Sediment Chemistry - Macroinvertebrate Fauna Relationships in Urban Streams

Project S5: National River Health Program
Final Report Prepared by:
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For the Urban Water Research Association of Australia July 1998

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Foreword

This report describes the outcomes of a research project conducted under the Urban Research and Development sub-program of the National River Health Program (NRHP).

The NRHP is an on-going national program established in 1993, managed by the Land and Water Resources Research and Development Corporation (LWRRDC) and Environment Australia. Its mission is to improve the management of Australia's rivers and floodplains for their long-term health and ecological sustainability, through the following goals:

1. To monitor and assess the health of Australia's rivers.
2. To enhance the management of river flows, water allocation and water use to ensure the sustainability of river and floodplain ecosystems.
3. To encourage active management to improve the health of Australia's rivers, based on a sound understanding of the ecological and hydrological processes.
4. To evaluate the effectiveness of river management actions at a national scale.

Urban streams and estuaries (i.e. those affected by runoff and discharges from urban areas) are an important subset of Australia's waterways. Most are degraded biologically, physically and chemically and therefore require appropriate methods to be developed for health assessment and management. The Urban R&D Sub-program, managed by the Water Services Association of Australia, comprises 8 research projects which were developed to meet research priorities for urban streams and estuaries within the goals of the NRHP and to complement existing NRHP projects on non-urban rivers. Thus, research focuses on development of standardised methods for assessing the ecological health of urban streams and estuaries which can be linked with data on water and sediment quality. The urban R&D projects commenced in 1996.

The definition of health in urban waterways used is "the ability to support and maintain a balanced, integrative, adaptive community of organisms having a species composition, diversity and functional organisation as comparable as practicable to that of natural habitats of the region".

The eight projects of the Urban Sub-Program are:

Decision support system for management of urban streams	Dr John Anderson Southern Cross University, Lismore
RIVPACS (River InVertebrate Prediction and Classification System) for urban streams	Dr Peter Breen CRC for Freshwater Ecology, Monash University, Melbourne
DIPACS (Diatom Prediction and Classification System) for urban streams	Dr Jacob John Curtin University, Perth
Sediment chemistry- macroinvertebrate fauna relationships in urban streams	Dr Nick O'Connor Water EcoScience, Melbourne
Classification of estuaries	Dr Peter Saenger Southern Cross University,Lismore
Literature review of ecological health assessment in estuaries	Mr David Deeley Murdoch University, Perth
Estuarine health assessment using benthic macrofauna	Dr Gary Poore Museum of Victoria, Melbourne
Estuarine eutrophication models	Dr John Parslow CSIRO Marine Laboratories, Hobart

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Executive Summary

The relationship between benthic macroinvertebrate communities and common urban stream pollutants (*e.g.* hydrocarbons, heavy metals) is poorly understood. Developing an understanding of this relationship is important in establishing a classification system that will assist natural resource managers in decision making. The present study was designed to investigate the relationship between urban stream pollutants and benthic macroinvertebrates and provide information that may be used for the development of an urban stream ecosystem health assessment tool, namely a macroinvertebrate-based prediction and classification system.

Forty-four sites were sampled in autumn and spring for macroinvertebrates and a range of physico-chemical parameters. Sites were chosen to give a range of different land uses. Physico-chemical parameters were

chosen to characterise the habitat of a site and the level of common urban contaminants in the sediment. Contaminants within sediments measured were heavy metals, polycylic aromatic hydrocarbons, benzene, toluene, ethylbenzene, xylene, phenols, organochlorine pesticides, polychlorinated biphenyls, petroleum hydrocarbons, oil and grease, phthalates and volatile halogenated organics.

Heavy metals occurred above detection limits at all sites and very high recordings were found at some sites (*e.g.* the concentration of zinc in Stony Creek in spring was 2500 mg/kg). However, most organic compounds occurred below detection limits most of the time. When organic compounds were recorded above detection limits they were generally an order of magnitude lower in concentration than heavy metals.

Sites in the lower Yarra River and in the highly industrialised parts of western Melbourne tended to have the highest concentrations of a broad range of contaminants. This pattern of occurrence was attributed to the nature of the industries in these areas. Principal components analysis of habitat and contaminant variables indicated several groupings of toxicants, each of which may be emitted from a common type of source. Electroplating industries, in particular, are likely to be a significant source of cadmium, lead, chromium, copper, and zinc, whereas mercury may be a side product of the manufacture of industrial alkalis. Sources of organic compounds, other than pesticides, were more difficult to identify but most probably originate from fuel and oil spills. One group of PAH's recorded a similar pattern of occurrence to heavy metals and may represent the effects of site runoff from factory sites and vehicle service areas.

Overall, the results showed that the patterns of distribution of sediment contaminants were complex and that several factors appeared to be involved in determining toxicant concentrations at any particular site. The concentrated distribution of particular contaminants indicated that the most important factor determining the degree of contamination was the proximity to the source. However, landscape features, such as the stream gradient, patterns of urbanization and direct anthropogenic stream alteration also appeared to play important roles.

Exploratory multivariate statistical analyses of macroinvertebrate community data revealed some broad scale relationships between particular environmental and contaminant variables. The only group of contaminants that seemed to have any relationship with macroinvertebrate community structure was heavy metals.

Due to the qualitative method of macroinvertebrate sampling, which aimed to maximise the diversity of species collected from pool habitats, it was not possible to undertake detailed analyses of relative abundances and densities. However, a ranking of species on the basis of frequency of occurrence at sampling sites indicated a macroinvertebrate fauna characterised by broadly distributed southern Australian taxa characteristic of lowland streams, including three genera of leptocerid caddisflies, several genera of midge larvae (chironomids), atyid shrimps, as well as some aquatic beetles.

Due to the wide variety of potential contaminants and the range of geomorphic alterations possible in urban streams, it was difficult to elucidate clear trends between types of effects and particular macroinvertebrate communities. While biological community structure can indicate the condition of stream ecosystem health, it is unlikely to provide clear indications as to the cause of that condition. As part of any macroinvertebrate-based urban stream health assessment tool it will also be important to define realistic acceptable target criteria for urban streams. The findings of this study should assist in the development of such tools.

Acknowledgements

Melbourne Water Corporation are thanked for rescheduling their Streamwatch field program to enable the collection of additional field data by AWT staff, and for making data from the Streamwatch program available for this study. Comments on drafts of this report by Vin Pettigrove of Melbourne Water are gratefully acknowledged.

Chapter 1: Introduction

Urban development in catchments has a major impact on the structure of waterways and on water quality. Widespread building and paving increases the imperviousness of the catchment surface, hence the proportion

of rainfall that runs off as stormflow, and the speed at which that runoff occurs. Intense short-term, or flashy, runoff events have greater erosive power and in natural watercourses this may cause extensive bank and bed erosion. Commonly, urban streams have been subjected to engineering works to allow flood peaks to pass quickly, including channelisation and stream-bed paving. These changes have a profound effect on stream ecological communities which must cope with more frequent and intensely scouring high flows, lower base flows since steady groundwater seepage is diminished by catchment paving, and decreased habitat availability.

In addition to physical changes, urban streams are commonly exposed to a range of contaminants from diffuse and point source discharges, such as industrial effluent and stormwater runoff. Urban stormwater can be contaminated with a wide range of material including dust and soil, litter and garden rubbish, animal wastes, fertilisers and pesticides, oil and grease, sewage overflows, and tip and landfill leachate (O'Loughlin *et al*. 1992). In addition, contaminants may also be washed out of the atmosphere. Material that builds up in the catchment over dry periods is generally considered to account for the poor quality of "first flush" stormwater. Many of the toxic constituents of stormwater (*e.g.* heavy metals, pesticides, solvents, petroleum products, and numerous organic chemicals) are hydrophobic and bind with sediment particles. These contaminated particles can concentrate in the depositional areas of a stream and can have adverse environmental effects.

In order to meet increasingly stringent public standards for the condition of aquatic environments, urban waterway managers need effective methods for classifying and assessing the environmental condition of urban streams. Over the last two decades methods for the assessment of river ecosystem health have focussed on measuring the condition of one or more important components of the ecosystem; usually the fish or macroinvertebrate communities (*e.g.* Karr 1981, Plafkin *et al.* 1989, Wright 1995). More recently, in Australia, the Federal Government has funded a National River Health Program that includes an initiative to develop tools for riverine ecosystem health assessment. So far the program has developed a river health assessment tool, AUSRIVAS, which is based on the condition of stream macroinvertebrate communities. The present AUSRIVAS assessment package is focussed on non-urban waterways. Before it can be applied to urban streams, a greater understanding of the relationship between urban stream macroinvertebrate communities and their habitat is required. This paper addresses one aspect of the relationship, that between urban stream benthic macroinvertebrates and the level of contamination of the sediment which they inhabit.

Forty-four urban and semi-urban sites were sampled for sediment toxicants on two occasions across metropolitan Melbourne and 41 of these sites were also sampled for benthic macroinvertebrates on the same dates. Data from these samples was subjected to exploratory multivariate analyses to; 1) identify relationships between benthic macroinvertebrate community structure and sediment toxicants; and 2) provide recommendations for the design of effective urban stream ecosystem health assessment tools.

Chapter 2: Materials and Methods

2.1 Selection of Toxicants

There is a bewildering array of potential toxicants that may enter a stream through stormwater and bind to stream sediments. Aside from the input of a wide variety of contaminants of known chemical makeup (*e.g.* runoff from a streamside spraying of blackberry with a particular brand of herbicide) many industrial

discharges consist of complex effluents (*e.g.* urban sewage, pulp mill effluent, etc) that may contain a suite of bioactive organic molecules. In order to delimit the number of analyses required and for simplicity, we chose to undertake screening analyses for several classes of toxicants (Table 2-1). Toxicants were chosen on the basis of their likely occurrence above detection limits in Melbourne metropolitan streams, and their known toxicity.

Table 2.1 Classes of toxicants monitored in this study and their likely sources.

Toxicant	**Likely source**
Heavy metals	Runoff from urban and industrial roofing, parking areas, car service areas, road runoff, and industrial effluents (Pitt *et al*. 1995).
Phenols	Phenols and alkylated phenols are major industrial raw materials, being important constituents of coal-derived substitutes for natural crude oil or boiler fuel. They are also used in detergents, paints, pesticides, textile and petroleum recovery chemicals, metal working fluids, and personal care products (Southworth *et al*. 1985).
Polycyclic Aromatic Hydrocarbons (PAHs)	Runoff from urban and industrial roofing, parking areas, car service areas, road runoff, industrial effluents, creosote from timber yards, atmospheric inputs from settled particulate air pollution (Pitt *et al*. 1995).
Benzene, Toluene, Ethylbenzene, Xylene (BTEX)	Major components of oils - mainly used as organic solvents.
Petroleum Hydrocarbons	Indicators of petroleum contamination, road runoff, vehicle service areas and general stormwater.
Organochlorine Pesticides	Runoff from fields, gardens, rural areas, and storage areas.
Polychlorinated biphenyls PCBs	Used as insulators in large electrical transformers - commonly associated with telecommunications and electrical installations.
Oil & Grease	From domestic sewage and grey water, road & parking area runoff, some industrial effluents.
Phthalate esters	Widely used as plasticizers and enter streams through sewage discharges, paper and textile mill effluent, and through refuse incineration.

2.2 Sampling Locations

Forty-four sites were sampled across metropolitan Melbourne (Table 2-2, Figure 2-1). Site locations were chosen, based on surrounding landuse activities, to give a likely range of contamination levels.

Table 2.2 Sample sites locations, numbers, Melbourne Water Corporation Site Codes, latitude, longitude, and site category;
H = High density housing/industrial, M = Medium/low density housing, A = Agriculture, and F = Forested.

Watercourse	**Location**	**Site Number**	**Site Code**	**Latitude**	**Longitude**	**Site Category**
Kororoit Creek	Warmington Road, Sunshine	1	MKC02	37°48'07"	144°49'41"	M
Laverton Creek	Merton Road, Laverton	2	MLC01	37°51'51"	144°46'43"	H

Maribyrnong River	Canning Street Ford, Avondale Heights	3	MMR01	37°46'18"	144°50'58"	M
Maribyrnong River	Flora Street, Keilor	4	MMR02	37°43'19"	144°50'18"	A
Maribyrnong River	Keilor Public Golf Course, Sydenham	5	MMR03	37°40'48"	144°48'12"	A
Deep Creek	Trap Street, Bulla	6	MMR04	37°37'59"	144°47'56"	A
Jacksons Creek	Sunbury Road, Sunbury	7	MMR05	37°35'06"	144°44'21"	M
Steeles Creek	Rosehill Road, Keilor East	8	MMY32	37°44'59"	144°52'46"	M
Stony Creek	Drew Street, Yarraville	9	MSC04	37°49'06"	144°52'31"	H
Bass River	Ferriers Road, Loch	10	SBA01	38°21'33"	145°42'11"	A
Bass River	McGraths Road	11	SBA02	38°28'07"	145°30'51"	A
Bunyip River	Ballarto Road, Koo-Wee-Rup North	12	SBR01	38°09'45"	145°31'59"	A
Bunyip River	near Labertouche Road North	13	SBR03	37°59'06"	145°45'19"	F
Cardinia Creek	Ballarto Road, Cardinia	14	SCC04	38°08'55"	145°25'46"	A
Dandenong Creek	Pillars Crossing, Dandenong	15	SDC01	38°01'57"	145°10'57"	H
Dandenong Creek	Brady Road, Endeavour Hills	16	SDC02	37°57'30"	145°13'51"	M
Dandenong Creek	High Street, Glen Waverley	17	SDC03	37°52'46"	145°11'23"	M
Dandenong Creek	Boronia Road, Wantirna	18	SDC04	37°50'47"	145°12'31"	M
Dandenong Creek	Edgar Track, Dandenong Ranges National Park	19	SDC05	37°50'50"	145°19'57"	F
Deep Creek	Ballarto Road, Cardinia	20	SDE01	38°09'02"	145°26'48"	A
Eumemmering Creek	Worsley Road, Dandenong	21	SEC01	38°02'36"	145°11'04"	M
Lightwood Creek	u/s of Main Creek, Point Nepean National Park	22	SLC01	38°27'10"	144°56'09"	F
Lang Lang Creek	South Gippsland Hwy, Lang Lang	23	SLR01	38°15'27"	145°32'50"	A
Lang Lang Creek	Drouin/Poowong Road	24	SLR02	38°14'12"	145°47'03"	A
Main Creek	Baldry Crossing, Baldry Road, Point Nepean National Park	25	SMA01	38°25'21"	144°57'31"	A
Merricks Creek	Frankston-Flinders Road, Merricks	26	SME01	38°23'10"	145°06'10"	A
Tarago River	Morrisons Road, Longwarry North	27	STR01	38°04'43"	145°45'42"	A

Tarago River	d/s Tarago Reservoir	28	STR02	38°01'15"	145°56'09"	A
Watsons Creek	Hastings-Dandenong Road, Somerville	29	SWC01	38°13'42"	145°12'55"	A
Coldstream Drain	Station Street, Coldstream	30	YCD01	37°43'27"	145°22'05"	A
Ennismor Cres. Drain	Aquarius Court, Donvale	31	YEC01	37°47'35"	145°12'07"	M
Gardiners Creek	Eric Raven Reserve, Glen Iris	32	YGC05	37°51'43"	145°03'38"	H
Merri Creek	Roseneath Street, Clifton Hill	33	YLY06	37°47'43"	145°00'03"	H
Mullum Mullum Creek	Blackburn Road, Templestowe	34	YMC01	37°44'47"	145°10'04"	M
Merri Creek	Summerhill Road	35	YMY26	37°34'25"	144°57'50"	M
Wandin Yallock Creek	Sunnyside Road, Seville	36	YWY02	37°45'23"	145°29'16"	A
Yarra River	Dights Falls, Abbotsford	37	YYR01	37°47'55"	144°59'59"	M
Yarra River	Chandler Hwy, Fairfield	38	YYR02	37°47'21"	145°01'26"	M
Yarra River	Fitzsimmons Lane, Templestowe	39	YYR03	37°44'36"	145°07'58"	M
Yarra River	Kangaroo Ground-Warrandyte Road, Warrandyte	40	YYR04	37°44'24"	145°12'57"	M
Yarra River	Spadonis Reserve, Coldstream	41	YYR05	37°40'54"	145°20'47"	A
Yarra River	Maroondah Hwy, Healesville	42	YYR06	37°40'44"	145°29'13"	A
Yarra River	Healesville-Koo-Wee-Rup Road, Woori Yallock	43	YYR07	37°46'14"	145°31'58"	A
Yarra River	d/s Armstrong Creek, Reefton	44	YYR08	37°40'30"	145°50'52"	F

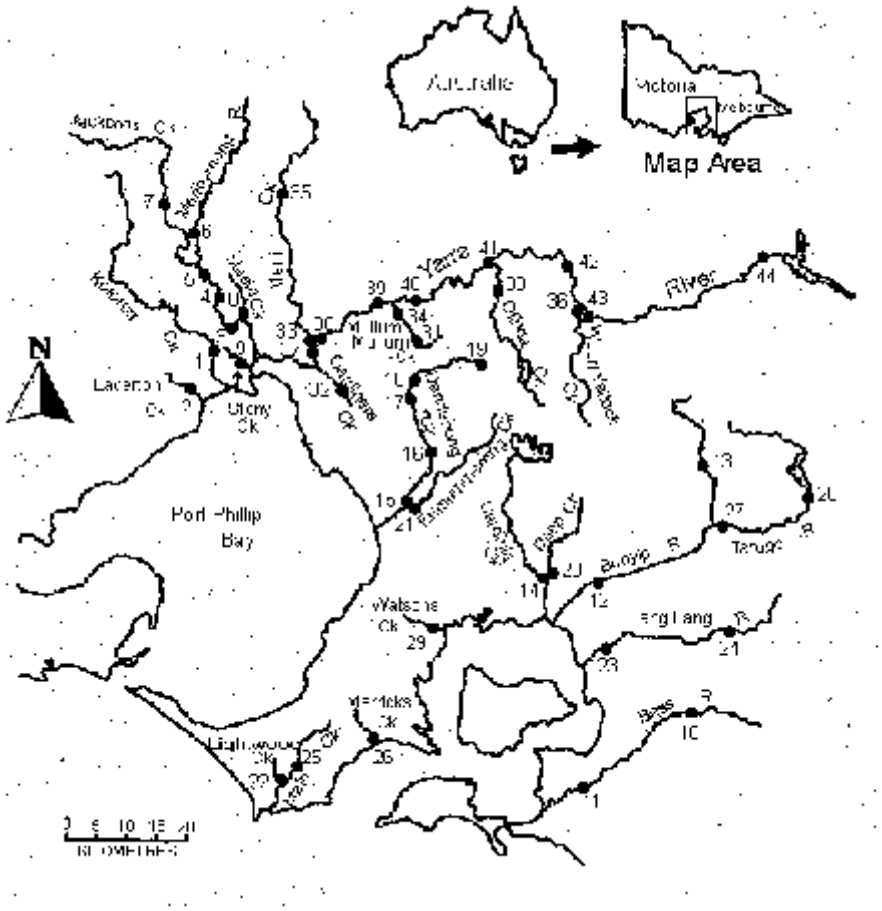

Figure 2.1 Map of study sites. See Table 2-2 for further details.

(original size image)

2.3 Sample collection

Macroinvertebrates and sediments were collected in autumn 1996 (between 25 March 1996 and 29 April 1996) and in spring 1996 (between 28 November 1996 and 13 December 1996). These seasons were chosen to represent flow extremes, with lowest flows generally occurring in autumn and highest flows occurring in spring.

2.3.1 Macroinvertebrate Sampling

Macroinvertebrate samples were collected according to the protocols developed as part of the Monitoring River Health Initiative (MRHI, 1994). This is a qualitative method of sampling designed to collect the greatest diversity of macroinvertebrates possible in a limited time. The protocol was developed to enable the sampling of a wide variety of stream types in Australia, and as a result, not all of the six recognised habitats (*i.e.* riffles, pools, edge sweep, macrophytes, logs/sticks or deep water pools/run) are likely to be present in a single stream. This is particularly true in urban streams, where anthropogenic effects have resulted in stream modifications to the extent that habitats such as edge sweeps (*e.g.* an undercut bank or backwater with abundant benthic leaf litter), macrophytes, and woody debris are rarely found. In the present study, therefore, only pools were sampled. The pool edges (*i.e.* equivalent to MRHI edge sweep), however, were sampled as part of the whole pool since this microhabitat was generally very small and contiguous with the rest of the pool. Other habitats were also sampled as part of an ongoing companion program ("Streamwatch") funded by the Melbourne Water Corporation. The results of the Streamwatch program are reported by Smith *et al.* (1997).

Pool habitats are defined as stretches of water with little or no current. The habitat, including edges, was sampled using 250 µm mesh sweep nets. Sampling involved vigorously sweeping the net through the water column or over aquatic vegetation and above the substrate, ensuring the substrate was sufficiently disturbed

to collect bottom dwelling animals. Sampling was carried out for approximately a 10 minute period or over a 10 metre stretch of water at each pool site. The contents of the net were washed into a white sorting tray and animals were collected over a 30 minute period. Attempts were made to collect the greatest diversity of taxa by avoiding collection of numerous individuals of a single taxa. All samples were preserved in the field using 70% ethanol and returned to the laboratory for identification.

2.3.2 Habitat Assessment and *In-Situ* Physico-Chemical Sampling

At each site physical habitat descriptions were made, including stream flow, stream-bed composition (*i.e.* bedrock, boulder, cobble, pebble, gravel, and silt or clay), predominant type and location of aquatic and riparian vegetation, percentage canopy cover and channel width.

2.3.3 Sediment Sampling

Sediment for the determination of heavy metals was collected from depositional areas at each site by scooping sediment into a plastic bucket. Collected sediment was sieved through a 65 μm nylon mesh net and approximately 100 g of the sieved material was retained in plastic or glass jars for later laboratory analysis.

Sediment for the organics analyses in autumn was collected by scooping handfuls of material into a stainless steel container. The operator wore rubber gloves to minimise contamination of the sediment during the sampling process. The sediment was then passed through a 2 mm sieve to achieve a uniform particle size and the slurry placed into glass jars which were kept chilled until analysed.

In spring, it was decided to add phthalates to the list of organic contaminants to be analysed, thus sediment was collected using a stainless steel scoop rather than by hand, to further minimise any possible contamination of the samples.

2.4 Sample Analysis

2.4.1 Macroinvertebrates

Taxa were identified to the lowest practicable level. In general, this meant identification to species level, however, in some cases it was to genus, family, order or class according to the availability of keys.

2.4.2 Sediments

Heavy Metals – ICP/MS or ICP/AES.
Sediments were analysed for Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu) , Mercury (Hg), Lead (Pb) and Zinc (Zn). Metals were leached into a hot mixture of nitric and hydrochloric acids and following dilution with water, metal contamination was determined by Inductively Coupled Plasma (ICP) Mass Spectrometry (ICP/MS) or Atomic Emission Spectroscopy (ICP/AES). This method is based on USEPA 3050 protocol for ICP.

Polycyclic Aromatic Hydrocarbons - Gas Chromatography/Mass Spectrometry (GC/MS).
PAH's were analysed by GC/MS using a method based on the USEPA SW 846 series. The system used consisted of a Hewlett Packard 5890 series IL GC with 5898A mass spectrometer engine and a HP-5MS 30 m x 0.25 μm column with ultra high purity helium as the carrier gas. A selected ion monitoring technique was used in the identification and confirmation of the PAH's. The technique was based on three selected ions which were specific to the standard retention time and intensity ratio. Quantitation was by direct reading from calibration tables using three points of known concentration.

Benzene, Toluene, Ethlybenzene and Xylene (BTEX) - Purge and Trap GC/MS
Sediment extracts were analysed using 4650 PC, 0-I purge and trap interfaced with a Hewlett Packard 5890 series II GC with a 5972 series mass selective detector. A selected ion monitoring technique was used in identification and confirmation of the BTEX components and the quantitation was by calibration tables. Ultra high pure helium gas was used in purging the BTEX out of the extract solution and a K Vocarb 3000

trap was used in trapping the volatile compounds. When the purging was completed the sorbent tube was heated and back flushed with helium to desorb trapped sample components which were then cryofocussed on a capillary precolumn. BTEX were then transferred to the DB-624 column 30m x 0.53 mm x 3 μm and detected by a mass selective detector.

Phenols - High Performance Liquid Chromatography (HPLC)
Phenol and alkyl phenol residues in sediment were analysed by HPLC using a LKB, Bromma 2150 HPLC pump, Novapak Radial Compression C_{18}, 4 μm packing, 100 mm x 5 mm ID and Novapak guard column, and a Waters 464 Amperometric detector with a glassy carbon electrode. The Water 712 WISP auto sampler was used in sampling and the peaks were identified by comparing the retention times of standards to those of the samples and quantified through calibration tables.

Organochlorine Pesticides (OCP's), Polychlorinated Biphenyls (PCB's) and Phthalate Esters - GC/Electron Capture Detection (GC/ECD)
Sediment extracts were analysed by HP 5890 series II GC/ECD using a SGE, BPX 35, 25 m x 0.22 mm x 0.25 μm column. The peaks were identified by comparing the retention times of standards to those of the samples. Quantitation was carried out using calibration tables. Results were reported on a dry weight basis. PCB's were reported on a congener basis using a range of PCB's which were selected from the 209 possible congeners (potential environmental significance was used as a criteria for the selection).

Total Petroleum Hydrocarbons (TPH) - GC/Flame Ionisation Detection (GC/FID)
Sediments extracts were analysed using a Hewlett Packard 5890 series GC/FID and a BPX5, 25 m x 0.22 m x 0.25 μm. Retention times of calibration standards were used in detecting and identifying the hydrocarbon ranges between C_6 and C_{36}. Quantitation was carried out by auto-integrating specific limits which were preset as boundaries ranging between C_6 - C_9, C_{10} - C_{28}, C_{29} - C_{36} fractions.

Oil and Grease - Fourier Transform Infra-Red Spectroscopy (FTIR)
Sediment extracts were analysed by FTIR using calibration plots of known standards on the absorbance region between 3200 cm^{-1} to 2700 cm^{-1}. The samples were placed in a sodium chloride liquid cell with reference cells to compensate for the background. Later work was carried out using a gravimetric procedure with a hexane/ether solvent mixture due to the unavailability of freon (1,1,2 - trichlorofluroethane).

Volatile Halogenated Organics
Sediments were analysed only in autumn for chlorinated hydrocarbons using purge and trap GC/mass spectrometry.

To report results for all sediment analyses as concentrations per dry weight of sediment sampled, preweighed subsamples of each sample were oven dried to a constant weight at 60°C and the moisture content determined.

2.5 Data Analysis

Sediment toxicant and habitat data (environmental data):
In order to reveal the relationships between variables environmental data were analysed using principal components analysis (PCA). For groups of toxicants (*e.g.* PAH's) where individual members of the group were infrequently recorded, concentrations of all members of the group were summed for each sample and only the total value for the group (*e.g.* Total PAH) was used in the PCA.

Macroinvertebrate community data:
To identify temporal and spatial trends in the macroinvertebrate data, ordination of the macroinvertebrate presence-absence sample data was conducted using semi-strong hybrid multidimensional scaling (MDS) on Bray-Curtis sample dissimilarity coefficient matrices. Ten MDS ordinations in two and three dimensions were performed and the ordination with the lowest stress value in each dimension was retained for further analysis. The twenty most frequently occurring taxa were tabulated to provide an indication of the type of species found during the study.

Species-Environment Relationships:
Environmental data were correlated with the ordination by conducting a principal axis correlation (PCC) using the software package PATN (Belbin, 1992). This procedure calculates a vector of maximum linear correlation for each environmental variable in the reduced dimensional space of the ordination. PCC also specifies the direction taken by a vector, which can then be plotted to depict an environmental trend on the ordination. The maximum correlation of a sample variable was judged significant ($p < 0.05$) if it was greater in absolute magnitude than at least 95 random permutations of the variable (also known as Monte Carlo significance testing).

Chapter 3: Results

- 3.1 Sediment toxicant analyses
- 3.2 Macroinvertebrate community data

3.1 Sediment toxicant analyses

With the exception of volatile halogenated organic compounds, all contaminants were recorded above analytical detection limits at one or more sites (Table 3-1). The distribution of contaminants was patchy and most likely related to local point sources.

Heavy metals

Arsenic, cadmium, chromium, copper, mercury, nickel, lead, and zinc were above analytical detection limits at all sites on all sampling occasions. As with other contaminants, the results were highly variable but in general, regions with heavy industry were found to have greater concentrations of all heavy metal contaminants. Most notably, zinc concentrations in Stony Creek in western Melbourne and Merri Creek at Clifton Hill were extremely high.

Polycyclic Aromatic Hydrocarbons (PAHs)

There was some degree of concordance between sites that had elevated concentrations of heavy metals and concentrations of PAH's above detection limits. Sites in western Melbourne, and the central metropolitan region of the Yarra River were found to have the highest levels of PAH's. There also appeared to be some seasonality in these results, with generally fewer sites with recordings of PAH concentrations above detection limits in spring than in the preceding autumn. This may be due to the scouring effect of high spring stream flows. Counter to this trend, however, was that the highest concentrations of a broad range of PAH's were found at one site on Merri Creek at Clifton Hill in spring. This could be due to a continuous local point source of contamination.

Benzene, Toluene, Ethylbenzene, Xylene BTEX

Benzene and Toluene were recorded at one site, Jackson Creek, Sunbury, in autumn only. These were the only members of the BTEX group of solvents (which also includes ethylbenzene and xylene) that were recorded above analytical detection limits on any occasion. Thus the BTEX group did not appear to be a significant contaminant in metropolitan Melbourne over the duration of this study.

Petroleum Hydrocarbons

Petroleum hydrocarbons occurred in high concentrations in both industrial sites and at sites on the urban-rural fringe. Due to the general nature of the analysis and the quite different landuses upstream of the sites where they were recorded, it seems likely that the sources are also different. Industrial sites are probably contaminated with industrial effluents and road runoff, while the urban-rural fringe sites may be contaminated with runoff from petrol stations and vehicle maintenance garages.

Phenols

Gardiners Creek, Glen Iris, Yarra River at Dights Falls and Deep Creek at Bulla were the only sites, sampled that showed trace quantities of 2-methyl or 3-methylphenol in autumn. However, the source is not known and these chemicals were not present at these or any other sites in the following spring.

Organochlorine Pesticides

Organochlorine pesticides had a similar patterns of occurrence to petroleum hydrocarbons. In urban-rural fringe areas, this may be due to their use in market gardens and for termite control. Its not known why they should also be found at urban-industrial sites, but it is possibly the historical use of the now banned forms of this class of pesticides, including DDT.

Polychlorinated biphenyls PCBs

PCB's were recorded just above detection limits at only one site on Steele's Creek in western Melbourne in autumn. They do not appear to be a significant contaminant in urban streams in Melbourne. An exception to this view may be stream sites near long term telecommunications installations, since PCB's have been widely used as insulators in telecommunications and other electrical equipment and have been subjected to unsafe disposal practices in the past.

Oil & Grease

Oil and grease levels were generally high at all sites on all occasions, except the Tarago River in autumn. Most notably, concentrations in spring were around an order of magnitude greater than autumn. This large seasonal difference may be due to higher inputs of oil and grease and their subsequent adsorption to sediment particles during the high spring flow period, followed by gradual degradation of oils and grease over the summer-autumn low flow period.

Phthalate esters

In contrast to the seasonal pattern shown by oil and grease, concentrations of phthalate esters were generally higher in autumn than in spring. This pattern was most strongly shown by diethyl, n-butyl, di-iso butyl, di-n butyl, and di-amyl phthalate. Concentrations of dimethyl and bis(2-ethylhexyl) phthalate showed the same seasonal pattern but less marked. Occasional high concentrations of phthalates (> 5 mg/kg) tended to occur at the same sites that showed high levels of other organic contaminants, possibly indicating a point source of complex effluent. However they also occurred at other sites for unknown reasons. The seasonal differences observed for phthalates should be noted with caution, since the rubber gloves worn by the samplers during the autumn sampling may have contaminated the samples.

Volatile Halogenated Organics

All volatile halogenated organic compounds tested at all sites were below the detection limit of 0.1 mg/kg dry wt. To assess the possibility that non-detection could have been due to sampling error, the sample collection procedure was discussed with the Australian Government Analytical Laboratories' (AGAL) Chief Organic Chemist, Mr Barrie Magor, to determine whether losses of these volatiles could have occurred during sampling or transit. While a more complex method of sample collection could have been used for these volatiles, such as *in situ* trapping onto Tenax or activated carbon adsorbents, it was felt that losses due to the sampling procedures used would have been minimal.

It seems likely, therefore, that any volatile halogenated organics which may have been present in the streams sampled did not pass into the sediments in significant quantities, or that this class of contaminant is only found deeper in the sediments (*i.e.* > 10 cm) than was sampled in the present study. Further analyses for volatile halogenated organics was not conducted in the second round of sampling in spring.

Table 3.1 Minimum, mean and maximum concentrations of toxicants found during the study. Mean values have been calculated by assuming the detection limit was the actual concentration of the toxicant recorded.

Class of Toxicant	**Toxicant**	**Minimum**	**Mean**	**Maximum**
		mg/kg	**mg/kg**	**mg/kg**

Heavy Metals	Arsenic	0.91	6.86	59.0
	Cadmium	0.023	0.42	4.60
	Chromium	2.9	37.30	160
	Copper	0.05	25.14	155
	Mercury	<0.0025	0.11	1.7
	Nickel	5.00	20.24	78
	Lead	2.85	52.94	750
	Zinc	20.5	207.11	2500
Polycyclic Aromatic Hydrocarbons (PAH's)	Naphthalene	<0.05	<0.050	0.1
	2-methylnaphthalene	<0.05	<0.05	<0.05
	Acenaphthylene	<0.05	<0.05	0.1
	Acenaphthene	<0.05	<0.05	0.1
	Fluorene	<0.05	<0.05	0.1
	Phenanthrene	<0.05	0.40	1.5
	Anthracene	<0.05	0.17	0.45
	Fluoranthene	<0.05	0.80	3.5
	Pyrene	<0.05	0.90	3.6
	Benzo(a)anthracene	<0.05	0.40	1.3
	Chrysene	<0.05	0.41	1.2
	Benzo(b)fluoranthene	<0.05	0.52	2.0
	Benzo(k)fluoranthene	<0.05	0.34	1.2
	Benzo(a)pyrene	<0.05	0.62	3.0
	Dibenz(ah)anthracene	<0.05	0.13	0.2
	Benzo(ghi)perylene	<0.05	0.33	1.5
	Indeno(1,2,3-cd)pyrene	<0.05	0.35	1.4
	Total PAH's	<0.05	3.81	18.8
Benzene, Toluene, Ethylbenzene, Xylene (BTEX)	Benzene	<0.05	0.06	0.035
	Toluene	<0.05	<0.05	0.10
	Ethylbenzene	<0.05	<0.05	<0.05
	Xylene	<0.05	<0.05	<0.05
	Total BTEX	<0.05	0.20	0.40

Petroleum Hydrocarbons	C_6-C_9 hydrocarbons	5.5	6.77	8.0
	C_{10}-C_{14} hydrocarbons	6.0	15.0	27.0
	C_{15}-C_{28} hydrocarbons	3.75	67.08	530.0
	C_{29}-C_{36} hydrocarbons	6.0	55.77	430.0
	Total petroleum hydrocarbons	5.5	89.10	960
Phenols	Phenol	<0.0025	<0.0025	<0.0025
	3-Methylphenol	<0.0025	0.14	0.25
	2-Methylphenol	<0.0025	0.05	0.05
	4-Methylphenol	<0.0025	<0.0025	<0.0025
	2-Ethylphenol	<0.0025	<0.0025	<0.0025
	4-Ethylphenol	<0.0025	<0.0025	<0.0025
	2,4-Dimethylphenol	<0.0025	<0.0025	<0.0025
	2,3,5-Trimethylphenol	<0.0025	<0.0025	<0.0025
	4-Nitrophenol	<0.0025	<0.0025	<0.0025
Organochlorine Pesticides	HCB	<0.05	0.007	0.007
	Dicloran	<0.05	0.01	0.01
	Total BHC(α,β,Δ)	<0.05	0.01	0.014
	Lindane	<0.05	0.005	0.005
	Heptachlor	<0.05	0.01	0.013
	Aldrin	<0.05	0.005	0.005
	Chlorpyrifos	<0.05	0.01	0.012
	Total Chlordane (oxy,cis,trans)	<0.05	0.013	0.02
	Heptachlor Epoxide	<0.05	0.02	0.02
	Total Endosulphan (α,β, sulphate)	<0.05	0.025	0.045
	op-DDE, pp-DDE	<0.05	0.008	0.01
	Dieldrin	<0.05	0.010	0.028
	Endrin	<0.05	0.035	0.035
	op-DDD, pp-DDD	<0.05	<0.05	<0.05
	op-DDT, pp-DDT	<0.05	0.035	0.11

	Methoxychlor	<0.05	0.014	0.025
	Dicofol	<0.05	0.044	0.12
	Total OC pesticides	<0.05	0.042	0.24
Polychlorinated biphenyls PCBs	Total PCB's	<0.025	0.025	0.045
Oil & Grease	Oil and Grease	5	1885	13000
Phthalate esters	Dimethyl phthalate	<0.05	7.4	54.1
	Diethyl phthalate	<0.05	1.764	7.9
	n-Butyl phthalate	<0.05	<0.05	<0.05
	di-iso Butyl phthalate	<0.05	0.49	6.2
	di-n Butyl phthalate	<0.05	3.47	54.5
	di-Amyl phthalate	<0.05	<0.05	<0.05
	bis(2-ethyl hexyl) phthalate	<0.05	0.95	6.95
Volatile halogenated hydrocarbons	Dichlorodifluoromethane	< 0.01	< 0.01	< 0.01
	Chloromethane	< 0.01	< 0.01	< 0.01
	Vinyl chloride	< 0.01	< 0.01	< 0.01
	Chloroethane	< 0.01	< 0.01	< 0.01
	Trichlorofluoromethane	< 0.01	< 0.01	< 0.01
	1,1-Dichloroethane	< 0.01	< 0.01	< 0.01
	Methylene chloride	< 0.01	< 0.01	< 0.01
	trans-1,2-Dichloroethene	< 0.01	< 0.01	< 0.01
	1,1-Dichloroethane	< 0.01	< 0.01	< 0.01
	2,2-Dichloropropane	< 0.01	< 0.01	< 0.01
	cis-1,2-Dichloroethene	< 0.01	< 0.01	< 0.01
	Bromochloromethane	< 0.01	< 0.01	< 0.01
	Chloroform	< 0.01	< 0.01	< 0.01
	1,1,1-Trichloroethane	< 0.01	< 0.01	< 0.01
	Carbon tetrachloride	< 0.01	< 0.01	< 0.01
	1,1-Dichloropropene	< 0.01	< 0.01	< 0.01
	1,2-Dichloroethane	< 0.01	< 0.01	< 0.01
	Trichloroethene	< 0.01	< 0.01	< 0.01

1,2-Dichloropropane	< 0.01	< 0.01	< 0.01
Bromodichloromethane	< 0.01	< 0.01	< 0.01
cis-1,3-dichloropropene	< 0.01	< 0.01	< 0.01
trans-1,3-dichloropropene	< 0.01	< 0.01	< 0.01
1,1,2-Trichloroethane	< 0.01	< 0.01	< 0.01
Tetrachlorethane	< 0.01	< 0.01	< 0.01
1,3-Dichloropropane	< 0.01	< 0.01	< 0.01
Dibromochloromethane	< 0.01	< 0.01	< 0.01
Chlorobenzene	< 0.01	< 0.01	< 0.01
1,1,1,2-Tetrachloroethane	< 0.01	< 0.01	< 0.01
1,1,2,2-Tetrachloroethane	< 0.01	< 0.01	< 0.01
1,2,3-Trichloropropane	< 0.01	< 0.01	< 0.01
2-Chlorotoluene	< 0.01	< 0.01	< 0.01
4-Chlorotoluene	< 0.01	< 0.01	< 0.01
1,3-Dichlorobenzene	< 0.01	< 0.01	< 0.01
1,4- Dichlorobenzene	< 0.01	< 0.01	< 0.01
1,2- Dichlorobenzene	< 0.01	< 0.01	< 0.01
1,2-Dibromo-3-chloropropane	< 0.01	< 0.01	< 0.01
1,2,4-Trichlorobenzene	< 0.01	< 0.01	< 0.01
Hexachlorobutadiene	< 0.01	< 0.01	< 0.01
1,2,3-Trichlorobenzene	< 0.01	< 0.01	< 0.01

PCA of habitat and toxicant data indicated several underlying relationships in the data. The first principal component (PCA1) accounted for 34% of the total variance and consisted of a group of positively correlated habitat variables (Table 3-2). These were mainly coarse substrate particle sizes, channel size, channel flow, and streamside vegetation. The fact that no toxicant variables were correlated with PCA1 indicates that toxicants were present in stream sediments irrespective of the main habitat types. Since mainly fine sediments were sampled for toxicant analyses, even in predominantly coarse sediment river reaches, this is not surprising. However, the finding does indicate that the toxicants are distributed broadly along the longitudinal stream gradient rather than clustered strongly in upper or lower reaches of the stream catchments.

All of the heavy metals analysed, excluding arsenic and mercury, were correlated with PCA2. Highest concentrations of these variables were found in the small urban creeks of the industrialised parts of western Melbourne, indicating strong local point source inputs of industrial effluents.

Total petroleum hydrocarbons, phthalates and to a lesser degree PAHs, were strongly correlated with PCA3 which may indicate that these organic contaminants derive from a common type of source. The PCA was unable to construct a single principle component that strongly accounted for total PAH's which were also correlated with PCA6.

PCA4 accounted for oil and grease and fine sediment habitats. However, these were inversely correlated with each other, indicating that the highest values for oil and grease were found at sites that had relatively less sand, silt and clay substrates than other sites.

Total organochlorine pesticides were alone in being highly correlated with PCA5, meaning that they were uncorrelated with other variables (see section 3.1).

The fact that arsenic and mercury, which were correlated with PCA6, were not correlated with the other metal groups means that the sources of these metals, or the mechanism by which they become concentrated in stream sediments, must differ from the remaining heavy metals.

Table 3.2 Principal components analysis of habitat and sediment toxicant data collected during this study. Since many of the toxicants within a class occurred only infrequently, only total concentrations for all members of that class (*e.g.* Total phthalates) were used for data analysis. Total PCB was excluded from the analysis since it was only recorded at one site.

Components	**% of Total variance**	**Variable**	**r**
1	34.1	Vegetation cover	0.974
		Average channel width	0.901
		Average flow	0.973
		% Bedrock	0.949
		% Boulders	0.879
		% Cobbles	0.889
		% Pebbles	0.931
		% Gravel	0.709
2	20.0	Cadmium	0.893
		Chromium	0.513
		Copper	0.881
		Lead	0.822
		Zinc	0.865
3	8.4	Total petroleum hydrocarbons	0.738
		Total phthalates	0.840
		Total PAH's*	0.410
4	6.8	Oil & Grease	-0.688
		% Sand	0.565
		% Silt	0.761
		% Clay	0.809

5	4.8	Total organochlorines	-0.967
6	4.5	Arsenic	0.683
		Mercury	0.630
		Total PAH's*	0.412

* Total PAH's were equally correlated with principal components 3 and 6.

3.2 Macroinvertebrate community data

Initial ordinations were conducted on the whole data set (*i.e.* 41 sites for the two sampling seasons of autumn and spring), however, seasonal differences amongst sites appeared small in relation to site differences and graphs of ordination coordinates were difficult to interpret. Therefore, the data set was summed across seasons and another MDS ordination performed in two and three dimensions. Due to large difference in stress values between the two and three-dimensional ordinations, only the three-dimensional ordination was retained for further analysis (Figures 3-1 to 3-3).

Attempts at finding structure in the macroinvertebrate community data were not particularly successful. There appeared to be no strong groupings of sites in MDS ordination space that were associated with particular subcatchments, or types of land use (*e.g.* land use categories in Table 2-2). However, there was a trend towards more polluted sites (*i.e.* sites with broad range of toxicants recorded above detection limits) to have higher scores on the first MDS axis.

Monte-Carlo significance testing showed that no organic contaminants had a significant principal axis correlation with macroinvertebrate MDS coordinates. Aside from channel dimensions, flow and substrate habitat variables, which are well known to be important determinants of macroinvertebrate distributions, heavy metals was the only other group to show a significant correlation with macroinvertebrate community structure. The principal axis for cadmium, chromium, copper, lead and zinc was primarily correlated with MDS axis 1 (Figure 3-1) while arsenic was partially correlated with MDS axes 2 and 3 (Figures 3-1 to 3-3). It appears likely, therefore, that although many sites contained a suite of organic toxicants, macroinvertebrate communities are more strongly affected by heavy metal contamination of sediments than other toxicants in Melbourne urban streams. Concentrations of some metals at some sites were extremely high. For example the concentration of zinc in Stony Creek in spring was 2500 mg/kg. In contrast, although organic toxicants were recorded above detection limits at many sites, they never reached more than a few mg/kg at any site with the exception of some phthalates (*e.g.* dimethyl phthalate at 54 mg/kg in Stony Creek in autumn).

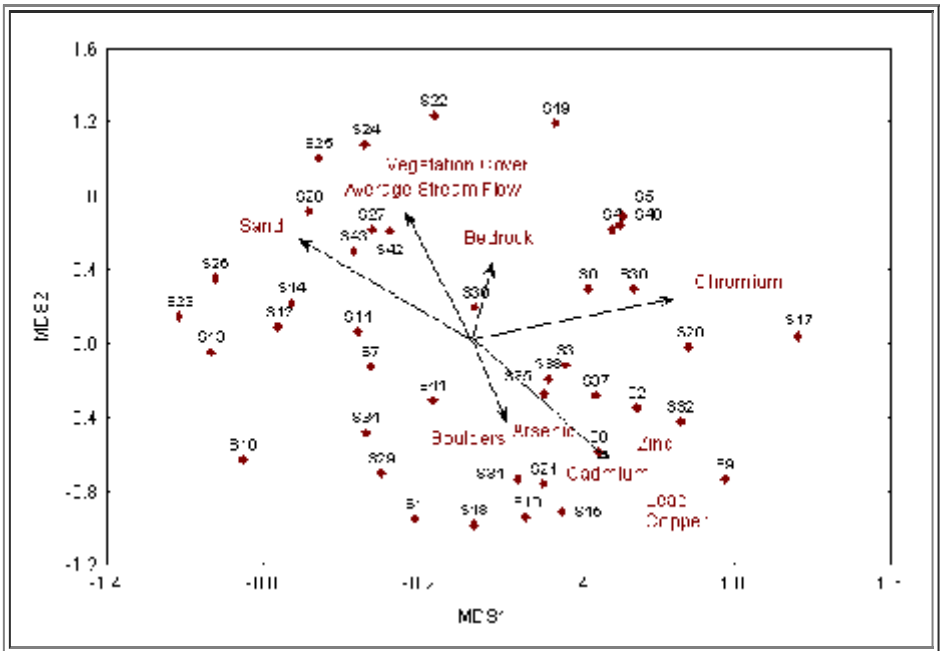

Figure 3.1 Axes 1 and 2 of a three-dimensional multidimensional scaling ordination of macroinvertebrate presence-absence data for each site. Spring and autumn data have been summed for each site prior to undertaking the ordination. Arrows on each graph indicate the direction of maximum linear correlation of each environmental variable. Only variables whose correlation was found to be significant (by a Monte-Carlo randomisation test) with a probability of $p < 0.05$ are shown. Coordinates for each site are labelled with the site number (*e.g.* S12 = Site 12).

(original size image)

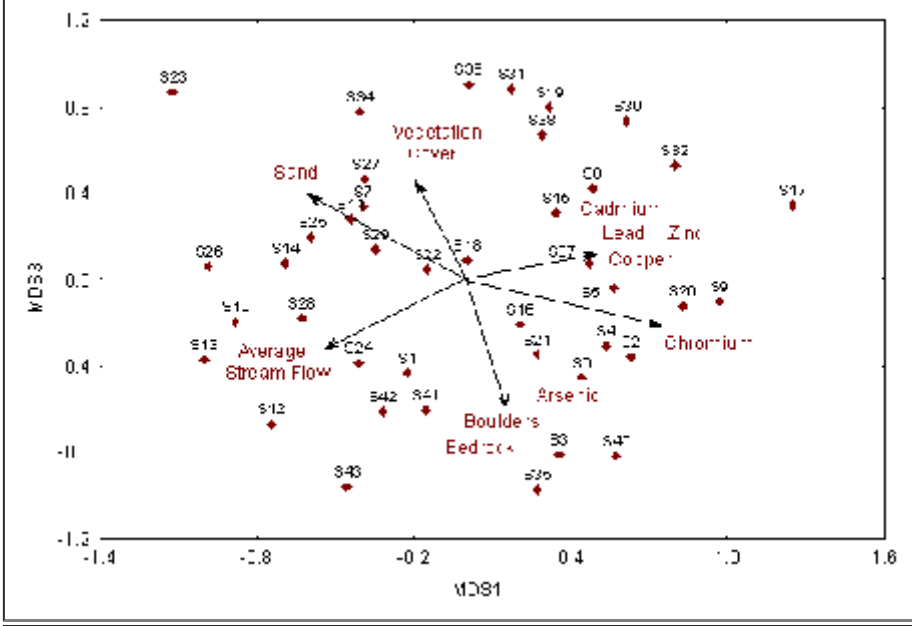

Figure 3.2 Axes 1 and 3 of a three-dimensional multidimensional scaling ordination of macroinvertebrate presence-absence data for each site. See legend of Figure 3-1 for more information.

(original size image)

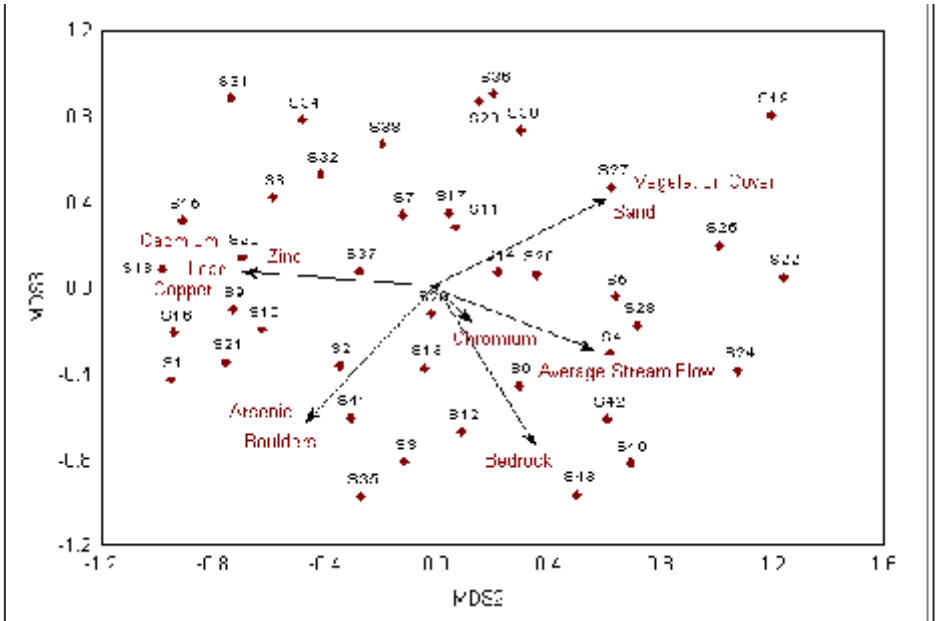

Figure 3.3 Axes 2 and 3 of a three-dimensional multidimensional scaling ordination of macroinvertebrate presence-absence data for each site. See legend of Figure 3-1 for more information.

(original size image)

Due to the qualitative method of macroinvertebrate sampling, which aimed to maximise the diversity of species collected from pool habitats, it is not possible to report on the effects of the measured toxicants on community indices such as numbers of species or total numbers of individual animals. However, an indication of the fauna typically found in Melbourne urban stream pool habitats can be gleaned from a compilation of the 20 most frequently recorded taxa (Table 3-3). This shows that the fauna consists of a range of broadly distributed southern Australian taxa, characteristic of lowland streams, including three genera of leptocerid caddisflies, several genera of midge larvae (chironomids), atyid shrimps, as well as some aquatic beetles.

Table 3-3 The 20 most frequently recorded macroinvertebrate taxa collected during the study. Forty-one sites were sampled on two occasions each (Spring and Autumn) giving a total of 82 sampling occasions. The maximum number of possible records for any species, therefore, is 82. Abbreviations for taxonomic groupings are: An.Ol.= Annelida, Oligochaeta, An.Hi. = Annelida, Hirudinea. Tr.Lpt = Trichoptera, Leptoceridae, Di.Ch - Diptera, Chironomidae, He.Co = Hemiptera, Corixidae, Col.Dy = Coleoptera, Dytiscidae, Col.Hyd = Coleoptera, Hydrophilidae O.C. = Odonata, Coenagrionidae, Eph.Ca. = Ephemeroptera, Caenidae, Eph.Le. = Ephemeroptera, Leptophlebiidae, M.P. = Mollusca, Planorbidae/Physidae, M.Hy. = Mollusca, Hydrobiidae, A.Ce = Amphipoda, Ceinidae, Ac.Hy = Acarina, Hydracarina. Cr.De. = Crustacea, Decapoda. Spp. indicates that the group may consist of more than one species. AWTV indicates the Australian Water Technologies Victorian macroinvertebrate voucher collection.

No. of records	Rank	Taxon	Group
67	1	Oligochaeta (all unidentified spp.)	An.Ol.
66	2	Planorbidae/Physidae spp.	M.P.
64	3	*Cricotopus*/*Paratrichocladius* sp.	Di.Ch
61	4	*Micronecta* spp. (L)	He.Co
58	5	*Paratya australiensis*	Cr.De

46	6	*Austrochiltonia* spp.	A.Ce
46	7	*Polypedilum* spp.	Di.Ch
45	8	Hydrobiidae spp.	M.Hy
40	9	*Ischnura heterosticta*	O.C.
38	10	Hydracarina spp.	Ac.Hy
34	11	Glossiphonidae	An.Hi
34	12	*Chironomus* spp.	Di.Ch
33	13	*Procladius* spp.	Di.Ch
32	14	*Triplectides simulis*	Tr.Lpt
27	15	*Triplectides ciuskis*	Tr.Lpt
26	16	*Necterosoma* penicillatus.	Col.Dy
25	17	*Caenidae unidentified*	Eph.Ca
24	18	*Paracymus pygmaeus*	Col.Hyd
21	19	*Nousia sp. AWTV A1*	Eph.Le
21	20	*Notalina spira*	Tr.Lpt

Chapter 4: Discussion

- 4.1 Sediment toxicants
- 4.2 Contaminant sources
- 4.3 Macroinvertebrate-sediment toxicant relationships
- 4.4 Recommendations

4.1 Sediment Toxicants

Patterns of distributions of toxicants covered in this study were complex and several factors appeared to be involved in determining toxicant concentrations at any particular site. The clumped distribution of particular contaminants indicates that the most important of these factors is the source of the contaminant, however, landscape features (*e.g.* stream gradient) and patterns of urbanisation and direct anthropogenic stream alteration also appear to play a key role. The interplay of these factors means that many unique combinations of stream alteration and contamination may exist and that even with 44 stream sites located across Melbourne only a few sites could be classified as similar on the basis of sediment contaminants.

Complex effluents from major industries and runoff from highly built up areas appear to be a major source of sediment contamination in the Melbourne urban area. With the exception of occasional gross pollution incidences, identification of individual sources is difficult, since many contaminants may be derived from many different sources and their inputs or discharges to streams may occur sporadically. Attempts are being made in many countries to improve urban stream water quality through such initiatives as the adoption of industry codes of practice for waste discharges and international standard environmental management systems (*e.g.* ISO 14000) and the construction of stormwater treatment systems. Baseline data plays an important role in assessing the performance of these initiatives and such data sets are now being developed for Melbourne by the Melbourne Water Corporation (*e.g.* Lewin 1997, Melbourne Water Corporation 1997). The data collected for this study forms part of Melbourne Water's ongoing urban stream monitoring program, "Streamwatch" which is an extensive program including monitoring of water quality, biological health, toxicants, and litter. Aside from the Streamwatch program, no extensive studies of stream toxicants

have previously been undertaken in Melbourne. However, there have been a number of site specific studies (*e.g.* Bagg *et al*., 1981, Pouliot 1993, Reed 1992) and an earlier study, on heavy metals only, conducted by the Victorian Environment Protection Authority (EPA 1981).

Lewin (1997) undertook a limited comparison of data from 1994 and 1995 samplings at four Streamwatch sites which were located at, or close to sites sampled by the EPA in 1981. She found that concentrations of some heavy metals had increased at some sites and decreased at others, indicating that both transport and accumulation mechanisms were acting. In the absence of continued inputs of heavy metals, it is likely that scouring stormflows would eventually wash contaminated sediments to sea. The rate of such transport mechanisms is not known, although it is probably in the order of decades.

Reed (1992) reported that sediments at a number of sites in Kororoit Creek in western Melbourne were contaminated with heavy metals. Reed also noted that there were some monthly differences in contamination with higher concentrations occurring in late autumn than in summer. She speculated that this may be due to a number of factors including higher rainfall in autumn washing material into the creek bed, higher stream flows possibly scouring the stream bed and exposing previously buried contaminated sediment, and reduced industrial discharges over the Christmas period prior to the summer sampling.

A study on a limited range of PAH's in several Melbourne streams was conducted by Bagg *et al*. (1981). They reported levels of benzo(a)pyrene in sections of the Yarra River, Stony Creek, and Moonee Ponds Creek which were markedly greater than reported for the present study, and attributed these high values to oil spills. Although benzo(a)pyrene was recorded at some sites in the present study within the range of values in the range reported by Bagg *et al*., in general concentrations were below analytical detection limits. This contrasts to Bagg *et al*.'s findings where relatively high concentrations of benzo(a)pyrene concentrations were recorded from all sites they sampled in Melbourne. The finding may indicate some minor improvement in stream sediment quality over the 20 years since their study was conducted.

4.2 Contaminant sources

The results of the PCA indicated that no toxicant variables were correlated with the measured geomorphic variables (*e.g.* percentage substrate type *etc*.). Therefore local stream geomorphology was not an important determinant of contamination. Contaminants appeared to be distributed more in relation to degree of urbanisation, with some differentiation between classes of contaminant and the locations at which they were recorded. For example, highest concentrations of cadmium, copper, chromium, lead and zinc were found in highly industrialised parts of western Melbourne. PCA showed these variables to be highly correlated with each other, indicating a common type of source which is most probably electroplating industries. Electroplating industries commonly produce wastewaters containing zinc and chrome (Nalco 1988). Copper, tin, silver, and cadmium are also commonly involved in electroplating (Cole *et al.*, 1981) and are also likely to be released with effluents. Electroplating with chromium metal anodes does not proceed satisfactorily so lead anodes are commonly used (Cole *et al.*, 1981) and this may account for the correlation between lead and other heavy metals in urban stream sediments.

Since concentrations of mercury and arsenic in sediments were not correlated with other heavy metals, it is likely that they are derived from other types of sources. Mercury contamination may possibly be a by-product of the manufacture of sodium hydroxide. This is commonly performed by electrolysis of sodium chloride by a mercury cathode in a brine solution. The spent brine solution is usually discharged as effluent and may contain small quantities of mercury (Cole *et al.*, 1981). ICI Australia Ltd at Yarraville has manufactured sodium hydroxide in Melbourne's western suburbs and at Botany in New South Wales (Cole *et al.*, 1981).

According to Nalco (1988), the solubility of arsenic in water is so low that its presence is usually an indicator of either mining or metallurgical operations in the catchment, or runoff from agricultural areas where arsenical materials have been used. Gold has been mined at Warrandyte in the past and this may account for the relatively high levels of arsenic found at a site on Yarra River at Warrandyte in this study. Other sites, particularly Eumemmering Creek at Dandenong (59 mg/kg, autumn 1996), also recorded high levels of arsenic, however, the source at these sites is unknown.

In general, industries discharging wastes to waterways in Melbourne have a license to do so from the State Environment Protection Authority. Other industries may discharge to sewer through a trade waste agreement with Melbourne Water or truck their waste to dedicated disposal sites. It is possible that the observed high levels of heavy metals at some sites may be due to illegal discharges, poor site management practices or past practices prior to connection to sewer.

A cluster of sites on the Yarra River downstream of Warrandyte recorded elevated concentrations of petroleum hydrocarbons with carbon chain lengths from 15 to 28 which is indicative of diesel oil through to asphalt (Cole *et al.*, 1981). These sites also had elevated concentrations of a wide range of PAH's and these too are probably derived from fuel and oil contaminated runoff.

4.3 Macroinvertebrate-sediment toxicant relationships

Exploratory multivariate statistical analyses of macroinvertebrate community data revealed some broad scale relationships between particular environmental and contaminant variables. One of the major findings of this study is that only heavy metals seemed to have any relationship with macroinvertebrate community structure. Other contaminants, which were all organic compounds, did not exhibit any significant relationship with macroinvertebrate communities. Although many ecotoxicological studies have demonstrated the toxicity of the organic compounds measured in this study, concentrations of the compounds never reached the concentrations exhibited by heavy metals. If these compounds have similar levels of toxicity to heavy metals in river sediments, then this may account for the lack of a significant relationship with macroinvertebrate communities.

Due to the wide variety of potential contaminants and the range of geomorphic alterations possible in urban streams, it was difficult to elucidate clear trends between types of effects and particular macroinvertebrate communities. Similar views were expressed by Pitt *et al*. (1995), in a study of urban stormwater toxicity. They concluded that effects of stormwater runoff on receiving waters depended a wide range of factors including the magnitude of the dry and wet weather discharges; the transport and fate mechanisms of the toxicants; and the effects from other discharges and receiving water conditions. They considered that these factors and the site-specific relationships between them make the prediction of receiving water effects difficult, if not impossible. While the authors felt that *in situ* biological community structure studies could give an indication of receiving water effects, particularly if control sites were available, it would be difficult to relate any identified impacts to any specific pollutant.

4.4 Recommendations

Since this study has shown that the relationship between macroinvertebrate communities and the environmental condition of urban streams is complex, it will be important to ensure that an urban macroinvertebrate-based prediction and classification scheme will be sensitive to the types of impacts observed in urban streams. This may be best achieved by 1) simplifying the type of physical and chemical analytical testing required as part of routine environmental monitoring and assessment programs, as well 2) identifying an acceptable target macroinvertebrate fauna for urban streams.

The first point may be addressed by developing a single toxicant index. The data collected as part of this study will assist in the development of such an index, however, before an index can be developed more information is required on the temporal variability of toxicants and what are acceptable background levels. Based on the findings of this study it may be necessary to weight some contaminants on the basis of their likely toxicity.

The second point, which may only be attained by expert consensus, is an important consideration for urban streams, since it will be impossible to attain a truly natural ecological community given the degree of hydraulic alteration of the catchment from its natural state.

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