07	1.1
Tentacles	0.15	6.9

The medusae of *Phyllorhiza* contained the lowest zinc concentrations. The highest concentration of zinc in jellyfish parts was found in the mouthparts. This was followed by the zinc content of the tentacles. The equivalent values of chromium and zinc in the tissue of jellyfish would be expected to be much higher than fish on a dry weight basis due to the high water content.

There have been proposals for the commercial harvesting of jellyfish from the Swan River estuary as a food export.

5. Discussion

Swimming, skiing and boating (power, sail and rowing) are important popular recreational activities in the Swan River estuary. Both amateur and professional fishermen utilise the waters of the Swan River estuary in and adjacent to Perth Water for catching edible fish, crabs and prawns. The small estuarine shrimp *Palaemonetes australis* is utilised as bait by some fishermen. The large edible mussels *Mytilus edulis* occurs in the lower estuary and is not usually found in Perth Waters. This area is found to contain the smaller *Xenostrobus securis* and the introduced bag-mussel species *Musculista senhousia*, neither of which is eaten by the public.

Result comparisons between different analysts reporting data from the same area, and from widely separate geographic locations are difficult in the light of analytical and experimental variability (Gilmore and Kay, 1979).

In the absence of large quantities of edible species of mussels, bivalves and shrimp in the study area, available edible health standards were applied to fish and all animals sampled in this survey.

5.1 Waters

The application of Estuarine Environmental Water Quality Criteria for the protection of aquatic organisms tends not to be applied to the area immediately adjacent to drain outlets. This area is usually termed the 'mixing zone'. Similarly the criteria are not applied within the drain environment within which aquatic organisms may live and feed.

The concept of beneficial use must be applied to management of drains, streams, waterways and mixing zones and the appropriate mix of conservation areas and public exclusion zones identified and advertised.

5.1.1 Drain outfalls-chromium

The chromium concentrations found during this survey of Perth CBD drain water confirmed the levels found by Taylor in 1980 and Schulz and Hosja in 1988. These data do not confirm either an increase or decrease in drain chromium concentrations since Taylor's survey in 1980.

Some of the higher instantaneous total chromium concentrations in drains exceeded the 4-day LC_{50} concentrations of annelid, mollusc larvae and crustacean zoecae (Mance 1987). The toxicity of chromium to annelids may increase because of a reduced salinity at the drain-estuary mixing zone.

Table 5.1

Comparison of means and ranges of water chromium concentrations in drains and adjacent to outfall areas.

Main Drain	Chromium ($\mu\text{g/L}$)	Authors
Claisebrook	(<1.0-27)	this study
Claisebrook	1-6	Taylor 1980
Claisebrook	10-50	Schulz and Hosja 1988
Claisebrook	<50	WAWA 1990
Claisebrook	<50-50	Hosja 1987
Hill St	240-2 500	Schulz and Hosja 1988
Victoria Ave	27-5 700	Schulz and Hosja 1988
Victoria Ave	410-680	Hosja 1987
William Street (PCC) branch of the MBMD)	71-12 000	Schulz and Hosja 1988

The maximum concentrations of total chromium both in Main Drain waters and within a significant in-estuary mixing zone adjacent to their outfalls, exceeded both the single sample and the six month median concentration criterion of the Water Quality Criteria for Marine and Estuarine Waters, for the harvesting of aquatic animals. These criteria however are not normally applied to drain waters but are used to assess the size and fate of estuarine mixing zones.

The chromium concentrations from individual air conditioner cooling tower waste water can exceed $24,000\mu\text{g/L}$ depending on the chemical treatment used (Holt 1985). Routine maintenance carried out on air conditioner units to remove sludge and contaminant build-up can add to the instantaneous metal concentration of a drain.

As they move closer to the estuary outfalls in summer, these concentrated wastes become progressively diluted, as they mix with ground water, other more dilute wastes, by the movement of tidal estuarine water into the pipes and finally ion entering the river itself. Consequently in any 24 hour period the instantaneous metal levels at the estuarine end of the drain can vary significantly. These variations are more likely to be detected during continuous monitoring as found by Schulz and Hosja in 1987.

Schools of juvenile mullet, are frequently observed swimming against the outflowing plume of these drains for long periods. These are probably feeding on insect larvae, detritus, drift and epifauna within the plume. Small fish feeding in this manner have been observed to have in their gut contents sand, gravel and sticks, which are inadvertently swallowed (Pen, & Hyndes, pers. comm.).

It is likely therefore that these fish will include along with their preferred diets some of the adsorbed metals which exist in high solution concentrations at the drain outfalls. This may partially explain why in 1980 Marks, Plaskett et. al. found that some small fish species (<50 g) such as sea mullet from the Swan River estuary, had higher metal concentrations than the adult fish while Perth herring showed no such relationship with body weight.

These chromium results indicate that the chromium concentrations in drains are within the ranges found in the past 10 years.

The adjacent area within 400 metres of the CBD drain outfalls from the should be excluded for the taking of edible animals and for contact recreation.

Juvenile fish which are observed to feed in and inhabit the area immediately adjacent to drain outfalls should be tested for sub-lethal changes and metal content in long-term exposures.

Realistic concentration criteria should be set for stormwater drains which carry metal contaminants to the Swan River.

Future sampling of the drain outfalls should be carried out on an integrated basis.

5.1.2 Drain outfalls-zinc

The concentrations of zinc in the Main Drains in this survey were within the ranges found by Taylor in 1980, the WAWA 1990 and by Schulz and Hosja in 1988. These data do not indicate either a decline or increase in zinc levels in these drains over the past decade.

The concentrations of zinc in the Claisebrook Main Drain in this survey did not exceed the chromium concentration criterion for a single sample, but did exceed the six monthly median concentrations of the Water Quality Criteria for Marine and Estuarine Waters, for the harvesting of aquatic life. The zinc concentration in the upstream outlet of the Mounts Bay Main Drain exceeded the single sample criterion of 200µg/L.

Table 5.2

Comparison of means and ranges of water zinc concentrations in drains and areas adjacent to outfalls.

Main Drain	zinc (µg/L)	Authors
Claisebrook	20-320	WAWA 1990
Claisebrook	58-81	this study
Claisebrook	70-160	Schulz and Hosja 1988
Claisebrook	80-120	Hosja 1987
Claisebrook	140-260	Taylor 1980
Hill St	70-1 200	Schulz and Hosja 1988
Mounts Bay	(14-250)	this study
Mounts Bay	20-100	WAWA 1990
Mounts Bay	60-260	Hosja 1987
Mounts Bay	80-530	Taylor 1980
Victoria Ave	110-680	Schulz and Hosja 1988
Victoria Ave	140-240	Hosja 1987
William Street (PCC - branch of the Mounts Bay MD	72-8 600	Schulz and Hosja

The same process of dilution in both the drains and in their mixing zone in the estuary would apply but the Water Quality Criteria are not normally applied to these areas.

These results indicate that the zinc concentrations in drains are within the ranges found in the past 10 years.

The adjacent area within 400 metres of the CBD drain outfalls from the should be excluded for the taking of edible animals and for contact recreation.

Juvenile fish which are observed to feed in and inhabit the area immediately adjacent to drain outfalls should be tested for sub-lethal changes and metal content in long-term exposures.

Realistic concentration criteria should be set for stormwater drains which carry metal contaminants to the Swan River.

Future sampling of the drain outfalls should be carried out on an integrated basis.

5.1.3 Waterbody- chromium

Table 5.3

Comparison of means and ranges of total chromium concentrations of heavy metals from various areas.

Site	Chromium (µg/L)	Authors
Melville Water 88/89	(<0.5-6.2) 0.79	This study
Perth Water 1988-89	(<0.5-4.5) 0.77*	This study
Upstream of Causeway 1988-89	(<0.5-5.6) 0.81*	This study
Maylands 1988-89	1.0*	Atkins et al. (1990)
Perth Water 9/1979-3/1980	<1.0-1.0	Taylor (1980)
Middle Swan Bridge 9/1979-3/1980	<10.0	Taylor (1980)
Riverton Br 9/1979-3/1980	<10.0	Taylor (1980)
Cockburn Sound 1978	<20.0	Chegwidden (1979)
Murray River 1978-1986	<20.0	Mackay, Hillman & Rolls (1988)
Sea-water (Cranston & Murray)	0.15	cited in Forstner and Wittmann (1979)
Brisbane River	<1.0-23.0	Australian Littoral Society Inc, (1990)
Seawater	0.005-0.8	var, authors cited in Richard, 1991
Seawater	0.1-0.5	Langard in Waldron, 1980
unfiltered ocean water	0.03-0.6	Bruland; cited in Carpenter et. al., 1991
St Lawrence River	0.23-0.68	Campbell and Yeats, (1984)
North Sea open waters	0.4	Mance 1987
Rural rivers	2.4-6.0	Mance 1987
Urban rivers	7.4-11.0	Mance 1987

Polluted waters (Permutter et. al.,)	500-1 400	cited in Richard and Bourg 1991
River Danube	7.2*	in Forstner and
(Quentin and Winkler)	(3-18)	Wittman (1979)
Ruhr (Rhruverband)	25.0* (10-115)	in Forstner and Wittman 1979)
Streams to L Michigan (Robbins et. al.,)	3.0* (0.3-69)	in Forstner and Wittman (1979)

*=denotes mean value concentration

The ranges of chromium for the Swan River estuary water body sites were all less than the Marine and Estuarine Water Quality Criteria for the harvesting of aquatic life, for a single sample (7µg/L).

The means and ranges of chromium concentrations were similar to levels obtained in the Swan River by Taylor (1980) and Atkins et. al., (1990).

The individual Swan River estuary site SRF1 consistently had slightly elevated values apart from the areas adjacent to drain outfalls. Site SRF1 had an average and median of 2.3µg/L of chromium for all surface and bottom samples over three sampling periods (n=6). Based on the limited samples taken, the estuarine site SRF1 exceeded the Marine and Estuarine Water Quality Criteria for a six month median for the harvesting of aquatic life. This high result appeared to be associated with its proximity to the outfall of the Mounts Bay Main Drain located downstream. It also may indicate the large area of influence of that drain. The size of this mixing zone will be influenced by drain and estuarine salinity and wind-mixing conditions. The area of mixing zone is likely to be greatest in calm conditions when estuarine salinities are high and when there is considerable dispersion of buoyant fresh drain plumes.

In March 1989 the mean surface and bottom chromium concentrations in Perth Water were highest along the foreshore nearest to the Perth Central Business District.

The 1988-89 Swan water body mean chromium concentrations were all well below 4-day LC₅₀ ranges for the various stages of development of the 4 main phyla annelids, molluscs, crustaceans and fish. The water body concentrations were also less than the important longer-term (28-day LC₅₀) for annelids. The mean chromium concentrations were less than the means of polluted rivers such as The Danube, Ruhr and streams flowing into Lake Michigan (Table 5.3).

The chromium concentration ranges in the Swan Estuary were typical of rural and urban Rivers and were higher than those found in unpolluted marine waters and also in the fresh and marine waters of the St Lawrence River (Table 5.3).

The mean concentrations of chromium in the Swan River Estuary are lower than those of polluted rivers and streams and of the same order of magnitude of Cockburn Sound.

The ranges are typical of those found in rural and urban Rivers.

The chromium concentrations would have met the median than the MEWQC.

The lower end of estuarine chromium concentration ranges were similar to background seawater data.

5.1.4 Waterbody - zinc

Table 5.4

Comparisons of means and ranges of zinc concentrations in various areas.

Site	zinc (µg/L)	Authors
Melville Water 1988-89	(<5.0-10.0) 5.0*	This study
Perth Water 1988-89	(<5.0-57.0)	This study
Upstream of Causeway 1988-89	(<5.0-17.0)	This study
Maylands 1988-89	(7.0-13.0) 10.0*	This study
Perth Water -9/1979-3/80	<10.0-40	Taylor 1980
Middle Swan Bridge 1979-1980	<10.0-20.0	Taylor 1980
Canning-Riverton Bridge 1979-1980	<10.0-20	Taylor 1980
Cockburn Sound 1978	3-13	Chegwidden 1979
Lake Macquarie (NSW)-1987	1-28	Batley 1987
Murray River (WA) 1978-86	<20-220	Mackay et al. 1988
Derwent Estuary Tas. 1973-74	12-420	Bloom and Ayling 1977

Derwent Estuary Tas 1977 (Tas)	1500	Bloom and Ayling 1977
Macquarie Harbour (Tas.)	1.0-4.0	Carpenter et. al., 1991
Gordon River (Tas.)	0.3	Carpenter et. al., 1991
Bristol Channel (UK) 1975-1980	(19-23)*	From Mance, 1987
polluted Severn Estuary (UK)	(11-22)*	From Mance, 1987
background Sea-water surface Bruland et. al., 1978	0.01	cited in Forstner and Wittman 1979
background Ocean-water - Bruland 1983	0.03-0.6	cited in Carpenter et. al., (1991)
Corio Bay (Vic)	3.9-67	Smith et. al., (1981)
Brisbane River	10-130	Australian Littoral Society Inc, (1990)
Linggi River Basin - polluted	60-5120	Nather Khan and Lim, 1991
coast of Aqaba	35.0	Wabah, 1985
Mediterranean (various authors)	(10.0-38.3)* 1.0-365	cited in Salomons and Forstner, (1984)
Temperate estuaries	2-30	IHD-WHO working group, (1987)
Gulf of Elefsis 1977-78	20.7* (9.3-29.2)*	Scoullos 1981
North Sea open waters	1.0	Mance 1987
Rural rivers	25-26	Mance 1987
Urban rivers	68-69	Mance 1987

=denotes means ; () * =denotes range of means

None of the main waterbody sites exceeded the Marine and Estuarine Water Quality Criteria for either a single sample or the six-month median for zinc.

The maximum zinc concentrations in the Swan River estuary waterbody sites in 1988-89, were highest in the Perth Water area and lowest in Melville Water. The highest mean concentrations were in East Perth Waters (Table 5.4). These were similar to those found in the Swan-Canning estuaries by Taylor in 1980, and also by Atkins et. al. in 1990.

The highest individual waterbody zinc concentration in 1989 was 57µg/L at the bottom of grid site SRG4 in Perth Water. This was only approximately a quarter of the single sample criteria for estuarine beneficial uses of harvesting of seafoods. In Perth Water, as found with chromium the highest mean zinc concentration was associated with those sites located adjacent to the Perth CBD foreshore in March 1989.

Swan River Perth water body zinc concentrations were similar to those of Corio Bay (lined with heavy industries), the Gulf of Elefsis (which receives high loads of dissolved zinc from industrial and sewage sources) and other temperate estuaries (Table 5.4). Melville Water sites had zinc concentration ranges lower than the Brisbane, Murray Rivers and the polluted Linggi River basin. The ranges were similar to Cockburn Sound but higher than in Macquarie Harbour. The mean zinc concentrations were lower than polluted estuaries such as the Derwent River, the Gulf of Elefsis, the Bristol Channel, the Severn Estuary and the Mediterranean Sea (Table 5.4).

The highest estuarine zinc concentration was below the Minimum Effect Concentration of the marine amphipod *Allorchestes compressa*.

None of the main waterbody sites exceeded the Marine and Estuarine Water Quality Criteria for either a single sample or the six-month median for zinc.

The zinc concentrations in the Swan Waters adjacent to and upstream of, the CBD were higher than those downstream.

Downstream zinc concentrations were higher than background ocean water and pristine river water values.

The mean concentrations of zinc in the Swan River Estuary are lower than those of polluted rivers, streams and estuaries but of the same order of magnitude as Cockburn Sound.

The ranges are typical of those found in rural and urban Rivers.

It is unlikely that the estuarine body zinc concentration would adversely affect aquatic organisms. The highest estuarine zinc concentration was below the Minimum Effect Concentration (MEC) for a marine amphipod.

5.2 Sediments

Sediment chromium and zinc concentrations varied substantially throughout the estuary. The concentrations in sediments may be affected by the overlying water's physical-chemical characteristics and the particle size distributions and organic matter content.

There was a demonstrated relationship between undisturbed sediment metal content and Loss on Ignition (organic content).

5.2.1 Sediments-total chromium

Metal loads to the CBD sediment, based on both questionnaire and sampling surveys suggest that the estimated sediment areal loading of chromium is high when compared to areal loading in San Francisco Bay.

The zinc areal loading was lower than that of San Francisco Bay. It is obvious that the expected projected increase in chromium and zinc to the River sediments adjacent to the CBD cannot be permitted to continue unabated.

Table 5.5

Mean concentrations and ranges of chromium in surface sediments (dry weight basis).

Site	chromium (mg/kg)	Authors
Melville Water	47.8* (9.2-74)	This study
Perth Water 1988-89	51.5* (8.2-100)	This study
Upstream of Causeway 1988-89	73.1* (25-150)	This study
Maylands	15.3* (7.5-23)	This study
Control sites-all u/s & d/s	28.4* (7.5-55)	This study
Perth Water 1985	9-200	McConchie 1985
Chidley Point 1980	3.6-71.0	Chegwidden 1980
Swan River at Jane Brook	1.5-3.9	Chegwidden 1980
Cockburn Sound 1979	6.2-68.3	Chegwidden 1979

Princess Royal Harbour	1.3-42.4	Talbot 1983
Derwent Estuary	0.5-258	Bloom and Ayling, 1977
Brisbane River Estuary	63-91	Moss and Bennett, 1991
Brisbane River freshwater - maximum	112	Moss and Bennett, 1991
Rivers North Queensland	43-235	Moss and Bennett, 1991
Illinois River	17	Mathis and Cumings in Mance, 1987
unpolluted sediments	6-5.7	Mathis and Cumings in Mance, 1987
Iraja River	17 536	Pfeiffer, 1982
Humber Estuary	44*	Gameson in Mance, 1987
Rostronguet Estuary (UK)	1 060	From Forstner and Wittmann 1979
Acushnet Estuary (New Bedford Hr)	3 200	From Forstner and Wittman 1979
San Francisco Bay	144-310*	Bradford and Luoma, 1980
Olbia Bay Italy	3-27	Phillips, 1991
S Gilla Lagoon - Sardinia	20-50	Capone et. al., 1983
Baltic Sea	0.5-252	Brugmann, 1981

* denotes means

There is no criteria for metals in estuarine sediments and the following terrestrial soil criteria is used as a guide only.

The upper limits suggested in Australian Guidelines for management of contaminated soils above which further investigations should be initiated (ANZEC NH&MRC, 1990) is 100mg/kg for total chromium.

Estuarine grid site sediment total chromium concentrations were highest in samples taken adjacent to the CBD Main Drain outfalls. This included Perth Water sites and those upstream of the Causeway Bridges at East Perth. There were a

total of 4 estuarine grid site sediment samples which were in excess of the draft chromium soil criteria for contaminated soils. Three sites had around 100mg/kg of chromium in 1989. Two of those were upstream of the Causeway which also had the highest mean sediment chromium concentrations in the estuary.

One was from Perth Water in 1988. No site was so high that it would be required to have treatment if it was a terrestrial soil (third category).

The ranges of sediment chromium in adjacent to the CBD were similar to the Brisbane River Estuary and slightly lower than those found by McConchie in Perth Waters. They were around a third to a half the concentrations in the sediments of the Baltic Sea, some North Queensland rivers, the Derwent Estuary and San Francisco Bay. The maximum chromium concentrations were much lower than the polluted sediments of the Iraja River, the Restronguet and Acushnet Estuaries.

Control sites and Maylands sediments had the lowest survey mean chromium concentrations of 28.4mg/kg and 15.3 mg/kg respectively. These were lower than in the Humber Estuary. The ranges in the control and Maylands sites were similar to Princess Royal Harbour, Olbia Bay (which receives both treated and untreated domestic sewage) and the S Gilla Lagoon which receives waste waters from urban centres and industrial plants. The ranges were higher than in unpolluted sediments and those of the Swan River upstream at Jane Brook (Table 5.5).

Melville Water sediments had similar chromium concentrations to the Marine sediments of Cockburn Sound.

Mean Swan river chromium concentrations were highest in sediments adjacent to the CBD.

**East Perth Water > Perth Water sites
>MelvilleWater > Control sites >
Maylands sites..**

Four Swan River grid site 'hotspots' exceeded the soil criteria of 100 mg/kg of chromium.

The levels of chromium were lower than other moderate to heavily contaminated areas in the Baltic, Tasmania, San Francisco and UK rivers.

There is no indication that chromium levels are falling in the Swan River estuary sediments.

Some Swan River CBD sediments are more heavily polluted with chromium than Cockburn Sound and Princess Royal Harbour.

5.2.2 Sediment adjacent to drains outfalls-chromium

Table 5.6

A comparison between sediment chromium concentrations adjacent to drain outfalls (a dry weight basis).

Main Drain	chromium (mg/kg)	Study
Bayswater	2.4-52	Chegwidden 1980
Bayswater	8.2	Klemm and Deeley 1991
Bennett St	13-100	This study
Claisebrook	17-275	Chegwidden 1980
Claisebrook	18-23	This study
Hill St	10-22	This study
Mounts Bay	54-81	This study
Plain St	12-75	This study
South Belmont	5.3-24	Chegwidden 1980
Victoria Ave	8.3-83.0	Chegwidden 1980
Victoria Ave	19-56	This study
Victoria Ave	200	McConchie 1885

The only CBD drain with sediment at the concentration at which further investigations should be initiated was adjacent to the Bennett Street Main Drain.

The chromium concentration for sediment adjacent to the VAMD in this study was about a quarter of the level found by McConchie in 1985 and about a half that by Chegwidden in 1980. Sediments adjacent to the CMD and also the MBMD were low in total chromium. There was a good correlation between sediment chromium and the loss on ignition adjacent to drain outfalls.

5.2.3 Sediments-total zinc

The upper limits suggested in Australian Guidelines for management of contaminated soils above which further investigations should be initiated (ANZEC NH&MRC, 1990) is 350mg/kg for zinc.

Table 5.7

Sediment zinc concentrations from various waterbodies (dry weight basis).

Site	Zinc conc (mg/kg)	Study
Melville Water 1988/89	191.2* (33.0-300)	This study
Perth Water 1988-89	299.4* (70-640)	This study
Upstream of Causeway 1988-89	304* (130-530)	This study
Maylands 1988-89	185*	This study
all up & down-stream sites 1988-89	187-2* (45-260)	This study
Perth Water 1985	129-1 200	McConchie 1985
Chidley Point 1980	5.7-246	Chegwidden June 1980
Bayswater	160-360	Atkins, et. al., 1990
Maylands	160-360 (380)*	Chegwidden June 1980
Swan R. Jane Brook 1980	6.0-14	Chegwidden 1980
Cockburn Sound 1979	3.0-62	Chegwidden 1979
Princess Royal Harbour	3-1-184	Talbot, 1983
Corio Bay Victoria	4-398	Smith, et. al., 1981
Lake Macquarie (NSW)	39-1 410	Batley, 1987
Derwent Estuary (Tas.)	41-9 120	Chegwidden 1980
Lake Burley Griffin	441-1 080	Hart 1982
Brisbane River estuary	123-270	Moss and Bennett, 1991
Gulf of Elefsis	239	Scoullas, 1981
Severn Estuary	282-288	Owens in Mance, 1987
Humber Estuary	203*	Gameson in Mance, 1987

Mae Klong, Chin, Bang Pakong and Chao Praya River-mouths	43-78*	Knutzen, 1981
Restronguet Estuary (UK)	3 000	Forstner and Wittmann, 1979
Rio Tinto Estuary (Spain)	3 100	Forstner and Wittmann, 1979
Acushnet Estuary (Hr)	2 300	Forstner and Wittmann, 1979
Corpus Christi Bay (US)	11 000	Forstner and Wittmann, 1979
Sorford (Norway)	118 000	Forstner and Wittmann, 1979
South Carolina Estuaries	112.7-max (14.2-61.7)*	Sanders, 1984
Olbia Bay, Italy	14-153	Phillips, 1991
Baltic Sea	6-639	Brugmann, 1981
San Francisco Bay	3-504	Bradford and Luoma, 1980
Adriatic 1979-86	47-353	Martincic, 1989

*=denotes means

The mean Melville Water sediment zinc concentrations were similar to those upstream of the Bunbury Rail Bridge. None of the Melville Water, Maylands or Control grid site sediments would have exceeded the zinc soil criterion of 350mg/kg. The Melville Water values for zinc in sediments were slightly higher than those encountered previously at Chidley Point. They were slightly lower than concentrations in the Adriatic but higher than those in Olbia Bay in Italy which receives both treated and untreated domestic sewage (Table 5.7). The mean Melville Water sediment zinc concentrations were 2/3 those of the areas adjacent to the CBD outfalls (Perth and East Perth Waters).

A total of six Perth Water sediment grid sites in 1988 and in 1989 exceeded the soil criterion for zinc. Upstream of the Causeway bridges East Perth Water sediments at three sites exceeded the Australian guide-lines contaminated soil criteria of 350mg/kg. The mean sediment zinc concentrations of Perth and East Perth Water areas were greater than those of the Humber and much greater than those of the South Carolina Estuaries which are polluted by domestic and industrial effluents.

The maximum total zinc concentration in Perth and East Perth sediment was about half that found by McConchie in 1985. The higher sediment concentrations were similar to those in San Francisco Bay which receives sewage effluent, greater than in Corio Bay (polluted by heavy industries) and greater than levels in the Gulf of Elefsis which receives high loads of dissolved zinc from industry and sewage. The maxima were less than the maxima in Princess Royal Harbour, Lake Burley Griffin (polluted with zinc from a disused mine site) and Lake Macquarie. These maxima were also significantly less than those of the heavily polluted Derwent Estuary, the Rio Tinto (Spain), the Sorford, the Restronguet (UK) and Acushnet Estuaries.

The Swan River Estuary mean sediment zinc concentrations were greatest adjacent to the CBD

East Perth Sediments > Perth Water > Melville Water > Control sites > Maylands

The maximum zinc concentrations were greater than those upstream at Bayswater and at Jane Brook.

The maxima were below some heavily contaminated sediments but were also above other water bodies receiving zinc wastes.

The zinc concentration in sediments downstream of the Narrows were similar to those found a decade ago.

5.2.4 Sediment adjacent to drains-total zinc

The sediment adjacent to the outfalls of the Mounts Bay, Bennett St, Plain St and the Claisebrook Main Drains all exceeded the draft guide-lines for contaminated soil of 350mg/kg, at which further investigation should be initiated. The levels adjacent to the VAMD and the CMD were lower than the levels previously found by Chegidden and McConchie.

Apart from the Mounts Bay Main Drain, the levels of zinc adjacent to CBD outfalls were lower than drains with acknowledged zinc contamination such as the South Belmont Main Drain.

Table 5.8

A comparison between estuarine sediment zinc concentrations adjacent to drain outfalls.

Main Drain	zinc (mg/kg)	Study
Bayswater	41	Klemm and Deeley, 1981
Bayswater	63-900	Chegwidden, October 1980
Bennet St	53-420	This study
Claisebrook	147-2 190	Chegwidden, 1980
Claisebrook	170-630	This study
Hill St	38-120	This study
Mounts Bay	200-840	This study
Plain St	160-530	This study
South Belmont	264-680	Chegwidden, Oct 1980
Victoria Ave	56-405	Chegwidden, 1980
Victoria Ave	200-310	This study
Victoria Ave	250-1 200	McConchie 1985

5.3 Biota

5.3.1 Bivalves

The capacity of bivalves to accumulate trace metals makes them useful indicators of environmental pollution.

Comparative data for chromium concentrations in bivalves is not as abundant as that available for zinc. There is no toxicity data for our local species which were available as part of this survey.

The two small bivalve species used in this survey though abundant in some areas are not considered for human consumption. They were sampled in the absence of edible species in order to assess the relative levels of environmental contamination.

5.3.1.1 Bivalves- chromium

Table 5.9

Comparison of ranges of chromium concentrations in bivalves (wet weight basis).

Site	Chromium	Study
Melville Water <i>X securis</i>	<0.5-0.5	This study
Melville Water <i>Mytilus edulis</i>	<0.5	Chegwidden, 1980
Melville Water <i>Spisula</i>	0.2-1.9	This study
Narrows Bridge <i>X securis</i>	0.82	Schulz and Hosja, 1988
Perth Water <i>X securis</i>	<0.5-2.6	This study
Perth Water <i>Spisula</i>	0.5-4.6	This study
Victoria Ave MD <i>X securis</i>	13-17	This study
Bennet St MD <i>X securis</i>	3.9-5.3	This study
Plain St MD <i>X securis</i>	1.1-4.0	This study
u/s Causeway <i>X securis</i>	<0.5-4.7	This study
u/s Causeway <i>Spisula</i>	1.8	This study
Claisebrook MD <i>X securis</i>	0.2-1.0	Schulz and Hosja, 1988
Maylands <i>X securis</i>	0.3-1.0	This study
Bayswater Swan River <i>X securis</i>	0.2-0.4	Klemm and Deeley, 1991
Canning Estuary <i>M edulis</i>	<0.5	Chegwidden, 1980
Princess Royal Harbour <i>M edulis</i>	0.37-0.76	Talbot, 1983
CBH - C. Sound <i>Mytilus edulis</i>	2.4-4.1	Chegwidden, 1979
Tomales Bay <i>Mytilus edulis</i>	<0.2	Bradford and Louma, 1980

There is no Maximum Permitted Concentration (MPC) listed for chromium under the Health Act 1911 Health (foodstuffs) (general) Regulations 1987

Section A12, The Water Quality Criteria for Cockburn Sound- Heavy Metals in seafood for chromium is 5.5mg/kg of wet body weight.

The mussel *Xenostrobus securis* growing adjacent to both the Victoria Ave and Bennett Street Main Drains had levels of chromium in excess of 5mg/kg (wet weight). At the VAMD the maximum chromium concentration of (17 mg/kg) in this survey were lower than those of those found by Schulz and Hosja in 1988.

Mean water body bivalve chromium concentrations in this survey were 1.5 and 1.3mg/kg for *Spisula* and *Xenostrobus* respectively. These were slightly higher than those of Melville Water but less than a small sample from upstream of the Causeway bridges, and than found in Cockburn Sound. The concentration of chromium in Melville Water *Xenostrobus* were similar to the levels in the same species in Bayswater and those found in the edible mussel *Mytilus edulis* from the same area, Princess Royal Harbour and in the Canning River (Table 5.9).

The levels of chromium in bivalves is related their proximity to the CBD and especially the proximity to CBD main Drain outlets.

Some unacceptable levels of chromium (>5mg/kg) were detected in 'hot spots'.

The levels of chromium in bivalves in the main water body generally satisfactory.

The chromium concentrations adjacent to the VAMD were lower than those of the previous study.

5.3.1.2 Bivalve - Zinc Concentrations

MPC=Maximum Permitted Concentration Health Act 1911 Health (foodstuffs) (general) Regulations 1987 Section A12, is=1000mg/kg as wet weight.

No bivalve had zinc concentrations above 72mg/kg. The results indicate that there is a relatively low level of zinc contamination in Swan River bivalves.

The maximum levels of zinc in the non-edible mussel *Xenostrobus securis* and the bivalve *Spisula trigonella* from the Melville Water and Maylands areas were higher than in the estuary adjacent to the CBD. The zinc levels in bivalves in Melville Water bivalves were similar to concentrations of zinc previously found in the larger edible mussel species *Mytilus edulis*, from the Swan at Dalkeith and Blackwall Reach, the lower Canning River estuary and in Princess Royal Harbour at Albany (Table 5.9).

Table 5.10

Ranges of zinc concentrations in bivalves (wet weight basis).

Site	Zinc (mg/kg)	Study
Melville Water <i>X securis</i>	10.0-72.0	This study
Melville Water <i>Spisula</i>	10.0-17.0	This study
Swan Blackwall Reach <i>M edulis</i>	31-73.3	Chegwidden, 1980
Swan Dalkeith <i>M edulis</i>	31.3-76	Chegwidden, 1980
Narrows <i>X securis</i>	8.0	Hosja, 1987
Narrows <i>X securis</i>	8-12	Schulz & Hosja, 1988
Perth Water <i>X securis</i>	11.6-21.4* 8.8-49	This study
Perth Water <i>Spisula</i>	14.5* 9.4-29.0	This study
Perth Water <i>X securis</i>	0.8-15.3	Blackmore, 1985
Victoria Ave MD <i>X securis</i>	15-31	This study
Victoria Ave MD <i>X securis</i>	9-24	Schulz & Hosja, 1988
Bennett St MD <i>X securis</i>	13-16	This study
Plain St MD <i>X securis</i>	14-23	This study
u/s Causeway <i>X securis</i>	21-28* 12-45	This study
u/s Causeway <i>Spisula</i>	16.0	This study
Claisebrook MD <i>X securis</i>	14	Schulz * Hosja, 1988
Claisebrook MD <i>X securis</i>	12	This study
Maylands <i>X securis</i>	13-40	This study

Swan Bayswater <i>X securis</i>	14-20	Klemm & Deeley, 1991
Canning Bridge <i>M edulis</i>	27.6-55.7	Chegwidden, 1980
Canning Deepwater Point <i>M edulis</i>	43.5-72.5	Chegwidden, 1980
Cockburn Snd. <i>Mytilus edulis</i>	17.1-134.8	Chegwidden, 1979
Princess Royal Harbour <i>Mytilus edulis</i>	32.4-69.3	Talbot, 1983
Corio Bay <i>Mytilus edulis</i>	27.3* 21-82	Smith et al., 1981
Port Phillip Bay <i>Mytilus edulis</i>	26.9-32.7	Arnott et. al., 1988
Western Port Bay <i>Mytilus edulis</i>	16.9-54.9	From Chegwidden
Lake Macquarie <i>Trichomya hirsuta</i>	14*	Batley, 1987
Derwent Est. <i>Mytilus edulis</i>	85.6* 28.4-224	Bloom & Ayling, 1977
Nth Island NZ <i>Mytilus edulis</i>	12.6* 3.8-26	Chegwidden, 1979
Tomales Bay <i>Mytilus edulis</i>	16.4*	Bradford & Louma, 1980
San Francisco Bay <i>M edulis</i>	34*	Bradford & Louma, 1980
Marseille (Fr) <i>M edulis</i>	34-107	cited in Knutzen, 1981
Baltic Sea	16-110	Brugmann, 1981

* = denotes mean

The maximum zinc levels were lower than those found in edible mussels *Mytilus edulis*, from Cockburn Sound, the polluted Derwent Estuary and Corio Bay, which has heavy industry and a major port lining its shores. Maximum concentrations of zinc were also less than in *M edulis* from Marseilles and the Baltic Sea.

Perth Water *Xenostrobus* mussels had zinc concentration ranges similar to those upstream of the Causeway and edible mussels in Port Phillip and Western Port Bays in Victoria (Table 5.9).

The levels of zinc in mussels growing adjacent to CBD drain outfalls were lower than those in the main Perth Water body sites. This indicates that the drains do not play a large role in the zinc concentrations in the mussels.

The zinc concentrations in the tissue of Swan River estuary bivalves in this study appear to have remained constant over the past decade and are not considered a risk to health. They are comparable to mussels from other urbanised areas.

The levels of zinc in Swan River bivalves have not altered significantly over the past decade.

The levels of zinc in bivalves were similar to other urbanised areas but lower than heavily polluted ares.

CBD drains are not a major contributor to the zinc in mussels growing adjacent to their outlets.

The levels of zinc in Swan River bivalves were well below local health standards.

5.3.2 Crustacea

Edible species of crustacea in this survey were only able to be collected from the vicinity of the CBD in the second half (1989) of the sampling survey and this resulted in a small sample size.

5.3.2.1 Crustaceans-chromium

There is no Maximum Permitted Concentration (MPC) listed for chromium under the Health Act 1911 Health (foodstuffs) (general) Regulations 1987 Section A12, The Water Quality Criteria for Cockburn Sound-Heavy Metals in seafood for chromium is 5.5mg/kg of wet body weight.

The concentration of chromium in the flesh of both edible and non edible species of crustacea from the Swan River estuarine system was low, at less than 0.4mg/kg (Table 5.11). The edible blue manna crab and the school and King prawn species would have limited contact time with the CBD unlike the more permanent common estuarine shrimp *Palaemonetes australis*.

Table 5.11

Comparison of chromium concentrations in crustacean flesh (wet weight).

Area/species	Chromium (mg/kg)	Study
Perth Water (shrimp) <i>P australis</i>	<0.1	This study
Canning Mt Henry <i>P australis</i>	0.2	This study
Middle Swan Bridge <i>P australis</i>	0.2	This study
Bayswater <i>P australis</i>	0.4	Atkins et. al., 1990
Bayswater <i>P australis</i>	0.1-0.2	SRT unpublished
Perth Water <i>Portunus pelagicus</i>	0.1	This study
Perth Water prawn <i>Penaeus latisulcatus</i>	<0.1	This study
Cockburn Sound crab <i>Portunus pelagicus</i>	0.8-1.2	Chegwidden, 1979
Orkdalsfjorden Hardanger-fjorden, Nor. <i>Carcinus maenus</i> (Lande 1977)	1.6	Forstner & Wittmann, 1979
Saldahna Bay SA <i>Jasus lalandii</i> (Fourie (1976)	0.03	Forstner & Wittmann, 1979
Melkbosch Strand West Coast SA <i>Jasus lalandii</i> (Van As et. al., 1975)	0.08	Forstner & Wittmann, 1979

The levels of chromium in crustacea were lower than those in Cockburn Sound and other water bodies. The international data of chromium in crustacea is scarce.

There would seem to be no evidence that crustacea from the Swan River estuary are bio-accumulating chromium from the environment, with CBD shrimp similar to control shrimp. Levels of chromium in the flesh of the widely distributed non-edible shrimp

P australis were very low., and similar to levels found by Atkins et. al in the upper estuary.

The levels of chromium in Swan River crustacea associated with the CBD are low when compared to other areas.

5.3.2.2 Crustaceans-zinc

Table 5.12

Comparison of Zinc concentrations (wet weight basis) in crustacea.

Area/Species	Zinc (mg/kg)	Study
Perth Water <i>P australis</i>	28	This study
Canning Mount Henry <i>P australis</i>	25	This study
Middle Swan Bridge <i>P australis</i>	21	This study
Bayswater <i>P australis</i>	36	Atkins et. al., 1990
Bayswater <i>P australis</i>	12-20	Klemm & Deeley, 1991
Guildford <i>P australis</i>	10	Klemm & Deeley, 1991
Perth Water <i>Portunus pelagicus</i>	34	This study
Cockburn Sound <i>Portunus pelagicus</i>	8.6-32.2	Chegwidden, 1979
Sth Carolina Estuaries <i>Callinectes sapidus</i>	28.5-34.3*	Sanders, 1984
Northumberland Coast GB <i>Carcinus maenus</i> Wright, (1976)	23.7-43.2	cited in Forstner and Wittmann, 1979
Northumberland Coast GB <i>Cancer pagurus</i> Martin, (1974)	28.9	cited in Forstner and Wittmann, 1979
Terrance Bay Nova Scotia Can. <i>Cancer irroratus</i> Martin, (1974)	30.5	cited in Forstner and Wittmann, 1979

Orkdalsfjorden Hardanger-fjorden Norway <i>Carcinus maenus</i> Lande, (1977)	121	cited in Forstner and Wittmann, 1979
San Antonia Bay <i>Crangon crangon</i> Sims and Presley, (1976)	14	cited in Forstner and Wittmann, 1979

* =denotes mean

None of the zinc concentrations in crustacea, exceeded the Maximum Permitted Concentration of 150mg/kg wet weight.

The concentrations of zinc in the pooled flesh of the shrimp, *Palaeomonetes australis* from the lower estuary was higher than found in control shrimp samples upstream at the Middle Swan Bridge and the Guildford sites, but were lower than levels in the Bayswater area.

The blue swimmer crab from Perth Waters adjacent to the CBD, had similar tissue zinc concentrations as those from Cockburn Sound. The crab is migratory and the time it spent in the area is unknown.

The absence of edible marine samples of crustacea at the beginning of the survey, prevented in-estuary zinc concentration comparisons from being determined over the summer period. Samples of crabs and prawns need to be taken at sites downstream.

The zinc concentrations in Swan River crustacea were well below the health criteria.

Perth Water shrimp had slightly higher zinc concentrations than control site shrimp.

The levels compare favourably with those of crustacea from Cockburn Sound and the cited international data.

5.3.3 Fish

5.3.3.1 Fish- chromium

There is no Maximum Permitted Concentration (MPC) listed for chromium under the Health Act 1911 Health (foodstuffs) (general) Regulations 1987 Section A12. The Water Quality Criteria for Cockburn Sound-Heavy Metals in seafood for chromium is 5.5mg/kg of wet body weight.



Table 5.13

Comparison of the chromium concentrations in fish muscle from various areas (wet weight).

Area	Chromium (mg/kg)	Study
Swan Estuary Table fish adjacent to CBD	<0.1-0.27	This study
Swan Estuary non-table fish adjacent to CBD	<0.1-0.5	This study
Swan-Bayswater	<0.04	Atkins, et. al., 1990
Swan-Avon	0.017-0.76	Marks, et. al., 1980
Cockburn Sound	0.04-0.36	Plaskett and Potter, 1979
UK Coastal Waters Ratkowsky	<0.2-0.6	cited in Mance, 1987
Cape West Coast SA - <i>Scomber japonicus</i> Van As et. al., 1975	0.65	cited in Forstner and Wittmann, 1979
North Island - NZ <i>Seriola grandis</i> Brooks and Rumsy, 1974	0.02	cited in Forstner and Wittmann, 1979
North Island - NZ <i>Trigla kumu</i> Brooks and Rumsy, 1974	0.01-0.02	cited in Forstner and Wittmann, 1979

The chromium concentrations fish muscle were well below the 5.5 mg/kg criterion used by Chittleborough et. al., in Cockburn Sound fish surveys.

The chromium concentrations fish muscle were very low at less than 0.4mg/kg wet weight. They were similar to levels cited from previous similar studies in the Swan River estuary, Cockburn Sound and other international fish surveys. The data are scarce, but it appears that chromium is not significantly concentrated in the muscle of edible and non edible fish species.

The levels of chromium in the flesh of Swan River fish are very low.

The muscle tissue chromium concentrations are fairly uniform in all both edible and inedible fish species irrespective of their mode of feeding.

The levels of chromium in Swan River fish flesh has remains fairly constant for the past decade

5.3.3.2 Fish- zinc

Table 5.14

Comparison of the zinc concentrations in fish muscle (wet weight basis).

Area	Zinc (mg/kg)	Study
Swan Table fish adjacent to CBD	<0.5-20	This study
Swan non-table fish adjacent to CBD	5.4-34	This study
Swan Estuary Bayswater	6-8	Atkins, et. al., 1990
Swan-Avon	2.2-18.6	Marks, et. al., 1980
Cockburn Sound	15.1* (2.6-21.6)	Plaskett and Potter, 1979
Derwent River estuary	4.6-13.5* (max - 38.9)	cited in Hart 1982
Cape West Coast Sth Africa <i>Seriola pappei</i> (Van As, et. al., 1975)	6.7	cited in Forstner and Wittmann, 1979
Cape West Coast Sth Africa. <i>Scomber japonicus</i> (Van As, et. al., 1975)	7.2	cited in Forstner and Wittmann, 1979
North Is. NZ <i>Seriola grandis</i> Brooks & Rumsy, 1974	9.5-56	cited in Forstner and Wittmann, 1979
North Is. NZ <i>Trigla kumu</i> Brooks & Rumsy, 1974	5.5-56	cited in Forstner and Wittmann, 1979

Sagres, South Portugal <i>Raja clavata</i> Stenner & Nickless, 1975	10.4	cited in Forstner and Wittmann, 1979
Bristol Channel GB <i>Scyliorhinus</i> spp Peden, et. al., 1973	11.5-13.7	cited in Forstner and Wittmann, 1979
Northumberland power station <i>Pleuronectes platessa</i> Wright, 1976	30.3	cited in Forstner and Wittmann, 1979

* Denotes Mean

The Maximum Permitted Concentration MPC of zinc in fish muscle under the Health Act 1911 Health (foodstuffs) (general) Regulations 1987 Section A12, is 150mg/kg.

None of the zinc levels in fish muscle exceeded the MPC.

Zinc levels in fish muscle were low in Perth Water fish species.

Zinc concentrations in table fish flesh were similar to those from previous studies on the Swan River estuary and in Cockburn Sound.

The flesh from non-edible fish species had maximum zinc concentrations within the range of species internationally.

Fish flesh from the Perth Water area had low levels of zinc, much lower than that the MPC.

Levels of zinc in Perth Water fish species were similar to levels found a decade ago.

There is no Maximum Permitted Concentration (MPC) listed for chromium under the Health Act 1911 Health (foodstuffs) (general) Regulations 1987 Section A12. The Water Quality Criteria for Cockburn Sound-Heavy Metals in seafood for chromium is 5.5mg/kg of wet body weight.

Generally the liver, viscera, male and female gonads contained higher concentrations of chromium than the muscle of the same species.

The Perth herring contained the highest levels of chromium contamination of its organs. The fish was one of the most abundant species caught in the Swan River estuary adjacent to the CBD.

Table 5.15

Comparison between the chromium concentration within the organs of adult fish species from the Swan-River estuary in 1988-89 (wet weight basis).

	Flesh	Liver	Visc- era	male gonad	female gonad
Fish spp 1988-89	mg / kg				
Cobbler	0.04- 0.2	0.11- 0.2	0.15	0.1	0.04
Perth herring	0.1- 0.27	3.0- 3.75	3.1	0.85	1.4
Mullet sea	0.04	0.3	2.25	n/a	n/a
6-line trumpeter	0.1- 0.11	0.04	1.2	n/a	0.3

n/a means not available

Levels of chromium in the organs may indicate some environmental contamination or chronic effect level for metabolic pathways. It is difficult to get a good handle on data because there is no toxicologic data for local species.

The concentrations of chromium in fish organs were generally much higher than in the flesh of the same species.

Perth herring from Perth Waters showed the highest levels of organ-based chromium contamination.

The Maximum Permitted Concentration MPC of zinc in fish muscle under the Health Act 1911 Health (foodstuffs) (general) Regulations, 1987 Section A12, is 150mg/kg.

Generally the liver, viscera, male and female gonads contained higher concentrations of zinc than the flesh of the same species.

Though not usually eaten, the female fish gonads of Perth herring, 6-line trumpeter and the livers of Sea mullet would have exceeded the Health criterion of 150mg/kg for zinc.

These data may indicate some environmental contamination or potential chronic effect level for fish metabolic pathways. The levels of fish organs needs to be investigated further. The variation of metals across the species may be significant.

Perth herring undergo spawning from November to January in the Swan River (Loneragan et. al., 1987).

Though not usually eaten, the female fish gonads of Perth herring, 6-line trumpeter and the livers of Sea mullet would have exceeded the Health criterion of 150mg/kg for zinc.

The concentrations of zinc in fish organs were generally much higher than in the flesh of the same species.

Perth herring from Perth Waters showed the highest levels of organ-based chromium contamination, especially within the female gonads. The highest levels in the female gonads, coincide with the spawning period for that species. This may exert some chronic fecundity problems.

Table 5.16

Comparison between the zinc concentration (mg/kg) within adult fish species from the Swan-River estuary in 1988-89 (wet weight basis).

Fish spp 1988/89	Flesh	Liver	Visc- era	male gonad	female gonad
Cobbler	5.60 22.1	15- 29.3	23	11	22
Perth herring	8.4- 10.7	29.5- 30.9	26	66	890
Mullet	11.5	150	34.5	n/a	n/a
6-line trum- peter 1988	11.0- 15.9	24	16	n/a	250

n/a means not available.

5.3.4 Macroalgae

5.3.4.1 Macroalgae-chromium

The mean chromium and zinc concentrations of *Gracilaria* in 1989 were higher than recorded in 1988.

The highest chromium concentrations were found in Perth Water *Gracilaria*. The next highest was the red macroalga growing adjacent to CBD drains and in Melville Water. The low background metal concentrations measured in control site samples were also recorded in some algal samples from Perth and East Perth Waters.

Table 5.17

Comparison of the chromium and zinc concentrations in macroalgae from various areas (wet weight).

Area/ macroalgal type	Cr (mg/kg)	Zn (mg/kg)	Author
Melville Water <i>Gracilaria</i>	1.4-3.7	34-40	This study
Perth Water <i>Gracilaria</i>	0.3-5.3	9.1-210	This study
Causeway u/s <i>Gracilaria</i>	0.2-3.0	6.6-180	This study
Perth Water CBD Drains <i>Gracilaria</i>	0.3-4.1	11-44	This study
Perth Water Drains <i>Grateloupea</i>	0.3	4.9	This study
Perth Water CBD Drains <i>Hypnea</i>	2.5	12	This study
Perth Water CBD Drains <i>Ulva</i>	0.6-1.6	5.5-6.7	This study
Control sites <i>Gracilaria</i>	0.5	15-17	This study
Swan River Rockby Bay <i>Ulva</i>	n/a	1-4.5	SRT . unpublished data
Swan River Rocky Bay <i>Enteromorpha</i>	n/a	8.1-81	SRT unpublished data
Cockburn Sound <i>Ulva lactuca</i>	0.1	2.5-4.4	Chegwidden, 1979
Cape West Coast, S Afr. <i>Ulva</i>	n/a	5.6	Van As, et. al., 1975*
Cape West Coast, S Afr. <i>Porphyra</i>	11	0.47	Van As, et. al., 1975*
Aqaba Coast red algae	n/a	19-30.7	Wabah, 1985
Aqaba brown algae	n/a	4.6-10.3	Wabah, 1985
Aqaba green algae	n/a	4.6-9.3	Wabah, 1985

n/a means not available. * denotes cited in Forstner and Wittmann, 1979

The highest zinc concentrations in *Gracilaria* were found in Perth and East Perth Waters. Maximum concentrations of zinc greatly exceeded the concentrations in control site and Melville Water site algal samples. The maximum levels exceeded maxima in red and other macroalgal species in Cockburn Sound and Aqaba.

The mean concentrations of chromium and zinc in *Gracilaria* sampled in this survey were highest in 1989.

The highest concentrations of chromium and zinc in *Gracilaria* were in Perth Water macroalgae.

The minimum chromium values in macroalgal samples adjacent to the CBD and drain outlets were similar to background levels.

The maximum zinc concentrations in *Gracilaria* greatly exceed those cited in the literature.

6. Conclusions

6.1 Waters

6.1.1 Drains

These chromium and zinc results indicate that the chromium concentrations in CBD drains discharging to the Swan River Estuary remain within the ranges found in previous surveys based on an inadequate number of samples.

Some levels of total chromium in CBD drain waters and a significant in-estuary mixing zone adjacent to their outfalls, exceeded the single sample and also the six month median concentrations Water Quality Criteria for Marine and Estuarine Waters, for the harvesting of aquatic life. These criteria however are not normally applied to drain waters. The median concentration in this study was calculated on insufficient samples and should be taken as a guide only.

Either realistic concentration criteria should be set for stormwater drains which carry metal contaminants to the Swan River or the taking of edible sessile animals and contact recreational activities should be excluded within 400 metres of the CBD drains outfalls.

Juvenile fish which are observed feeding in, and inhabit the area immediately adjacent to drain outfalls should be tested for sub-lethal changes and their metal content in long-term exposure trials.

Future sampling of the CBD drain outfalls should be carried out on an integrated and longer-term duration to include sufficient data to conform to the median Estuarine criteria. Samples should be collected at hourly intervals over a 24 hour period. Flows should be logged to enable loads to be calculated.

The results of this survey reasonably confirm that the levels of chromium in drains are high at times.

These data do not confirm any trend in drain metal levels over the past decade.

Sampling of the Central Business District Main Drains may need to be repeated within 5 years with sufficient data gathered to establish any long term trends in chromium and zinc concentrations and loads.

A sampling programme may need to be established which includes the sampling of juvenile mullet which feed within the drain plumes. The fish could be tested for zinc and chromium content and also for sub-lethal chronic effects.

6.1.2 Waterbody

Though higher mean chromium concentrations were adjacent to the CBD drains, none of the main waterbody sites exceeded the Marine and Estuarine Water Quality Criteria for either a single sample or the six-month median for either zinc or chromium.

The ranges of chromium and zinc are typical of those found in rural and urbanised rivers.

The mean concentrations of chromium and zinc in the Swan River Estuary are lower than those of polluted rivers and streams. They are of the same order of magnitude of Cockburn Sound. waterbody samples.

The lowest estuarine chromium concentrations were similar to background sea levels.

It is unlikely that the estuarine body zinc concentration would adversely affect aquatic organisms. The highest estuarine zinc concentration was below the Minimum Effect Concentration (MEC) for a marine amphipod.

Sampling of the estuarine body sites for chromium and zinc confirms the association of highest body site metal concentrations with the outfalls from CBD drains.



The authors acknowledge the limitations of instantaneous sampling of 40 water body sites, especially when all sites are sampled by one boat crew over a period of several hours and the daylight hours.

For future sampling strategies, waterbody sites could be sampled by a number of teams over a regular interval to produce a 6-monthly median for each major water body.

Sampling could be carried out at 10 year intervals to confirm trends.

6.2 Sediments

The metal concentrations in sediments were better correlated with sediment organic (LOI %) content in undisturbed waters. Mean Swan river chromium and zinc concentrations were highest in sediments adjacent to the CBD.

East Perth Water > Perth Water sites > Melville Water > Control sites > Maylands sites.

Based on the ranges of background and maximum concentrations in the survey, the criteria for contaminated terrestrial soils of 100mg/kg of chromium and 350 mg/kg (dry weight basis) appear to be a suitable criteria to adopt for estuarine sediments.

Of concern in this survey was that four Swan River sediment site 'hotspots' exceeded the soil criterion of 100mg/kg of chromium and twenty two sediment samples exceeded the soil criterion of 350mg/kg of zinc.

The levels of chromium were lower than other moderate to heavily contaminated areas in the Baltic, Tasmania, San Francisco and UK rivers. Some Swan River CBD sediments are more heavily polluted with chromium than Cockburn Sound and Princess Royal Harbour. The zinc concentration maxima were below some heavily contaminated sediments but were also above those other water bodies receiving zinc wastes.

There is no indication that chromium and zinc levels are falling in the Swan River estuary sediments.

The criteria for contaminated terrestrial soils of 100mg/kg of chromium and 350 mg/kg (dry weight basis) may be suitable criteria to apply to estuarine sediments.

Future metal analyses of the Swan River sediment should be carried out on standardised sieved fractions. Organic content to be determined. The role and significance of wind-stirred suspended particles on the transport of adsorbed metals may need to be determined.

Further analyses could be carried out on sediments from sites with higher metal concentrations at regular intervals. Future analyses could also include analyses for sediment cadmium, lead and copper concentrations.

The role bottom water dissolved oxygen plays in the release/uptake sediment metal should be investigated.

6.3 Biota

6.3.1 Bivalves

The levels of chromium in bivalves is related their proximity to the CBD and especially the proximity to CBD main Drain outlets. Some unacceptable levels of chromium (>5.5mg/kg-Cr-NSW Criterion) were detected in 'hot spots'. This is expected in drain waters but is not considered a human health risk because these bivalves are not normally eaten.

The highest levels of zinc in bivalves were found in mussels from Melville Water.

The chromium concentrations in bivalves varied considerably and except for those adjacent to the VAMD concentrations were generally satisfactory. Lower mean tissue chromium levels were found in the summer/autumn period, probably related to the reproduction stages and the sex of the animals sampled.



The levels of zinc in Swan River bivalves have not altered significantly over the past decade and CBD drains are not the only major contributor to the zinc in mussels growing adjacent to their outlets. The levels of zinc in bivalves were similar to other urbanised areas but lower than heavily polluted areas. The levels of zinc in Swan River bivalves were well below local health standards.

Samples of mussels may need to be collected at regular intervals for a number of sites in the Swan River and analysed for metals noting the reproductive stages of the animals at the time of analysis.

6.3.2 Crustacea

The levels of chromium and zinc in Swan River edible crustacean species associated with the CBD, were low when compared to other areas. The edible species were highly mobile and scarce in the survey samples.

The chromium and zinc concentrations in the flesh of Swan River crustacea were well below the available health criteria. The flesh of the small shrimp *Palaemonetes* from Perth Water had slightly higher zinc concentrations than control site shrimp. The metal levels compare favourably with those of crustacea from Cockburn Sound and the cited international data.

Crustacea are not good indicators of metal pollution and are not recommended for chromium or zinc metal analysis unless to be monitored on a long-term basis and the results are able to be compared to control animals of the same species.

6.3.3 Fish

The levels of chromium and zinc in the flesh of Swan River fish are very low.

There was little difference in muscle tissue chromium concentrations between both edible and non-edible fish species irrespective of their mode of feeding.

The levels of chromium and zinc in Swan River fish muscle has remained consistently low for the past decade

Fish flesh from the Perth Water area had low levels of zinc, much lower than that the MPC and the chromium concentrations were well below the available health criteria.

The concentrations of chromium in fish organs were generally much higher than in the flesh of the same species.

Perth herring from Perth Waters showed the highest levels of organ-based chromium contamination.

Though not usually eaten, the female fish gonads of Perth herring, 6-line trumpeter and the livers of Sea mullet would have exceeded the Health criterion of 150mg/kg for zinc.

The concentrations of zinc in fish organs were generally much higher than in the flesh of the same species.

Perth herring from Perth Waters showed the highest levels of organ-based chromium contamination, especially within the female gonads. The highest levels in the female gonads, coincide with the spawning period for that species. This may exert some chronic fecundity problems.

A similar, more extensive fish sampling exercise could be repeated at ten year intervals for all metals to determine trends.

Further toxicity work could also be carried out on the effects of all heavy metals on the local species of Perth herring. This work should include laboratory concentration based sub-lethal effects investigations on the fishes fecundity.

6.3.4 Algae

The commonly available red estuarine macroalga *Gracilaria* appears to be a good indicator of metal pollution.

The mean concentrations of chromium and zinc in *Gracilaria* sampled in this survey were highest in the 1989 summer/autumn period.

The highest concentrations of chromium and zinc in *Gracilaria* were in the Perth Water macroalgae.

The minimum chromium values in macroalgal samples adjacent to the CBD and drain outlets were similar to background levels.

The maximum zinc concentrations in *Gracilaria* greatly exceed those cited in the literature on red algae.

The red estuarine macroalga *Gracilaria* could be used as an indicator species of metal pollution.

6.4 Loads

There has been an increase in the amount of chromium and zinc being used in and discharged from Perth Central Business District air-conditioning cooling towers. It is feared that the loads to the Swan River Estuary will continue to increase with further expansion and development within the CBD.

Within the restricted area of the waters adjacent to the CBD the areal loading of chromium exceeds that of areas affected by sewage waste.



7. Terminology

Acute toxicity	a lethal response caused by a short exposure to a substance (at the most a few days-commonly 4).
Background level	In terms of stream water quality means the level of an indicator measured at a specified reference point upstream of all waste discharges possessing a measurable level of that indicator.
Beneficial use	any use of the environment or any element or segment of the of the environment that is conducive to public benefit, welfare, safety or health.
Benthic	of the bottom of a body of water. Benthic organisms include all burrowing forms, as well as those inhabiting the surface of the bottom surface.
Bio-accumulation	the uptake of contaminants from the water independently by each trophic level and species.
Biological monitoring	the sampling of aquatic communities to determine the quality of water or health of ecosystems.
Bio-magnification	the increase in concentration of a persistent compound in tissues of organisms proceeding up the food chain.
Biota	living component of an ecosystem.
Byssus	a series of threads used by some bivalves to attach to hard substrates.
Catchment	the area which drains to a watercourse.
Chronic toxicity	deleterious effects (severe or otherwise) resulting from prolonged exposure to toxicant (ie. more than a few days-usually over one tenth of the life span).
Composite sample	a sample formed by the combination several separate samples of test solution.
Contamination	the presence of a potentially harmful substance at above background concentrations in to the environment
Controls	a group of organisms of the same species as tested which are exposed to the same test conditions as the test populations but in the absence of the test substance.
Criteria	the scientific yardsticks upon which a decision or judgement may be made concerning the ability of water of a given quality to support a designated beneficial use.
Detritivores	organisms that feed on decaying organic matter.
Effluent	wastewater, treated or not, discharged into a body of water.
Epiphytes	small unicellular, filamentous and fleshy algae that are attached to algae or seagrasses.
Estuary	a partially enclosed coastal body of water characterised by tidal effects and mixing of fresh with sea water.
Flow-through test	a toxicity test in which there is a continuous or near continuous replacement of the test solution.
Gonad	reproductive organ.
Heavy metals	All metals or semi-metals, other than alkali or alkaline earth metals.
LC ₅₀	median effect concentration is that concentration which is estimated to cause a particular response in 50 % of the test population.
LC ₅₀	median lethal concentration, i.e. that concentration which is calculated to cause the mortality of 50 % of a test population over a specified period of exposure.
Load	the net amount of a substance discharged into a water body usually expressed as mass per unit time.
Marine waters	Water with dissolved inorganicions greater than 30 parts per thousand Median period of survival-(or median lethal time, or median survival time) is the length of time that 50 % of a test population survive at a particular concentration of a substance.
µg/L	micrograms per litre/ millionths of grams per litre.



mg/kg	milligrams per kilogram;/ thousandths of grams per kilogram.
Nominal concentration	the concentration of a test substance calculated from the mass added to a known volume of water.
Observed concentration	the concentration of a test substance measured analytically in a sample or samples of test solution recovered from a test chamber during the test.
Phytoplankton	single-celled algal plants that live in a water body.
Phyto-toxic	poisonous or harmful to aquatic plants.
Pollution	a change in water quality which causes a deleterious change in the biological community or makes the aesthetic character of the water unacceptable.
p.p.m	parts per million;/ milligrams per kilogram;/ mg/L;/ (0.0001 %).
Receiving waters	waters into which a discharge is occurring.
Sedentary	description of immobile benthic organisms.
Semi-static test	a toxicity test in which all or most of the test solution is replaced at intervals of 12 hour or more during the test.
Six month median	the concentration limit applied to the median of all samples taken within a n y s i x month period
Static test	a toxicity test in which the test solution is not replaced in the test
Sub-lethal	having a deleterious effect but not causing mortality.
Synergism	interactions of two or more substances to produce an effect in an organism greater or more serious than the sum of the individual effects.
Toxic	capable through chemical action of killing, injuring or impairing an organism.
Toxicant	substance which is poisonous to living things.
Toxicity test	the use of living organisms to define the poisonous effects of a substance or substances under controlled conditions.
Wet weight	if fish tissue contains 80 % water in its flesh, only one fifth of the meat contains solids. In that case a sample of that fish containing on a wet weight basis, 1.0 ppm of a metal, it would have (5 x 1.0 ppm=) 5.0 ppm of the metal on a dry weight basis. The conversion factor may vary significantly between species depending on the fat content.

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10. Appendices - CCWA Analytical Results



Appendix 1 water

MEDIUM	SITE	RIVER AREA	SAMPLE DEPTH	DATE	Water Cr µg/L	Water Zn µg/L
River	SRC4	Melville Water	Surface	12/15/88	0.7	7
River	SRC4	Melville Water	Bottom	12/15/88	1.0	8
River	SRC6	Melville Water	Surface	12/15/88	0.6	5
River	SRC6	Melville Water	Bottom	12/15/88	0.6	5
River	SRD3	Melville Water	Surface	12/15/88	0.6	<5
River	SRD3	Melville Water	Bottom	12/15/88	1.0	6
River	SRD5	Melville Water	Surface	12/15/88	1.0	7
River	SRD5	Melville Water	Bottom	12/15/88	1.4	5
River	SRD6	Melville Water	Surface	12/15/88	0.7	6
River	SRD6	Melville Water	Bottom	12/15/88	0.6	<5
River	SRE2	Perth Water	Surface	12/15/88	0.9	7
River	SRE2	Perth Water	Bottom	12/15/88	1.3	7
River	SRE3	Perth Water	Surface	12/15/88	0.7	11
River	SRE3	Perth Water	Bottom	12/15/88	1.7	10
River	SRE6	Melville Water	Bottom	12/15/88	<0.5	<5
River	SRE6	Melville Water	Surface	12/15/88	<0.5	7
River	SRF1	Perth Water	Surface	12/15/88	0.6	7
River	SRF1	Perth Water	Bottom	12/15/88	3.0	5
River	SRF2	Perth Water	Surface	12/15/88	1.3	11
River	SRF2	Perth Water	Bottom	12/15/88	1.6	6
River	SRF3	Perth Water	Surface	12/15/88	1.0	9
River	SRF3	Perth Water	Bottom	12/15/88	1.0	8
River	SRF4	Perth Water	Surface	12/15/88	0.7	8
River	SRF4	Perth Water	Bottom	12/15/88	1.8	8
River	SRG1	Perth Water	Surface	12/15/88	0.7	6
River	SRG2	Perth Water	Surface	12/15/88	0.7	5
River	SRG2	Perth Water	Bottom	12/15/88	0.6	10
River	SRG3	Perth Water	Surface	12/15/88	1.2	<5
River	SRG3	Perth Water	Bottom	12/15/88	<0.5	8
River	SRG4	Perth Water	Surface	12/15/88	1.3	11
River	SRG4	Perth Water	Bottom	12/15/88	1.5	8
River	SRG1	Perth Water	Bottom	12/15/88	1.3	10
River	SRH1	Perth Water	Surface	12/15/88	1.4	12
River	SRH1	Perth Water	Bottom	12/15/88	0.8	9
River	SR2	u/s Bunbury Bridge	Surface	12/20/88	0.6	14
River	SR2	u/s Bunbury Bridge	Bottom	12/20/88	1.5	18
River	SR3	u/s Bunbury Bridge	Surface	12/20/88	0.5	<5
River	SR3	u/s Bunbury Bridge	Bottom	12/20/88	0.9	<5
River	SRC6	Melville Water	Bottom	12/20/88	6.2	7
River	SRC6	Melville Water	Surface	12/20/88	0.5	<5
River	SRD3	Melville Water	Bottom	12/20/88	1.2	6
River	SRD3	Melville Water	Surface	12/20/88	0.9	<5
River	SRD5	Melville Water	Bottom	12/20/88	0.5	5
River	SRD5	Melville Water	Surface	12/20/88	1.2	<5
River	SRD6	Melville Water	Surface	12/20/88	0.9	<5
River	SRD6	Melville Water	Bottom	12/20/88	2.1	5
River	SRE2	Perth Water	Surface	12/20/88	0.6	8



Appendix 1 water

MEDIUM	SITE	RIVER	SAMPLE	DATE	Water Cr	Water Zn
		AREA	DEPTH		µg/L	µg/L
River	SRE2	Perth Water	Bottom	12/20/88	0.9	8
River	SRE3	Perth Water	Surface	12/20/88	0.6	5
River	SRE3	Perth Water	Bottom	12/20/88	1.5	<5
River	SRE6	Melville Water	Surface	12/20/88	<0.5	<5
River	SRE6	Melville Water	Bottom	12/20/88	0.6	6
River	SRF1	Perth Water	Surface	12/20/88	<0.5	5
River	SRF1	Perth Water	Bottom	12/20/88	1.7	8
River	SRF2	Perth Water	Surface	12/20/88	2.1	6
River	SRF2	Perth Water	Bottom	12/20/88	1.0	8
River	SRF3	Perth Water	Surface	12/20/88	0.5	7
River	SRF3	Perth Water	Bottom	12/20/88	<0.5	7
River	SRF4	Perth Water	Surface	12/20/88	0.8	6
River	SRF4	Perth Water	Bottom	12/20/88	0.6	9
River	SRG1	Perth Water	Surface	12/20/88	1.2	11
River	SRG1	Perth Water	Bottom	12/20/88	0.6	9
River	SRG2	Perth Water	Surface	12/20/88	0.6	5
River	SRG2	Perth Water	Bottom	12/20/88	0.9	7
River	SRG3	Perth Water	Surface	12/20/88	<0.5	5
River	SRG3	Perth Water	Bottom	12/20/88	0.8	6
River	SRG4	Perth Water	Surface	12/20/88	0.8	6
River	SRG4	Perth Water	Bottom	12/20/88	<0.5	7
River	SRH1	Perth Water	Surface	12/20/88	0.8	8
River	SRH1	Perth Water	Bottom	12/20/88	1.3	10
River	SRH2	Perth Water	Surface	12/20/88	1.3	<5
River	SRH2	Perth Water	Bottom	12/20/88	1.0	7
River	SRH3	Perth Water	Surface	12/20/88	0.8	5
River	SRH3	Perth Water	Bottom	12/20/88	<0.5	14
River	SRH4	Perth Water	Surface	12/20/88	0.6	<5
River	SRH4	Perth Water	Bottom	12/20/88	<0.5	8
River	SRI1	Perth Water	Surface	12/20/88	<0.5	<5
River	SRI1	Perth Water	Bottom	12/20/88	<0.5	7
River	SRI2	Perth Water	Surface	12/20/88	0.5	7
River	SRI2	Perth Water	Bottom	12/20/88	0.5	8
River	SRI3	Perth Water	Surface	12/20/88	0.5	<5
River	SRI3	Perth Water	Bottom	12/20/88	0.5	9
River	SRI4	Perth Water	Bottom	12/20/88	0.6	10
River	SRI4	Perth Water	Surface	12/20/88	0.8	6
River	SRJ1	Perth Water	Surface	12/20/88	0.7	5
River	SRJ1	Perth Water	Bottom	12/20/88	<0.5	9
River	SRJ2	Perth Water	Surface	12/20/88	0.5	10
River	SRJ2	Perth Water	Bottom	12/20/88	0.6	10
River	SRJ3	Perth Water	Surface	12/20/88	0.5	16
River	SRJ3	Perth Water	Bottom	12/20/88	1.1	7
River	SRK1	Perth Water	Surface	12/20/88	0.5	16
River	SRK1	Perth Water	Bottom	12/20/88	0.7	7
River	SRK2	Perth Water	Surface	12/20/88	<0.5	14
River	SRK2	Perth Water	Bottom	12/20/88	0.8	10



Appendix 1 water

MEDIUM	SITE	RIVER AREA	SAMPLE DEPTH	DATE	Water Cr µg/L	Water Zn µg/L
River	SRL1	Perth Water	Surface	12/20/88	0.6	7
River	SRL1	Perth Water	Bottom	12/20/88	0.6	7
River	SRL2	Perth Water	Surface	12/20/88	<0.5	9
River	SRL2	Perth Water	Bottom	12/20/88	<0.5	9
River	SRM1	East Perth Water	Surface	12/20/88	0.5	11
River	SRM1	East Perth Water	Bottom	12/20/88	0.8	12
River	SRM2	East Perth Water	Surface	12/20/88	<0.5	13
River	SRM2	East Perth Water	Bottom	12/20/88	<0.5	7
River	SRN1	East Perth Water	Surface	12/20/88	<0.5	11
River	SRN1	East Perth Water	Bottom	12/20/88	0.5	10
River	SRO1	East Perth Water	Surface	12/20/88	5.6	14
River	SRO1	East Perth Water	Bottom	12/20/88	0.9	11
River	SRP1	u/s Bunbury Bridge	Surface	12/20/88	1.0	12
River	SRP1	u/s Bunbury Bridge	Bottom	12/20/88	1.4	11
River	SRQ1	u/s Bunbury Bridge	Surface	12/20/88	<0.5	13
River	SRQ1	u/s Bunbury Bridge	Bottom	12/20/88	<0.5	12
Water drain	SRCMD1	East Perth Water	Surface	12/22/88	13.0	64
Water drain	SRCMD2	East Perth Water	Surface	12/22/88	11.0	60
Water drain	SRCMD3	East Perth Water	Surface	12/22/88	0.6	8
Water drain	SRCMD4	East Perth Water	Surface	12/22/88	7.1	47
Water drain	SRCMD5	East Perth Water	Surface	12/22/88	11.0	49
Water drain	SRCMD6	East Perth Water	Surface	12/22/88	2.9	17
Water drain	SRCMD7	East Perth Water	Surface	12/22/88	11.0	50
Water drain	SRCMD8	East Perth Water	Surface	12/22/88	11.0	52
Water drain	SRCMD9	East Perth Water	Surface	12/22/88	2.9	18
Water drain	SRCMD10	East Perth Water	Surface	12/22/88	3.3	20
Water drain	SRCMD1	East Perth Water	Surface	12/23/88	27.0	81
Water drain	SRCMD2	East Perth Water	Surface	12/23/88	23.0	67
Water drain	SRCMD3	East Perth Water	Surface	12/23/88	1.2	18
Water drain	SRCMD4	East Perth Water	Surface	12/23/88	2.7	23
Water drain	SRCMD5	East Perth Water	Surface	12/23/88	23.0	82
Water drain	SRCMD6	East Perth Water	Surface	12/23/88	1.3	16
Water drain	SRCMD7	East Perth Water	Surface	12/23/88	7.9	63
Water drain	SRCMD8	East Perth Water	Surface	12/23/88	22.0	70
Water drain	SRCMD9	East Perth Water	Surface	12/23/88	12.0	49
Water drain	SRCMD10	East Perth Water	Surface	12/23/88	2.0	29
River	SRC6	Melville Water	Surface	03/09/89	1.1	<5
River	SRC6	Melville Water	Bottom	03/09/89	0.6	10
River	SRD3	Melville Water	Surface	03/09/89	0.6	5
River	SRD3	Melville Water	Bottom	03/09/89	0.7	8
River	SRD4	Melville Water	Bottom	03/09/89	0.5	<5
River	SRD4	Melville Water	Surface	03/09/89	0.7	<5
River	SRD5	Melville Water	Surface	03/09/89	0.5	<5
River	SRD5	Melville Water	Bottom	03/09/89	0.8	5



Appendix 1 water

MEDIUM	SITE	RIVER AREA	SAMPLE DEPTH	DATE	Water Cr µg/L	Water Zn µg/L
River	SRD6	Melville Water	Surface	03/09/89	0.6	<5
River	SRD6	Melville Water	Bottom	03/09/89	0.5	7
River	SRE2	Perth Water	Surface	03/09/89	0.5	12
River	SRE2	Perth Water	Bottom	03/09/89	0.5	9
River	SRE3	Perth Water	Surface	03/09/89	0.8	<5
River	SRE3	Perth Water	Bottom	03/09/89	0.5	7
River	SRE6	Melville Water	Surface	03/09/89	<0.5	<5
River	SRE6	Melville Water	Bottom	03/09/89	1.1	8
River	SRF1	Perth Water	Surface	03/09/89	4.5	14
River	SRF1	Perth Water	Bottom	03/09/89	3.1	12
River	SRF1	Perth Water	Bottom	03/09/89	3.4	14
River	SRF2	Perth Water	Surface	03/09/89	1.2	6
River	SRF2	Perth Water	Bottom	03/09/89	<0.5	12
River	SRF3	Perth Water	Surface	03/09/89	0.5	14
River	SRF3	Perth Water	Bottom	03/09/89	<0.5	7
River	SRF4	Perth Water	Surface	03/09/89	0.5	<5
River	SRF4	Perth Water	Bottom	03/09/89	0.5	18
River	SRG1	Perth Water	Surface	03/09/89	0.5	6
River	SRG1	Perth Water	Bottom	03/09/89	0.5	20
River	SRG2	Perth Water	Surface	03/09/89	0.7	6
River	SRG2	Perth Water	Bottom	03/09/89	0.9	11
River	SRG3	Perth Water	Surface	03/09/89	0.7	6
River	SRG3	Perth Water	Bottom	03/09/89	<0.5	6
River	SRG4	Perth Water	Surface	03/09/89	0.5	7
River	SRG4	Perth Water	Bottom	03/09/89	0.7	57
River	SRH1	Perth Water	Surface	03/09/89	0.6	20
River	SRH1	Perth Water	Bottom	03/09/89	1.0	6
River	SRH2	Perth Water	Surface	03/09/89	<0.5	6
River	SRH2	Perth Water	Bottom	03/09/89	1.1	9
River	SRH3	Perth Water	Surface	03/09/89	1.3	5
River	SRH3	Perth Water	Bottom	03/09/89	0.5	10
River	SRH4	Perth Water	Surface	03/09/89	<0.5	6
River	SRH4	Perth Water	Bottom	03/09/89	1.3	8
River	SRI1	Perth Water	Surface	03/09/89	1.0	10
River	SRI1	Perth Water	Bottom	03/09/89	1.4	18
River	SRI2	Perth Water	Surface	03/09/89	0.5	<5
River	SRI2	Perth Water	Bottom	03/09/89	1.0	13
River	SRI3	Perth Water	Surface	03/09/89	0.8	11
River	SRI3	Perth Water	Bottom	03/09/89	<0.5	21
River	SRI4	Perth Water	Surface	03/09/89	<0.5	5
River	SRI4	Perth Water	Bottom	03/09/89	0.9	6
River	SRJ1	Perth Water	Surface	03/09/89	0.6	8
River	SRJ1	Perth Water	Bottom	03/09/89	1.3	<5
River	SRJ2	Perth Water	Surface	03/09/89	<0.5	15
River	SRJ2	Perth Water	Bottom	03/09/89	0.6	8
River	SRJ3	Perth Water	Surface	03/09/89	<0.5	9
River	SRJ3	Perth Water	Bottom	03/09/89	1.0	6



Appendix 1 water

MEDIUM	SITE	RIVER AREA	SAMPLE DEPTH	DATE	Water Cr µg/L	Water Zn µg/L
River	SRK1	Perth Water	Surface	03/09/89	1.1	9
River	SRK1	Perth Water	Bottom	03/09/89	1.1	9
River	SRK2	Perth Water	Surface	03/09/89	<0.5	12
River	SRK2	Perth Water	Bottom	03/09/89	0.8	12
River	SRL1	Perth Water	Surface	03/09/89	<0.5	10
River	SRL1	Perth Water	Bottom	03/09/89	1.0	7
River	SRL2	Perth Water	Surface	03/09/89	<0.5	12
River	SRL2	Perth Water	Bottom	03/09/89	<0.5	6
River	SRM1	East Perth Water	Surface	03/09/89	<0.5	7
River	SRM1	East Perth Water	Bottom	03/09/89	0.7	12
River	SRM2	East Perth Water	Surface	03/09/89	<0.5	17
River	SRM2	East Perth Water	Bottom	03/09/89	<0.5	6
River	SRN1	East Perth Water	Surface	03/09/89	<0.5	6
River	SRN1	East Perth Water	Bottom	03/09/89	0.7	10
River	SRO1	East Perth Water	Surface	03/09/89	<0.5	13
River	SRO1	East Perth Water	Bottom	03/09/89	0.8	10
River	SRP1	u/s Bunbury Bridge	Surface	03/09/89	<0.5	9
River	SRP1	u/s Bunbury Bridge	Bottom	03/09/89	0.5	7
River	SRQ1	u/s Bunbury Bridge	Surface	03/09/89	<0.5	8
River	SRQ1	u/s Bunbury Bridge	Bottom	03/09/89	<0.5	7
River	SRR1	u/s Bunbury Bridge	Surface	03/09/89	<0.5	11
River	SRR1	u/s Bunbury Bridge	Bottom	03/09/89	<0.5	11
Drain outfall	SRMBMD1 d/s	Perth Water	Surface	01/27/89	6.0	33
Drain outfall	SRMBMD1 u/s	Perth Water	Surface	01/27/89	420	250
Drain outfall	SRMBMD2	Perth Water	Surface	01/27/89	49.0	39
Drain outfall	SRMBMD3	Perth Water	Surface	01/27/89	140	93
Drain outfall	SRMBMD4	Perth Water	Surface	01/27/89	120	82
Drain outfall	SRMBMD5	Perth Water	Surface	01/27/89	40.0	30
Drain outfall	SRMBMD6	Perth Water	Surface	01/27/89	40.0	32
Drain outfall	SRMBMD7	Perth Water	Surface	01/27/89	70.0	41
Drain outfall	SRMBMD8	Perth Water	Surface	01/27/89	13.0	14
Drain outfall	SRMBMD9	Perth Water	Surface	01/27/89	84.0	50
Drain outfall	SRMBMD1d/s	Perth Water	Surface	02/24/89	140	49
Drain outfall	SRMBMD1u/s	Perth Water	Surface	02/24/89	780	250
Drain outfall	SRMBMD2	Perth Water	Surface	02/24/89	17.0	19
Drain outfall	SRMBMD3	Perth Water	Surface	02/24/89	19.0	22
Drain outfall	SRMBMD4	Perth Water	Surface	02/24/89	42.0	37
Drain outfall	SRMBMD5	Perth Water	Surface	02/24/89	42.0	20
Drain outfall	SRMBMD6	Perth Water	Surface	02/24/89	10.0	21
Drain outfall	SRMBMD7	Perth Water	Surface	02/24/89	20.0	27
Drain outfall	SRMBMD8	Perth Water	Surface	02/24/89	16.0	17
Drain outfall	SRMBMD9	Perth Water	Surface	02/24/89	4.7	15
Drain outfall	MBMD1d/s	Perth Water	Surface	02/24/89	840	300
Drain outfall	MBMD1u/s	Perth Water	Surface	02/24/89	90.0	52
Drain outfall	SRCMD1	East Perth Water	Surface	02/02/89	8.5	58
Drain outfall	SRCMD2	East Perth Water	Surface	02/02/89	5.3	41



Appendix 1 water

MEDIUM	SITE	RIVER AREA	SAMPLE DEPTH	DATE	Water Cr µg/L	Water Zn µg/L
Drain outfall	SRCMD3	East Perth Water	Surface	02/02/89	3.0	20
Drain outfall	SRCMD4	East Perth Water	Surface	02/02/89	2.6	25
Drain outfall	SRCMD5	East Perth Water	Surface	02/02/89	4.2	44
Drain outfall	SRCMD6	East Perth Water	Surface	02/02/89	1.3	22
Drain outfall	SRCMD7	East Perth Water	Surface	02/02/89	4.6	41
Drain outfall	SRCMD8	East Perth Water	Surface	02/02/89	4.7	44
Drain outfall	SRCMD9	East Perth Water	Surface	02/02/89	3.1	31



Appendix 2 sediments

MEDIUM	SITE	River Area	DATE	Blo Av Cr mg/kg	BAV Zn mg/kg	Sed Cr mg/kg	Sed Zn mg/kg	Loss on Ignition percent %
Sediment	SR16	Melville Water	11/16/88	n/a	n/a	23	230	19.9
Sediment	SR23A	Canning River	11/16/88	n/a	n/a	49	210	18.6
Sediment	SR5	u/s Bunbury Bridge	11/16/88	n/a	n/a	31	45	6.1
Sediment	SR9	u/s Bunbury Bridge	11/16/88	n/a	n/a	41	260	19.1
Sediment	SRC6	Melville Water	11/10/88	n/a	n/a	21	91	6.1
Sediment	SRD3	Melville Water	11/10/88	n/a	n/a	65	220	19.7
Sediment	SRD4	Melville Water	11/10/88	n/a	n/a	31	140	11.5
Sediment	SRD5	Melville Water	11/10/88	n/a	n/a	53	170	18.8
Sediment	SRD6	Melville Water	11/10/88	n/a	n/a	62	180	16.7
Sediment	SRE2	Perth Water	11/11/88	n/a	n/a	65	240	19.7
Sediment	SRE3	Perth Water	11/10/88	n/a	n/a	41	210	20.9
Sediment	SRE6	Melville Water	11/10/88	n/a	n/a	74	260	16.2
Sediment	SRE2	Perth Water	11/15/88	n/a	n/a	87	290	19.0
Sediment	SRE3	Perth Water	11/11/88	n/a	n/a	36	560	15.9
Sediment	SRE4	Perth Water	11/11/88	n/a	n/a	30	220	17.2
Sediment	SRE1	Perth Water	11/15/88	n/a	n/a	23	340	16.1
Sediment	SRE2	Perth Water	11/15/88	n/a	n/a	46	200	13.7
Sediment	SRE3	Perth Water	11/11/88	n/a	n/a	26	240	14.3
Sediment	SRE4	Perth Water	11/11/88	n/a	n/a	43	250	17.0
Sediment	SRE1	Perth Water	11/15/88	n/a	n/a	45	250	10.9
Sediment	SRE2	Perth Water	11/15/88	n/a	n/a	67	220	11.5
Sediment	SRE3	Perth Water	11/11/88	n/a	n/a	23	150	11.1
Sediment	SRE4	Perth Water	11/11/88	n/a	n/a	32	180	12.3
Sediment	SRE1	Perth Water	11/15/88	n/a	n/a	8.2	70	2.0
Sediment	SRE2	Perth Water	11/15/88	n/a	n/a	46	170	6.4
Sediment	SRE3	Perth Water	11/11/88	n/a	n/a	42	220	8.9
Sediment	SRE4	Perth Water	11/15/88	n/a	n/a	100	400	19.0
Sediment	SRE1	Perth Water	11/15/88	n/a	n/a	67	640	16.8
Sediment	SRE2	Perth Water	11/11/88	n/a	n/a	16	460	6.4
Sediment	SRE3	Perth Water	11/11/88	n/a	n/a	74	320	16.6
Sediment	SRE1	Perth Water	11/11/88	n/a	n/a	92	290	18.8
Sediment	SRE2	Perth Water	11/11/88	n/a	n/a	61	360	17.5
Sediment	SRE1	Perth Water	11/10/88	n/a	n/a	49	330	14.3
Sediment	SRE2	Perth Water	11/10/88	n/a	n/a	64	350	15.1
Sediment	SRE1	East Perth Water	11/10/88	n/a	n/a	83	310	15.8
Sediment	SRE2	East Perth Water	11/10/88	n/a	n/a	69	200	18.8
Sediment	SRE1	East Perth Water	11/10/88	n/a	n/a	88	320	18.6
Sediment	SRE1	East Perth Water	11/10/88	n/a	n/a	85	340	18.6
Sediment	SRE1	u/s Bunbury Bridge	11/10/88	n/a	n/a	40	240	19.2
Sediment	SRE1	u/s Bunbury Bridge	11/10/88	n/a	n/a	23	160	11.8
Sediment drain	SRE1	Perth Water	11/15/88	n/a	n/a	12	160	1.7
Sediment drain	SRE1	Perth Water	11/15/88	n/a	n/a	19	170	1.5
Sediment drain	SRE1	Perth Water	11/14/88	n/a	n/a	14	190	1.9
Sediment drain	SRE1	Perth Water	11/15/88	n/a	n/a	13	53	0.6
Sediment drain	SRE1	Perth Water	11/11/88	n/a	n/a	81	840	18.4
Sediment drain	SRE1	Perth Water	11/11/88	n/a	n/a	54	200	15.0
Sediment drain	SRE1	Perth Water	11/15/88	n/a	n/a	10	38	0.8
Sediment drain	SRE1	Perth Water	11/15/88	n/a	n/a	19	200	0.7
Sediment drain	SRE1	East Perth Water	11/10/88	n/a	n/a	23	630	6.6



Appendix 2 sediments

MEDIUM	SITE	River	DATE	Bio Av	BAV	Sed	Sed	Loss on
		Area		Cr	Zn	Cr	Zn	Ignition
				mg/kg	mg/kg	mg/kg	mg/kg	percent %
Sediment	SR16	Melville WaterD	03/23/89	31	140	55	140	1.6
Sediment	SR23A	Canning River	03/23/89	30	230	30	230	20.0
Sediment	SR5	u/s Bunbury Bridge	03/23/89	8.8	180	9.0	200	1.8
Sediment	SAC4	Melville Water	04/07/89			56	180	18.2
Sediment	SAC6	Melville Water	03/15/89	22	160	26	160	9.8
Sediment	SAD3	Melville Water	04/05/89	43	280	65	280	18.9
Sediment	SAD5	Melville Water	04/07/89	n/a	n/a	9.2	33	2.4
Sediment	SAD6	Melville Water	03/15/89	41	280	62	280	15.2
Sediment	SAR2	Perth Water	03/15/89	52	300	61	300	19.5
Sediment	SAR3	Perth Water	03/15/89	44	260	61	300	19.7
Sediment	SAR6	Melville Water	03/15/89	37	250	51	300	17.2
Sediment	SAR1	Perth Water	04/05/89	57	340	59	340	13.3
Sediment	SAR2	Perth Water	03/14/89	55	340	74	340	17.5
Sediment	SAR3	Perth Water	04/04/89	41	250	66	250	0.0
Sediment	SAR4	Perth Water	04/04/89	36	220	41	250	11.9
Sediment	SAG1	Perth Water	04/04/89	56	340	54	340	12.8
Sediment	SAG2	Perth Water	04/14/89	43	250	46	250	12.3
Sediment	SAG3	Perth Water	04/04/89	44	270	62	270	14.3
Sediment	SAG4	Perth Water	04/04/89	41	260	63	270	12.7
Sediment	SAH1	Perth Water	04/05/89	54	360	54	360	12.0
Sediment	SAH2	Perth Water	03/14/89	34	210	48	210	9.7
Sediment	SAH3	Perth Water	04/04/89	42	270	42	270	14.2
Sediment	SAH4	Perth Water	04/04/89	48	300	48	300	16.4
Sediment	SRI1	Perth Water	04/05/89	32	270	37	320	8.9
Sediment	SRI2	Perth Water	03/14/89	23	160	29	160	6.7
Sediment	SRI3	Perth Water	04/05/89	36	310	55	310	12.1
Sediment	SRI4	Perth Water	04/04/89	52	450	71	450	16.7
Sediment	SRJ1	Perth Water	04/05/89	57	350	68	450	16.3
Sediment	SRJ2	Perth Water	04/05/89	36	240	36	240	11.3
Sediment	SRJ3	Perth Water	04/05/89	25	190	35	240	12.0
Sediment	SRK1	Perth Water	04/06/89	56	330	98	410	15.5
Sediment	SRK2	Perth Water	04/06/89	55	360	55	360	18.2
Sediment	SRL2	Perth Water	04/06/89	51	340	59	360	18.0
Sediment	SRL1	Perth Water	04/06/89	36	360	39	360	12.1
Sediment	SRI1	East Perth Water	04/06/89	21	120	25	130	9.0
Sediment	SRI2	East Perth Water	04/06/89	45	330	45	330	21.0
Sediment	SRI1	East Perth Water	03/15/89	150	440	150	440	9.0
Sediment	SRI1	East Perth Water	03/15/89	110	530	110	530	13.9
Sediment	SRP1	u/s Bunbury Bridge	03/15/89	36	200	36	200	3.1
Sediment	SRI1	u/s Bunbury Bridge	03/15/89	7.5	160	7.5	160	1.2
Sediment drain	SFPSMD	Perth Water	03/14/89	60	380	60	400	17.8
Sediment drain	SFPSMD	Perth Water	03/14/89	72	520	75	530	19.3
Sediment drain	SRVAMD	Perth Water	03/14/89	56	310	56	310	19.1
Sediment drain	SRMBMD6	Perth Water	03/14/89	50	360	54	360	17.3
Sediment drain	SRHSMO	Perth Water	03/14/89	15	120	22	120	3.1
Sediment drain	SRMBMD1	Perth Water	03/14/89	50	350	56	350	18.7
Sediment drain	SACMD2	Perth Water	04/06/89	18	160	18	170	2.0
Sediment drain	SFBSMD	Perth Water	03/14/89	47	390	100	420	16.2



Appendix 3 Algae

SPECIES	SITE	Area	DATE	Chromium mg/kg (wet wt)	Zinc mg/kg (wet wt)
<i>Gracilaria</i>	SRE6	Melville Water	11/10/88	1.4	34
<i>Gracilaria</i>	SRF4	Perth Water	11/11/88	0.2	9.1
<i>Gracilaria</i>	SRG4	Perth Water	11/11/88	0.6	17
<i>Gracilaria</i>	SRH4	Perth Water	11/11/88	1.7	43
<i>Gracilaria</i>	SRI3	Perth Water	11/11/88	0.9	29
<i>Gracilaria</i>	SRI3	Perth Water	11/16/88	0.4	12
<i>Gracilaria</i>	SRI4	Perth Water	11/15/88	2.1	61
<i>Gracilaria</i>	SRJ3	Perth Water	11/11/88	0.2	17
<i>Gracilaria</i>	SRJ3	Perth Water	12/02/88	1.6	20
<i>Gracilaria</i>	SRK1	Perth Water	11/11/88	5.3	83
<i>Gracilaria</i>	SRK2	Perth Water	11/15/88	0.9	24
<i>Gracilaria</i>	SRK2	Perth Water	12/02/88	1.1	14
<i>Gracilaria</i>	SRL2	Perth Water	11/10/88	0.4	41
<i>Gracilaria</i>	SRM1	East Perth Water	12/02/88	0.2	25
<i>Gracilaria</i>	SRN1	Perth Water	12/02/88	0.5	6.6
<i>Gracilaria</i>	SRP1	u/s Bunbury Bridge	02/12/88	0.8	47
<i>Gracilaria</i>	SRPSMD	Perth Water	11/15/88	1.3	12
<i>Gracilaria</i>	SRVAMD	Perth Water	11/15/88	4.1	44
<i>Gracilaria</i>	SRBSMD	Perth Water	11/15/88	1.3	11
<i>Gracilaria</i>	SR23A	Canning River	04/07/89	0.5	17
<i>Gracilaria</i>	SR3	Middle Swan Br	04/07/89	0.5	15
<i>Gracilaria</i>	SRD6	Melville Water	03/15/89	3.5	30
<i>Gracilaria</i>	SRE6	Melville Water	03/15/89	3.8	50
<i>Gracilaria</i>	SRI1	Perth Water	04/04/89	1.5	17
<i>Gracilaria</i>	SRJ2	Perth Water	04/05/89	1.8	47
<i>Gracilaria</i>	SRJ3	Perth Water	04/05/89	2.8	40
<i>Gracilaria</i>	SRK2	Perth Water	04/06/89	3.0	210
<i>Gracilaria</i>	SRL1	Perth Water	06/04/89	1.3	38
<i>Gracilaria</i>	SRM1	East Perth Water	04/06/89	1.0	43
<i>Gracilaria</i>	SRM2	East Perth Water	04/06/89	2.6	180
<i>Gracilaria</i>	SRN1	East Perth Water	03/15/89	3.4	98
<i>Gracilaria</i>	SRP1	u/s Bunbury Bridge	03/15/89	2.1	140
<i>Grateloupea</i>	SRVAMD	Perth Water	03/14/89	0.3	4.9
<i>Hypnea</i>	SRVAMD	Perth Water	03/14/89	2.5	12
<i>Ulva</i>	SRBSMD	Perth Water	03/14/89	0.6	5.5
<i>Ulva</i>	SRVAMD	Perth Water	03/14/89	1.6	6.7



Appendix 4 Molluscs

Animal type	SPECIES	SITE	Area	DATE	Chromium mg/kg	Zinc mg/kg
Mollusc mussel	<i>Xenostrobus securis</i>	SRG2	Perth Water	15/11/88	1.1	21
Mollusc mussel	<i>Xenostrobus securis</i>	SRG3	Perth Water	11/11/88	1.4	17
Mollusc mussel	<i>Xenostrobus securis</i>	SRH1	Perth Water	15/11/88	2.6	27
Mollusc mussel	<i>Xenostrobus securis</i>	SRH2	Perth Water	15/11/88	1.2	17
Mollusc mussel	<i>Xenostrobus securis</i>	SRH3	Perth Water	11/11/88	1.4	16
Mollusc mussel	<i>Xenostrobus securis</i>	SRI1	Perth Water	15/11/88	1.1	23
Mollusc mussel	<i>Xenostrobus securis</i>	SRI2	Perth Water	15/11/88	1.4	24
Mollusc mussel	<i>Xenostrobus securis</i>	SRI2	Perth Water	02/12/88	0.7	12
Mollusc mussel	<i>Xenostrobus securis</i>	SRI3	Perth Water	02/12/88	1.0	16
Mollusc mussel	<i>Xenostrobus securis</i>	SRJ1	Perth Water	15/11/88	1.9	26
Mollusc mussel	<i>Xenostrobus securis</i>	SRJ2	Perth Water	11/11/88	0.8	17
Mollusc mussel	<i>Xenostrobus securis</i>	SRK1	Perth Water	02/12/88	1.1	14
Mollusc mussel	<i>Xenostrobus securis</i>	SRK2	Perth Water	15/11/88	1.6	20
Mollusc mussel	<i>Xenostrobus securis</i>	SRK2	Perth Water	15/11/88	1.4	49
Mollusc mussel	<i>Xenostrobus securis</i>	SRK2	Perth Water	15/11/88	0.5	16
Mollusc mussel	<i>Xenostrobus securis</i>	SRL2	Perth Water	10/11/88	2.2	27
Mollusc mussel	<i>Xenostrobus securis</i>	SRM1	East Perth Water	02/12/88	1.1	18
Mollusc mussel	<i>Xenostrobus securis</i>	SRN1	East Perth Water	02/12/88	1.2	21
Mollusc mussel	<i>Xenostrobus securis</i>	SRO1	East Perth Water	10/11/88	4.7	45
Mollusc mussel	<i>Xenostrobus securis</i>	SRP1	u/s Bunbury Bridge	06/12/88	1.6	19
Mollusc mussel	<i>Xenostrobus securis</i>	SRQ1	u/s Bunbury Bridge	10/11/88	1.0	40
Mollusc mussel	<i>Xenostrobus securis</i>	SRBSMD	Perth Water	15/11/88	5.3	13
Mollusc mussel	<i>Xenostrobus securis</i>	SRPSMD	Perth Water	15/11/88	4.0	23
Mollusc mussel	<i>Xenostrobus securis</i>	SRVAMD	Perth Water	15/11/88	17.0	31
Mollusc bivalve	<i>Spisula trigonella</i>	SRE2	Perth Water	15/11/88	1.8	16
Mollusc bivalve	<i>Spisula trigonella</i>	SRF2	Perth Water	15/11/88	1.1	11
Mollusc bivalve	<i>Spisula trigonella</i>	SRF3	Perth Water	15/11/88	0.8	12
Mollusc bivalve	<i>Spisula trigonella</i>	SRF4	Perth Water	11/11/88	2.9	18
Mollusc bivalve	<i>Spisula trigonella</i>	SRG1	Perth Water	15/11/88	2.5	19
Mollusc bivalve	<i>Spisula trigonella</i>	SRG2	Perth Water	15/11/88	1.4	13
Mollusc bivalve	<i>Spisula trigonella</i>	SRG4	Perth Water	11/11/88	1.5	15
Mollusc bivalve	<i>Spisula trigonella</i>	SRH1	Perth Water	15/11/88	1.3	12
Mollusc bivalve	<i>Spisula trigonella</i>	SRH2	Perth Water	15/11/88	1.1	11
Mollusc bivalve	<i>Spisula trigonella</i>	SRH3	Perth Water	11/11/88	1.6	14
Mollusc bivalve	<i>Spisula trigonella</i>	SRH4	Perth Water	11/11/88	2.3	16
Mollusc bivalve	<i>Spisula trigonella</i>	SRI2	Perth Water	15/11/88	4.6	24
Mollusc bivalve	<i>Spisula trigonella</i>	SRI3	Perth Water	02/12/88	0.5	9.4
Mollusc bivalve	<i>Spisula trigonella</i>	SRI4	Perth Water	15/11/88	1.6	18
Mollusc bivalve	<i>Spisula trigonella</i>	SRK2	Perth Water	02/12/88	3.5	29
Mollusc mussel	<i>Xenostrobus securis</i>	SRC6	Melville Water	15/03/89	0.5	10
Mollusc mussel	<i>Xenostrobus securis</i>	SRD6	Melville Water	15/03/89	0.3	72
Mollusc mussel	<i>Xenostrobus securis</i>	SRI1	Perth Water	05/04/89	0.6	11
Mollusc mussel	<i>Xenostrobus securis</i>	SRI4	Perth Water	04/04/89	1.9	18
Mollusc mussel	<i>Xenostrobus securis</i>	SRJ2	Perth Water	05/04/89	0.6	13
Mollusc mussel	<i>Xenostrobus securis</i>	SRK1	Perth Water	06/04/89	0.7	9.0
Mollusc mussel	<i>Xenostrobus securis</i>	SRL1	Perth Water	06/04/89	0.3	10
Mollusc mussel	<i>Xenostrobus securis</i>	SRL2	Perth Water	06/04/89	1.0	8.8



Appendix 4 Molluscs

Animal type	SPECIES	SITE	Area	DATE	Chromium	Zinc
					mg/kg	mg/kg
Mollusc mussel	<i>Xenostrobus securis</i>	SRM1	East Perth Water	06/04/89	0.2	12
Mollusc mussel	<i>Xenostrobus securis</i>	SRN1	East Perth Water	15/03/89	1.1	16
Mollusc mussel	<i>Xenostrobus securis</i>	SRO1	East Perth Water	15/03/89	0.3	12
Mollusc mussel	<i>Xenostrobus securis</i>	SRP1	u/s Bunbury Bridge	15/03/89	1.2	17
Mollusc mussel	<i>Xenostrobus securis</i>	SRQ1	u/s Bunbury Bridge	15/03/89	0.3	13
Mollusc mussel	<i>Xenostrobus securis</i>	SRVAMD	Perth Water	14/03/89	13.0	15
Mollusc mussel	<i>Xenostrobus securis</i>	SRBSMD	Perth Water	14/03/89	3.9	16
Mollusc mussel	<i>Xenostrobus securis</i>	SRCMD	East Perth Water	06/04/89	0.4	12
Mollusc mussel	<i>Xenostrobus securis</i>	SRPSMD	Perth Water	14/03/89	1.1	14
Mollusc bivalve	<i>Spisula trigonella</i>	SRD3	Melville Water	05/04/89	1.9	17
Mollusc bivalve	<i>Spisula trigonella</i>	SRD4	Melville Water	07/04/89	1.3	15
Mollusc bivalve	<i>Spisula trigonella</i>	SRD5	Melville Water	07/04/89	0.2	10
Mollusc bivalve	<i>Spisula trigonella</i>	SRE2	Perth Water	16/03/89	1.8	17
Mollusc bivalve	<i>Spisula trigonella</i>	SRE3	Perth Water	15/03/89	2.0	17
Mollusc bivalve	<i>Spisula trigonella</i>	SRF2	Perth Water	14/04/89	1.1	13
Mollusc bivalve	<i>Spisula trigonella</i>	SRF3	Perth Water	04/04/89	0.5	9.8
Mollusc bivalve	<i>Spisula trigonella</i>	SRF4	Perth Water	04/04/89	0.2	11
Mollusc bivalve	<i>Spisula trigonella</i>	SRG1	Perth Water	04/04/89	1.4	15
Mollusc bivalve	<i>Spisula trigonella</i>	SRG2	Perth Water	03/04/89	1.3	13
Mollusc bivalve	<i>Spisula trigonella</i>	SRG3	Perth Water	04/04/89	0.4	10
Mollusc bivalve	<i>Spisula trigonella</i>	SRG4	Perth Water	04/04/89	0.3	8.2
Mollusc bivalve	<i>Spisula trigonella</i>	SRH1	Perth Water	05/04/89	1.1	15
Mollusc bivalve	<i>Spisula trigonella</i>	SRH2	Perth Water	14/03/89	1.1	11
Mollusc bivalve	<i>Spisula trigonella</i>	SRH3	Perth Water	04/04/89	0.7	11
Mollusc bivalve	<i>Spisula trigonella</i>	SRH4	Perth Water	04/04/89	0.4	10
Mollusc bivalve	<i>Spisula trigonella</i>	SRI2	Perth Water	14/03/89	2.0	17
Mollusc bivalve	<i>Spisula trigonella</i>	SRI3	Perth Water	05/04/89	1.7	18
Mollusc bivalve	<i>Spisula trigonella</i>	SRI4	Perth Water	04/04/89	2.1	18
Mollusc bivalve	<i>Spisula trigonella</i>	SRJ1	Perth Water	05/04/89	1.5	14
Mollusc bivalve	<i>Spisula trigonella</i>	SRJ2	Perth Water	05/04/89	1.4	14
Mollusc bivalve	<i>Spisula trigonella</i>	SRK1	Perth Water	06/04/89	0.9	10
Mollusc bivalve	<i>Spisula trigonella</i>	SRK2	Perth Water	06/04/89	1.8	14
Mollusc bivalve	<i>Spisula trigonella</i>	SRL1	Perth Water	06/04/89	0.8	14
Mollusc bivalve	<i>Spisula trigonella</i>	SRL1	Perth Water	06/04/89	1.0	11
Mollusc bivalve	<i>Spisula trigonella</i>	SRL1	Perth Water	06/04/89	2.5	18
Mollusc bivalve	<i>Spisula trigonella</i>	SRM2	EPerth Water	06/04/89	1.8	16
Biota gastropod	<i>Bedevea paivae</i>	SRD4	Perth Water	11/11/88	0.7	85
Biota gastropod	<i>Velacumantis australis</i>	SRC6	Melville Water	10/11/88	0.7	39



Appendix 5 Fish

Common name	SPECIES	SITE	Water Area	DATE	Cr mg/kg Wet Wt	Zn mg/kg Wet Wt
blackbream flesh	<i>Acanthopagrus butcheri</i>	SPFISH2	Perth	09/11/88	0.1	7.0
blowfish gonads female	<i>Torquigener pleurogramma</i>	SPFISH2	Perth	09/11/88	<0.1	37
cobbler flesh	<i>Cnidoglanis macrocephalus</i>	SPFISH1	Perth	09/11/88	<0.1	6.2
cobbler flesh	<i>Cnidoglanis macrocephalus</i>	SPFISH1	Perth	09/11/88	<0.1	5.2
cobbler flesh	<i>Cnidoglanis macrocephalus</i>	SPFISH1	Perth	09/11/88	<0.1	55
cobbler gonads female	<i>Cnidoglanis macrocephalus</i>	SPFISH1	Perth	09/11/88	<0.1	22
cobbler gonads male	<i>Cnidoglanis macrocephalus</i>	SPFISH1	Perth	09/11/88	0.1	11
cobbler liver	<i>Cnidoglanis macrocephalus</i>	SPFISH1	Perth	09/11/88	0.2	15
gobbleguts whole minus viscera	<i>Apogon rueppellii</i>	SPFISH2	Perth	09/11/88	0.1	19
goby whole	<i>Amoya bifrenates</i>	SPFISH1	Perth	09/11/88	0.1	28
goby whole	<i>Amoya bifrenates</i>	SPFISH2	Perth	09/11/88	0.1	25
perth herring gonads male	<i>Nematolosa vlaminghi</i>	SPFISH2	Perth	09/11/88	0.1	54
perth herring gonads male	<i>Nematolosa vlaminghi</i>	SPFISH2	Perth	09/11/88	1.6	78
perth herring liver	<i>Nematolosa vlaminghi</i>	SPFISH2	Perth	09/11/88	4.9	36
perth herring liver	<i>Nematolosa vlaminghi</i>	SPFISH2	Perth	09/11/88	1.1	23
perth herring viscera	<i>Nematolosa vlaminghi</i>	SPFISH2	Perth	09/11/88	3.1	26
perth herring flesh	<i>Nematolosa vlaminghi</i>	SPFISH3	East Perth	09/11/88	0.1	8.4
trumpeter six-line flesh	<i>Pelates sexlineatus</i>	SPFISH2	Perth	09/11/88	0.1	11
trumpeter six-line liver	<i>Pelates sexlineatus</i>	SPFISH2	Perth	09/11/88	<0.1	24
coelenterate jellyfish brown mouthparts	<i>Phyllorhiza punctata</i>	SPFISH1	Perth	29/03/89	<0.1	15
coelenterate jellyfish brown medusa	<i>Phyllorhiza punctata</i>	SPFISH2	Perth	29/03/89	0.1	1.4
coelenterate jellyfish brown medusa	<i>Phyllorhiza punctata</i>	SPFISH2	Perth	29/03/89	<0.1	0.7
coelenterate jellyfish brown tentacles	<i>Phyllorhiza punctata</i>	SPFISH2	Perth	29/03/89	0.2	6.1
coelenterate jellyfish brown tentacles	<i>Phyllorhiza punctata</i>	SPFISH2	Perth	29/03/89	0.1	7.8
crustacea shrimp whole	<i>Palaemonetes australis</i>	SR23A	Canning	07/04/89	0.2	25
crustacea shrimp whole	<i>Palaemonetes australis</i>	SR3	u/s Swan	07/04/89	0.2	21
crustacea shrimp whole	<i>Palaemonetes australis</i>	SRJ3	Perth	05/04/89	<0.1	28
crustacean crab manna flesh	<i>Portunus pelagicus</i>	SPFISH1	Perth	04/04/89	0.1	34
crustacean prawn king flesh	<i>Penaeus latisukatus</i>	SPFISH2	Perth	29/03/89	<0.1	15
blowfish flesh	<i>Torquigener pleurogramma</i>	SPFISH1	Perth	29/03/89	0.1	6.7
blowfish liver	<i>Torquigener pleurogramma</i>	SPFISH1	Perth	29/03/89	<0.1	30
blowfish flesh	<i>Torquigener pleurogramma</i>	SPFISH2	Perth	29/03/89	0.5	8.0
blowfish gonads male	<i>Torquigener pleurogramma</i>	SPFISH2	Perth	29/03/89	2.1	76
blowfish liver	<i>Torquigener pleurogramma</i>	SPFISH2	Perth	29/03/89	0.7	16
cobbler flesh	<i>Cnidoglanis macrocephalus</i>	SPFISH1	Perth	04/02/89	0.2	7.6
cobbler flesh	<i>Cnidoglanis macrocephalus</i>	SPFISH1	Perth	03/04/89	0.2	0.3
cobbler liver	<i>Cnidoglanis macrocephalus</i>	SPFISH1	Perth	03/04/89	0.2	34
cobbler viscera	<i>Cnidoglanis macrocephalus</i>	SPFISH1	Perth	03/04/89	0.3	15
cobbler flesh	<i>Cnidoglanis macrocephalus</i>	SPFISH2	Perth	05/04/89	0.3	7.5
cobbler liver	<i>Cnidoglanis macrocephalus</i>	SPFISH2	Perth	05/04/89	0.1	25
cobbler viscera	<i>Cnidoglanis macrocephalus</i>	SPFISH2	Perth	05/04/89	0.1	24
cobbler flesh	<i>Cnidoglanis macrocephalus</i>	SPFISH3	East Perth	04/04/89	0.1	4.9
cobbler liver	<i>Cnidoglanis macrocephalus</i>	SPFISH3	East Perth	04/04/89	<0.1	30
cobbler viscera	<i>Cnidoglanis macrocephalus</i>	SPFISH3	East Perth	04/04/89	<0.1	29
gobbleguts whole	<i>Apogon rueppellii</i>	SPFISH2	Perth	29/03/89	<0.1	13
goby whole	<i>Amoya bifrenates</i>	SPFISH2	Perth	29/03/89	0.5	33
goby whole	<i>Amoya bifrenates</i>	SPFISH3	East Perth	29/03/89	0.6	34
Hardyhead Ogilby's flesh	<i>Pranesus ogilbyi</i>	SPFISH1	Perth	29/03/89	<0.1	34
Hardyhead Ogilby's minus head/viscera	<i>Pranesus ogilbyi</i>	SPFISH1	Perth	29/03/89	<0.1	37



Appendix 5 Fish

Common name	SPECIES	SITE	Water	DATE	Cr	Zn
			Area		mg/kg	mg/kg
					Wet Wt	Wet Wt
Hardyhead Ogilby's viscera	<i>Pranesus ogilbyi</i>	SFFSH1	Perth	29/03/89	0.6	30
Hardyhead Ogilby's whole	<i>Pranesus ogilbyi</i>	SFFSH1	Perth	09/04/89	0.7	42
Hardyhead Ogilby's minus head/viscera	<i>Pranesus ogilbyi</i>	SFFSH3	East Perth	29/03/89	<0.1	11
Hardyhead Ogilby's viscera	<i>Pranesus ogilbyi</i>	SFFSH3	East Perth	29/03/89	0.5	28
Hardyheads whole	<i>Atherinasoma wallacei</i> , <i>A. presbyteroides</i>	SFFSH1	Perth	09/04/89	0.1	51
Hardyheads whole	<i>Atherinasoma wallacei</i> , <i>A. presbyteroides</i>	SFFSH3	East Perth	29/03/89	0.3	60
Hardyheads whole minus head /viscera	<i>Atherinasoma wallacei</i> , <i>A. presbyteroides</i>	SFFSH1	Perth	09/04/89	0.1	39
mullet sea flesh	<i>Mugil cephalus</i>	SFFSH1	Perth	29/03/89	<0.1	20
mullet sea viscera	<i>Mugil cephalus</i>	SFFSH1	Perth	29/03/89	1.5	33
mullet sea whole minus head/viscera	<i>Mugil cephalus</i>	SFFSH1	Perth	29/03/89	<0.1	8.7
mullet sea liver	<i>Mugil cephalus</i>	SFFSH3	East Perth	04/04/89	0.3	150
mullet sea flesh	<i>Mugil cephalus</i>	SFFSH3	East Perth	04/04/89	<0.1	3.0
mullet sea viscera	<i>Mugil cephalus</i>	SFFSH3	East Perth	04/04/89	3.0	36
mullet sea whole minus head/viscera	<i>Mugil cephalus</i>	SFFSH3	East Perth	29/03/89	<0.1	11
mullet yelloweye whole	<i>Aldrichetta forsteri</i>	SFFSH3	East Perth	29/03/89	<0.1	15
perth herring minus head and viscera	<i>Nematolosa vlaminghi</i>	SFFSH1	Perth	29/03/89	<0.1	7.0
perth herring minus head and viscera	<i>Nematolosa vlaminghi</i>	SFFSH1	Perth	29/03/89	0.3	24
perth herring flesh	<i>Nematolosa vlaminghi</i>	SFFSH1	Perth	29/03/89	<0.1	16
perth herring liver	<i>Nematolosa vlaminghi</i>	SFFSH1	Perth	29/03/89	4.5	56
perth herring flesh	<i>Nematolosa vlaminghi</i>	SFFSH2	Perth	29/03/89	0.5	5.4
perth herring gonads female	<i>Nematolosa vlaminghi</i>	SFFSH2	Perth	29/03/89	1.4	890
perth herring liver	<i>Nematolosa vlaminghi</i>	SFFSH2	Perth	29/03/89	3.0	5.8
tailor flesh	<i>Pomatomus saltatrix</i>	SFFSH1	Perth	29/03/89	0.1	20
tailor whole minus head/viscera	<i>Pomatomus saltatrix</i>	SFFSH2	Perth	29/03/89	0.1	10
trumpeter six-line viscera	<i>Pelates sexlineatus</i>	SFFSH1	Perth	29/03/89	1.2	21
trumpeter six-line flesh	<i>Pelates sexlineatus</i>	SFFSH1	Perth	29/03/89	0.1	20
trumpeter six-line gonads female	<i>Sillago maculata</i> *	SFFSH2	Perth	29/03/89	0.3	250
trumpeter six-line flesh	<i>Pelates sexlineatus</i>	SFFSH2	Perth	29/03/89	0.2	19
trumpeter six-line liver	<i>Pelates sexlineatus</i>	SFFSH2	Perth	29/03/89	<0.1	43
trumpeter six-line whole minus head/viscera	<i>Pelates sexlineatus</i>	SFFSH2	Perth	29/03/89	0.1	25
trumpeter six-line flesh	<i>Pelates sexlineatus</i>	SFFSH3	East Perth	04/04/89	<0.1	7.8
trumpeter six-line viscera	<i>Pelates sexlineatus</i>	SFFSH3	East Perth	04/04/89	<0.1	11
trumpeter whiting flesh	<i>Sillago maculata</i>	SFFSH1	Perth	29/03/89	0.1	18
trumpeter whiting flesh	<i>Sillago maculata</i>	SFFSH2	Perth	29/03/89	0.1	12
trumpeter whiting viscera	<i>Sillago maculata</i>	SFFSH2	Perth	29/03/89	0.8	13
white bait whole	<i>Hyperlophus vittatus</i>	SFFSH1	Perth	29/03/89	<0.1	27
yellow tail flesh	<i>Amniataba caudavittatus</i>	SFFSH2	Perth	29/03/89	0.1	3.8
yellow tail gonads male	<i>Amniataba caudavittatus</i>	SFFSH2	Perth	29/03/89	0.3	210
yellow tail liver	<i>Amniataba caudavittatus</i>	SFFSH2	Perth	29/03/89	0.4	14