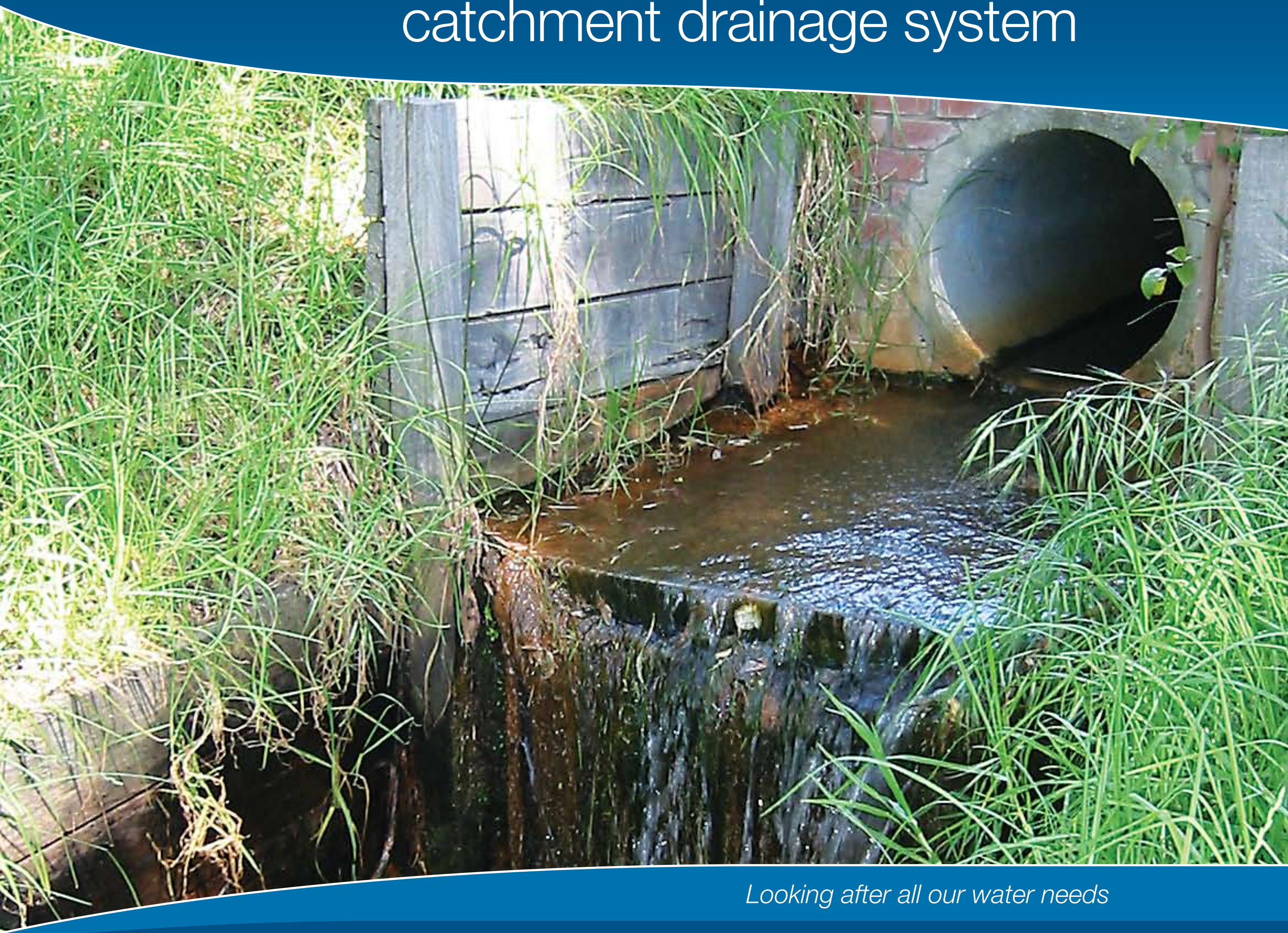
Government of **Western Australia**
Department of **Water**

A baseline study of contaminants in the Swan and Canning catchment drainage system



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A baseline study of contaminants in the Swan and Canning catchment drainage system

Department of Water

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Department of Water
168 St Georges Terrace
Perth Western Australia 6000
Telephone +61 8 6364 7600
Facsimile +61 8 6364 7601
www.water.wa.gov.au

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For more information about this report, contact Dr. Helen Nice, Water Science Branch, Department of Water.

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Overview

This assessment of contaminants in the Swan and Canning Catchment Drainage System is a baseline study conducted as part of the Non-Nutrient Contaminants Program (NNCP). The NNCP is a four part program, of which this study represents one component. This study has identified and quantified a range of contaminants entering the Swan Canning system that are typical of an urbanised catchment. From this baseline information subcatchments have been identified and prioritised for further investigation.

During 2006, 77 individual drain sites were assessed within 27 subcatchments. Both surface water (grab) and surface sediment (core) samples were analysed for a comprehensive suite of contaminants and water quality parameters known to be associated with stormwater. These comprised polycyclic aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPHs), polychlorinated biphenyls (PCBs), organochlorine (OC) pesticides, organophosphorus (OP) pesticides, herbicides, anionic surfactants, metals, chromium reducible sulphur suite, microbial parameters (faecal coliforms and enterococci), major ions and physical parameters. Representative compounds from these parameter groups were selected based on factors such as land uses in the Swan Canning catchment, known toxicity of compounds to aquatic organisms, persistence of these compounds in the environment and the availability of current laboratory analytical techniques. Although not the focus of this study, samples were also analysed for nutrients at the request of the SRT.

The results of these analyses were compared across subcatchments (and individual drains within subcatchments where appropriate) and are presented in this report. In addition, where guidelines were available for particular variables, these were applied to the data. A rationale for the selection of guidelines and their limitations and/or modifications with regard to the current dataset has been provided. Although it should be emphasised that guidelines do not currently exist for stormwater and associated sediments. Generally, the guidelines applied are conservative, relating to ecosystem health because it is recognised that although samples were collected from a series of drains and associated waterways, these all drain into the ecologically sensitive Swan Canning system. Therefore the use of guidelines in this study was to provide a general frame of reference only as to the state of water quality and sediments in the drains. Where the referenced guidelines are exceeded, this does not indicate that standards are not being met. Rather, it indicates that further consideration should be given to the particular situation, most probably in the form of targeted impact studies in the downstream receiving environment

Priorities for further investigation

Based on the information presented in this baseline study, subcatchments have been prioritised. These are listed with their associated contaminants in order of priority in Table 1.

Table 1 Prioritisation of subcatchments and associated contaminants

Priority	Subcatchments	Contaminants
1	Helena River	PAHs, OC pesticides and metals plus a potential issue with herbicides
1	Lower Canning	OC pesticides and metals plus a potential issue with herbicides, petroleum hydrocarbons, anionic surfactants and PAHs (and nutrients)
1	Upper Swan	OC pesticides and metals plus a potential issue with herbicides, petroleum hydrocarbons and anionic surfactants (and nutrients)
1	Mills Street Main Drain	OC pesticides and metals plus a potential issue with herbicides, petroleum hydrocarbons and PAHs (and nutrients)
1	Central Belmont Main Drain	OC pesticides and metals plus a potential issue with herbicides, petroleum hydrocarbons and PAHs
1	Maylands	OC pesticides and metals plus a potential issue with herbicides, petroleum hydrocarbons and PAHs
1	Blackadder Creek	OC pesticides and metals plus a potential issue with herbicides, PAHs and anionic surfactants
2	Bayswater Main Drain	OC pesticides and metals plus a potential issue with herbicides and petroleum hydrocarbons
2	South Belmont	OC pesticides and metals
2	Central Business District	PAHs and metals (and nutrients)
2	Perth Airport South	PAHs and metals
3	Bull Creek	Metals plus a potential issue with anionic surfactants, PAHs and petroleum hydrocarbons (and nutrients)
3	Helm Street	Metals and a potential issue with herbicides
3	Bickley Brook	Metals and a potential issue with herbicides
3	Bannister Creek	Metals and a potential issue with herbicides
4	Upper Canning	Metals
5	Bennett Brook	Potential issues with petroleum hydrocarbons and herbicides
5	Ellen Brook	Potential issue with petroleum hydrocarbons (and nutrients)
5	Susannah Brook	Potential issue with petroleum hydrocarbons (and nutrients)
5	St Leonards Creek	Potential issue with herbicides (and nutrients)
5	Jane Brook	Potential issue with herbicides
5	Yule Brook	Potential issue with herbicides

In addition to the above:

1) microbial levels exceeded guidelines in all subcatchments.
2) there are potential issues with metals in all subcatchments (only the priority metal areas are listed above – those that were consistently high in metal concentrations and consistently exceeded guidelines).
3) acidification of sediments is not currently an issue. However, subcatchments that contain sites that may potentially be of concern if disturbed (and complete oxidation occurred) are: Helena River, Bennett Brook, South Belmont, Central Belmont, Ellen Brook, Blackadder Creek, Lower Canning, Bull Creek, South Perth and Mills Street Main Drain.
4) although nutrients were not the focus of this study, they were assessed at the request of the SRT to provide background information.

This prioritisation of subcatchments was based on the number of parameters where guidelines were exceeded and/or where concentrations were consistently high, in addition to the potential for ecological harm based on the type of parameter. It should be noted that some specific sites within the lower priority subcatchments had elevated contaminant levels that may also warrant further investigation.

Summary of the parameters

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are typical components of asphalts, fuels, oils, greases, creosote and roofing tar and are also formed during the incomplete burning of fuels, refuse and other organic substances. PAHs were typically only found in the sediments of the drains. Individual PAHs consistently exceeded the guidelines applied at Helena River, Perth Airport South and Central Business District; and occasionally exceeded the guidelines at Blackadder Creek, Maylands, Central Belmont, Bull Creek, Mills Street Main Drain and Lower Canning subcatchments.

Total petroleum hydrocarbons

Total petroleum hydrocarbons (TPHs) originate from crude oil, are relatively volatile and are most likely to enter the environment as a result of road runoff containing vehicle fuel and oils. These compounds were detected sporadically in the sediments of sites within the Maylands, Upper Swan, Central Belmont, Bennett Brook, Lower Canning, Mills Street Main Drain, Ellen Brook, Susannah Brook, Bayswater Main Drain and Bull Creek subcatchments.

Polychlorinated biphenyls

Polychlorinated biphenyls (PCBs) have had a variety of applications including capacitor and transformer fluids, lubricating and cutting oils, pesticide and plastic additives and reactive flame retardants. A ban on the importation of PCBs has been in place in Australia since 1979 but their presence was investigated in the current study because they are highly persistent compounds and are thought to be ubiquitous in the environment. PCBs were not detected in either sediment or surface water samples in the current study. However, it is recommended that this ‘non-detect’ data be treated with caution, as the laboratory limit of reporting was relatively high compared to concentrations of these compounds that are known to cause deleterious effects to environmental health.

Organochlorine pesticides

Organochlorine pesticides (OC) pesticides are applied to control pests of agriculture, livestock and buildings. Their use has been phased out in Australia but they are often still present in the environment due to their persistent nature. OC pesticides were more common in sediments than surface water. OC pesticides were detected in the Bayswater Main Drain, Blackadder Creek, Central Belmont Main Drain, South Belmont Main Drain, Helena River, Maylands, Upper Swan, Mills Street Main Drain and Lower Canning subcatchments. They were consistently above guideline limits, where these were available. Chlordane and dieldrin were the most frequently reported OC pesticides and Helena River had the highest number of individual OC pesticides detected and typically the highest concentrations.

Organophosphorus pesticides

Like OC pesticides, the function of organophosphorus (OP) pesticides is to control pests. OP pesticides were not detected in either sediments or surface water in the current study. However, as for PCBs, it is recommended that the non-detect data be treated with caution because of laboratory limits of reporting.

Herbicides

Herbicides are applied to control or inhibit the growth of plant pests. Herbicides were more commonly found in surface water than sediment samples, although they were only detected in a small proportion of the samples analysed. Herbicides were detected, albeit sporadically, in the Bayswater Main Drain, Bennett Brook, Blackadder Creek, Central Belmont Main Drain, Helena River, Jane Brook, Maylands, St Leonards Creek, Upper Swan, Bannister Creek, Bickley Brook, Helm Street Main Drain, Lower Canning, Mills Street Main Drain and Yule Brook subcatchments. There was an apparent peak in herbicide detections during the August sampling period, perhaps related to the season of application and subsequent runoff due to rainfall. Simazine and atrazine were the most frequently detected herbicides. Herbicides exceeded guideline levels on two occasions only (at Upper Swan and Yule Brook subcatchments).

Anionic surfactants

Anionic surfactants enter waterways mainly by discharge of aqueous wastes from household and industrial laundering and cleansing operations. They were only measured in surface water and were detected on very few occasions (again the relatively high limit of reporting should be taken into account with non-detect data). Subcatchments where this occurred were Blackadder Creek, Bull Creek, Upper Swan and Lower Canning. Guidelines were exceeded at Blackadder Creek and Lower Canning subcatchments on one occasion each.

Metals

Metals occur naturally in the environment, although the majority of metals in the drain sediments and surface waters are likely to have originated from anthropogenic sources. Metals are commonly found in road runoff containing fuel and oil combustion by-products, products of tyre and brake wear and roof runoff. Additionally, atmospheric emissions from oil and coal combustion and from smelting and mining activities can contribute metals to the environment. On a local scale, there are many small industries in the subcatchments such as metal plating and auto-repair shops that may be contributing metals directly to the drains. Of the suite of 14 metals, all were detected in both sediment and surface water samples, with the exception of mercury, which was only detected in sediment samples. Generally, Bayswater Main Drain, Blackadder Creek, Bannister Creek, Mills Street Main Drain and Upper Canning subcatchments had significantly higher concentrations of metals than other subcatchments. Additionally, where guideline levels were available, these were exceeded in the sediment at Central Belmont (cadmium, lead and zinc), Upper Swan and Mills Street Main Drain (copper, lead and zinc), Central Business District (copper), Blackadder Creek (lead and zinc) and Helena River, Helm Street, Maylands, Perth Airport South and Lower Canning (lead). In the surface water, guidelines were exceeded in the majority of subcatchments (aluminium, iron, zinc and copper), Bayswater Main Drain (chromium, cobalt, and lead), Mills Street Main Drain and Bickley Brook (lead and chromium), Bannister Creek, Bull Creek and South Belmont (chromium) and Upper Swan (cobalt).

Chromium reducible sulphur suite

The chromium reducible sulphur suite is a set of analytical methods conducted to determine the presence of the potential for acid sulphate soils. Acid sulphate soils contain a naturally occurring horizon of sulphidic sediments, which, when disturbed, oxidise and produce sulphuric acid and iron oxides. Acidification of sediments was not considered to be a current issue at any of the sites sampled. However, stored acidity with the potential to be of environmental concern was observed more frequently at sites in subcatchments draining into the Swan River than the Canning River and potential acidity was generally observed in higher concentrations at sites in subcatchments that drain into the Swan River than the Canning River.

Microbial parameters (faecal coliforms and enterococci)

Faecal coliform and enterococci bacteria counts are used as an indication of faecal contamination of water in relation to the suitability of a waterbody for recreational activities. Whilst the drainage systems of the Swan Canning system were not designed with that purpose in mind, it is acknowledged that people do use some of these sites for recreational purposes. Therefore, there is the potential for human exposure to these bacteria. Faecal coliforms and enterococci are not exclusive to humans, being produced by all warm blooded animals. Their presence in the environment may be attributable to a variety of sources including sewer overflow, septic tanks, run-off or discharge from piggeries, poultry farms, dairies and stock holding yards. In addition, dog faeces from neighbouring recreational areas may be contributing to the load. Both faecal coliforms and enterococci were detected in all subcatchments and Primary Contact Recreational Guidelines were exceeded for either one or both parameters at all subcatchments. Secondary Contact Recreational Guidelines were also exceeded for either one or both parameters in the Blackadder Creek, Central Business District, Helena River, Henley Brook, Maylands, Perth Airport North, Perth Airport South, Bannister Creek, Bickley Brook, Lower Canning River, Mills Street Main Drain and Upper Canning River subcatchments. This suggests that recreational activity in these areas should be avoided until specific targeted studies are performed to inform on potential health impacts.

Major ions

Chloride to sulphate ratios in surface waters of some subcatchments indicated that an external source of sulphate (possibly from fertiliser use) may be entering the system. This occurred in the Bayswater Main Drain, Central Belmont Main Drain, Perth Airport South, South Belmont, Bannister Creek, Bennet Brook, Bickley Brook, Mills Street Main Drain and South Perth subcatchments.

In addition, the highest fluoride levels were detected in the Helena River, Blackadder Creek and Bayswater Main Drain subcatchments and high alkalinity was recorded in the Upper Swan and Lower Canning subcatchments.

Physical parameters

The Perth Metropolitan area experienced the driest year on record in 2006 with annual rainfall of below 470 mm compared to the average annual rainfall of 860 mm. Consequently, the drains did not receive the usual flow and concomitant dilution. Conversely, the usual load of contaminants from runoff events may not have reached the waterways during this period. Concentrations of total suspended solids appeared to be influenced by those rainfall events that did occur, with higher suspended solids levels being evident after rainfall. Total suspended solids were also more evident in the agriculture dominated subcatchments. Most subcatchments were within the acceptable range for pH except St Leonards Creek, Susannah Brook and South Perth, which exhibited low pH. Twelve individual drain sites exhibited high electrical conductivity suggesting their water quality may be influenced by estuarine mixing. Dissolved oxygen levels were generally poor in most subcatchments.

Context of the study

This baseline study has followed a broad-based ‘surveillance’ approach to determine the types, quantities and spatial variation of contaminants within the Swan Canning catchment drainage system. It represents one component of a multi-component study (the overall Non-Nutrient Contaminants Program). The information presented here has enabled the prioritisation of sites for further investigation in the subsequent study, *A baseline study of contaminants in the sediments of the Swan and Canning estuaries* (Nice 2009).

1 Introduction

1.1 Background to the Non-Nutrient Contaminants Program (NNCP)

The Non-Nutrient Contaminants Program (NNCP) was a three year project to determine the nature of contaminants (other than nutrients) delivered to and present in the Swan Canning system. The Swan Canning system comprises the Swan and Canning rivers and estuaries. Non-nutrient contaminants assessed as part of this program included pathogens, metals, low-level persistent organic compounds such as pesticides and herbicides, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and anionic surfactants.

The necessity to conduct a ‘non-nutrient’ assessment of contaminants within the system was identified by earlier SRT programs and investigations conducted by the Water and Rivers Commission operating within the Department of Environment (DOE) during the 1990s. In 1999 the SRT established the Swan Canning Cleanup Program (SCCP) to reduce nutrient loads entering the Swan Canning system. The aim was to reduce the extent and frequency of algal blooms. Contaminants other than nutrients were not a focus of this program. However, actions and recommendations from the SCCP Action Plan (SRT 1999a) and the SCCP review of contaminants in the Swan Canning system (SRT 1999b) included the need to assess non-nutrient contaminants within the Swan Canning system itself (the receiving environment), within existing drainage networks that discharge directly to the Swan Canning system and in groundwater associated with disused waste disposal sites adjacent to the Swan Canning system’s waterways and drains.

Major findings from the 1999 SCCP review of contaminants in the Swan Canning system (SRT 1999b) were that metal data in water, sediment and biota were spatially and temporally irregular. Data was also found to be compromised by inconsistent past sampling and analysis methods and unsuitable limits of reporting. In addition, there was a paucity of data for persistent organic compounds such as pesticides, herbicides, PAHs and PCBs within the Swan Canning system.

The need for a more comprehensive understanding of the non-nutrient component of contaminants both within and entering the Swan Canning system was also highlighted by subsequent drainage impact studies conducted by the Water and Rivers Commission (operating as the DOE) as a result of fish kills in the vicinity of drain outfalls to the Swan Canning system (DOE 2003a; DOE 2003b). In order to meet this need, the NNCP was developed to measure contaminants other than nutrients in the estuaries, rivers and drains of the Swan Canning system to complement existing nutrient-focused monitoring.

Scope of the NNCP

The Non-Nutrient Contaminants Program was a three year program that began in January 2006. The objective of the overall program was:

To determine the nature (types, concentrations and spatial variability) of non-nutrient contaminants delivered to and present in the Swan Canning system.

The NNCP comprised a series of studies:

- a baseline study of contaminants in the Swan and Canning catchment drainage system (this study)
- a baseline study of contaminants in groundwater at disused waste disposal sites in the Swan Canning catchment (Evans 2009)
- a baseline study of organic contaminants in the Swan and Canning catchment drainage system using passive sampling devices (Foulsham et al. 2009)
- a baseline study of contaminants in the sediments of the Swan and Canning estuaries (Nice 2009).

The NNCP program commenced with the *baseline study of contaminants in the Swan and Canning catchment drainage system*, which ran from February 2006 until November 2006. The findings of which, are the subject of this report.

1.2 Background to this baseline study

Stormwater is defined as water that flows over ground surfaces, in natural streams and in drains that has accumulated as a consequence of rainfall over a catchment (WRC 2004). The infiltration of stormwater can be inhibited by anthropogenic activities that increase impervious surfaces such as development and urbanisation in addition to the compaction of soil and removal of vegetation as a result of agricultural activities.

Conventional drainage systems such as piping and channelling have been designed to prevent flooding by transporting surface water runoff into waterways and basins (WRC 2004). While such urban drainage systems have been engineered to efficiently remove excess water, there is typically little consideration given to the prevention of downstream pollution. As a result anthropogenic contaminants such as surfactants, petroleum hydrocarbons, metals, pesticides and herbicides often accumulate in surface waters and sediments (Goonetilleke and Thomas 2003).

The Swan Canning system in Perth is bordered by the Swan coastal plain and is of ecological, cultural and social importance to the inhabitants of Western Australia. Although this system is not impacted by extensive shipping traffic, the transport of contaminants in stormwater has been identified as being of environmental concern (SRT 1999b), and indeed the most significant contributor to the deterioration of environmental quality in many of the natural and artificial waterbodies in Western Australia (Welker 1995). With increases in urbanisation, light industrialisation and agriculture throughout the Swan coastal plain there has been an increase in the volume of water that is removed by these drainage systems and delivered into nearby waterways WRC 2004). Existing information investigating the quality of stormwater within Western Australia is limited (Davies et al. 2000; SRT 1999b).

1.3 Objectives of this baseline study

The objectives of the baseline study of contaminants in the Swan and Canning catchment drainage system were as follows:

- to conduct a baseline investigation to identify and quantify surface water and sediment based non-nutrient contaminants of stormwater discharge entering the Swan Canning system via stormwater drains
- to prioritise subcatchments based on contaminants of potential concern

1.4 Contaminant selection

Representative compounds (and organisms where relevant) from each of the following parameter groups were selected for analyses within surface water and sediment samples:

- polycyclic aromatic hydrocarbons (PAHs)
- total petroleum hydrocarbons (TPHs)
- polychlorinated biphenyls (PCBs)
- organochlorine (OC) pesticides
- organophosphorus (OP) pesticides
- herbicides
- anionic surfactants
- metals
- chromium reducible sulphur suite
- major ions
- microbial parameters
- nutrients (nutrients were not the focus of this study, but were assessed at the request of the SRT to provide background information)

Selection of contaminants was based on:

- the findings of previous studies within the Swan Canning system (such as DOE 2003a; DOE 2003b)
- the known toxicity of key contaminants (such as contaminants that feature on the 'dirty dozen list' of persistent organic pollutants (Stockholm Convention 2001)
- the likelihood of contaminant occurrence due to land uses within the Swan Canning catchment
- the ability of laboratories to accurately analyse for the contaminants using endorsed methods

1.5 Guideline values applied

There are currently no guidelines available specifically for comparison with surface waters and sediments within stormwater drains. However, consideration was given to the sensitive nature of the receiving environment downstream from the drainage systems in the selection of guidelines for this study. As such, the most appropriate guidelines available were selected for comparison with the data presented in this report. These differed for different types of contaminants and/or environmental matrices and are summarised in Table 2.

Table 2 Guidelines applied and supporting information

Parameter	Guidelines selected	Application and limitations of guidelines applied
Non-nutrient contaminants in sediments	Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000) *Interim Sediment Quality Guideline Trigger Values: Low and High* (Simpson et al. 2005; ANZECC and ARMCANZ 2000)	Interim Sediment Quality Guideline (ISQG) – Low or Low Trigger Value is a threshold concentration. Below this concentration the frequency of adverse biological effects is expected to be very low. ISQG – High or High Trigger Value is intended to represent a concentration, above which adverse biological effects are expected to occur more frequently. Exceeding the trigger value concentrations does not necessarily mean that adverse biological effects will occur in the sediments, but further investigations should be undertaken to confirm this (Simpson et al. 2005).
Non-nutrient contaminants in surface water	*ANZECC guidelines for fresh and marine water quality – guidelines for 95% Ecosystem Protection in fresh waters* (ANZECC and ARMCANZ 2000)	The stormwater discharge is considered to have the potential to lower the ecological value of the receiving waterbodies that are considered to be ecologically sensitive (Swan and Canning rivers and estuary). Therefore, all data was assessed using the 95% trigger value (where available) for freshwater (ANZECC and ARMCANZ 2000).
Nutrient contaminants in surface water	*ANZECC guidelines for South West Australia for Lowland Rivers* (ANZECC and ARMCANZ 2000) SCCP targets for total nitrogen and total phosphorus concentrations (SRT 2004)	These guidelines apply to samples collected during base flow conditions. Some sampling in the current study took place during storm events. The SCCP targets relate to the number of total nitrogen and total phosphorus samples that exceed the target value in relation to the maximum number of allowable exceedences. The target values apply only to the winter period and three years of data is used to assess compliance (SRT 2004). These targets were applied in the current study at the request of the SRT as a guideline only, as each individual drain site was only sampled a maximum of four times over a one year period incorporating all seasons.
Physical measurements in surface water	*ANZECC guidelines for South West Australia for Lowland Rivers* (ANZECC and	For dissolved oxygen and pH, these guidelines apply to samples collected during base flow conditions. Some sampling in the current study took place during storm events.

Parameter	Guidelines selected	Application and limitations of guidelines applied
	ARMCANZ 2000)	
Microbial water quality	*ANZECC guidelines for primary and secondary recreational contact* (ANZECC and ARMCANZ 2000)	Data were compared with recreational guidelines for both primary and secondary contact. This was deemed appropriate because many of the stormwater drains sampled in this program are used for human recreation in addition to many of the receiving environments downstream from the drains. The guidelines refer to a median value over a bathing season comprising at least five samples taken per month. In the current study, the data are expressed as means because in some cases, less than five values were available. According to ANZECC and ARMCANZ (2000) at least five data points are required to calculate median values for comparison with guidelines. Additionally, the sampling regime in the current study did not apply specifically to a bathing season. Although new guidelines for the management of recreational waters exist (National Health and Medical Research Council 2005), these use a risk-based approach which requires significant baseline data which is not yet available for drain systems.
Chromium reducible sulphur suite (tests for acid sulphate soils)	*Draft Identification and Investigation of Acid Sulphate Soils* (DEC 2006)	The guidelines for coarse texture sands to loamy sands were selected for comparison with data from the current study. This is the most conservative option.

1) Note 1: There are no estuarine guidelines available for surface waters. In the absence of such guidelines, freshwater guidelines were selected over marine. These were deemed the most appropriate because the water within the drains was generally freshwater and during winter, rainfall in the catchment results in river flow, which, depending on strength and duration, can completely flush the estuary with freshwater. Although, as flow diminishes, salty water moves upstream, apart from the similarity of salinity, the estuarine waters are substantially different to those on the open coast (Brearley 2005), to which the marine guidelines apply.

2) Note 2: Guideline values are listed in Appendix A and displayed on graphs in the results section of this report.

2 Methods

2.1 Site selection

Sites were selected for sampling based on the ecological significance of the downstream environment, the location relative to land use and on accessibility. Sites were primarily at downstream locations within the drainage systems entering the Swan Canning system and were spread across the subcatchments to capture contamination attributed to a variety of land uses including rural, semi-rural, industrial, commercial and urban.

Seventy-seven individual drain sites were selected across 27 subcatchments draining into the Swan Canning system. Site locations are shown in Figures 1 and 2.

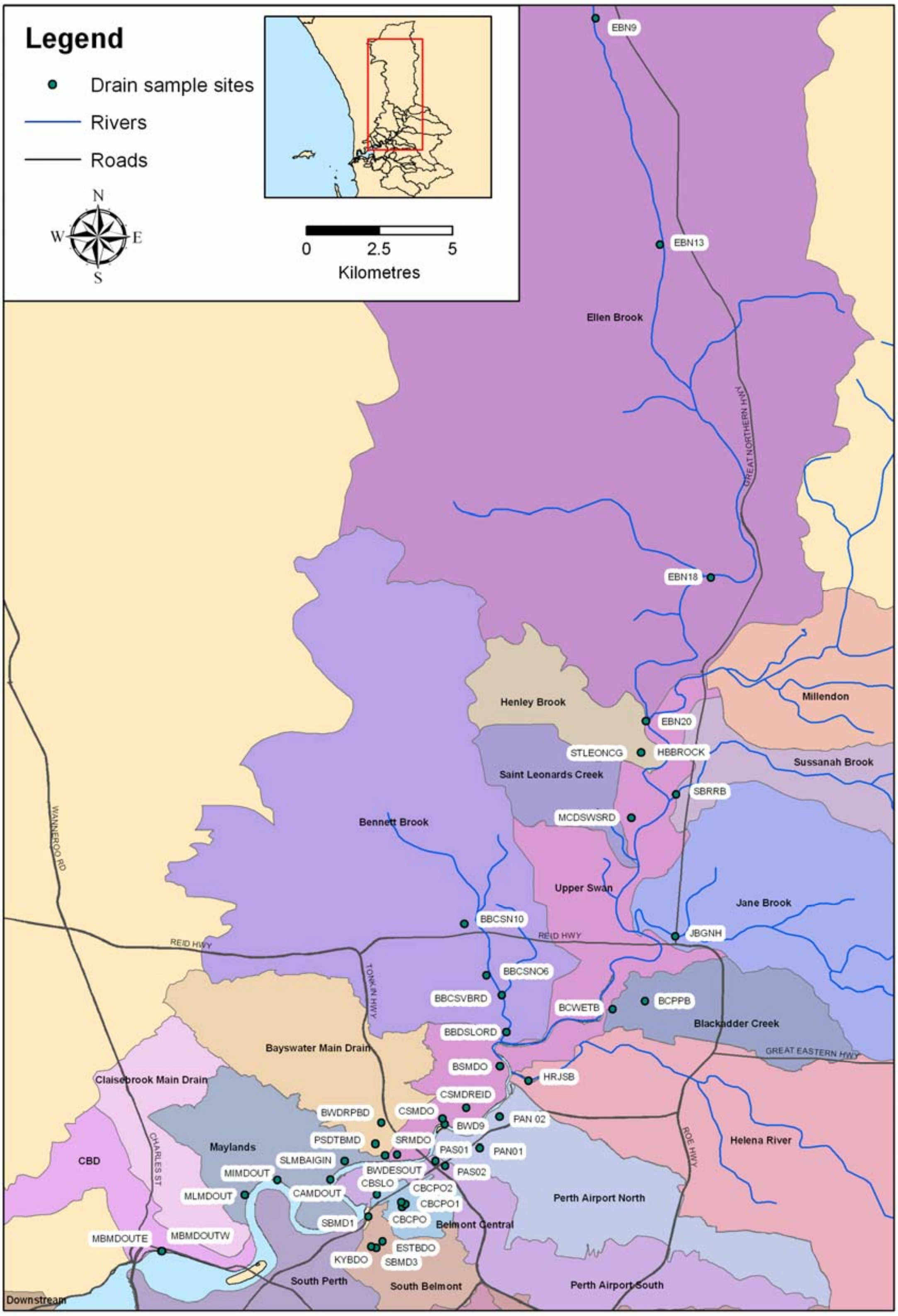

Figure 1 Drain sample sites in the Swan catchment

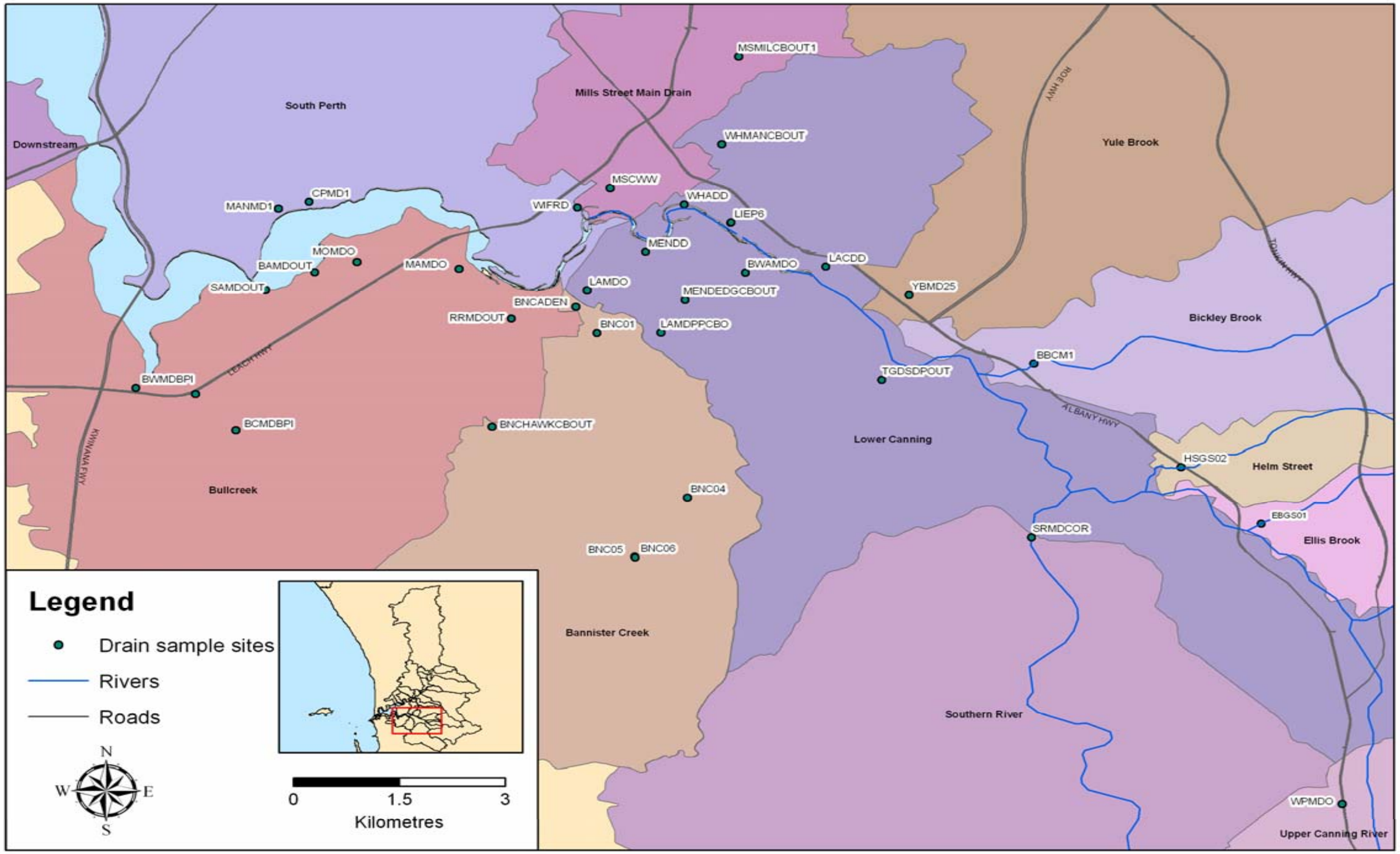

Figure 2 Drain sample sites in the Canning catchment

2.2 Water and sediment quality parameters

Parameters were selected based on land use activities within the subcatchments and the potential for a contaminant to harm the environment. Both sediment and surface water samples were collected.

The surface water parameters were divided into three groups:

Group 1: physicals and nutrients (nutrients were not the focus of this study but were requested by SRT to provide background information)

Group 2: major ions and microbial parameters

Group 3: organic compounds and metals

Refer to Tables 3 to 5 for parameters investigated, analytical methods applied and the limits of reporting for each group.

The sediment parameters comprised a suite of organic compounds and metals. Refer to Table 6 for parameters investigated, analytical methods applied and the limits of reporting for each group.

Samples were collected by Department of Water (DOW) and analysed by the National Association of Testing Authorities accredited laboratories: Pathwest (microbial analyses) and National Measurement Institute (chemical analyses).

Comment on limits of reporting

The limits of reporting used in this study were the lowest available at the time of sampling using accredited methods from commercial laboratories in Australia. National Measurement Institute is one of the leading laboratories in Australia in the development of lower detection limits to satisfy the ANZECC guidelines (ANZECC and ARMCANZ 2000). It should be noted that the guidelines are derived from toxicity data and in some cases are set at concentrations lower than current analytical methods are able to achieve (for example in the case of PCBs and OP pesticides).

Table 3 Parameter group 1: surface water – physicals and nutrients

Parameter	Method	Limit of reporting mg/L
Total suspended solids	Gravimetric method (APHA 1998; USEPA 1983; AS 1990).	<1
pH	Electrometry method (APHA 1998)	NA
Dissolved oxygen	Oxygen electrode method (APHA 1998)	NA
Conductivity	Instrumental measurement method (APHA 1998) reported at a standard temperature of 25.0° C	NA
Total nitrogen	Persulphate digestion method 4500-N C (APHA 1998); and the cadmium reduction method 4500- NO_3^-F (APHA 1998)	<0.025
Total oxidised nitrogen (NO_x^-N), or nitrate (NO_3^-) + nitrite (NO_2^-)	Cadmium reduction method 4500- NO_3^-F (APHA 1998)	<0.010
Ammonium nitrogen (NH_3^-N/NH_4^-N)	Phenate method 4500-NH_3 G (APHA 1998)	<0.010
Dissolved organic nitrogen	Analysis of TN in a filtered sample followed by subtraction of NH_3^-N/ NH_4^-N and NO_x^-N	<0.025
Total phosphorus	Persulphate digestion method 4500-P B.5 (APHA 1998); and the automated ascorbic acid reduction method 4500-P F (APHA 1998)	<0.005
Soluble reactive phosphorus	Automated ascorbic acid reduction method 4500-P F (APHA 1998)	<0.005

Table 4 Parameter group 2: surface water – major ions and microbial parameters

Parameter	Method	Limit of reporting mg/L
Total alkalinity (as CaCO3)	Electrometry and titration method (APHA 1998; USEPA 1983) using alkalinity method 2310 B and 2320 B (APHA 1998)	<1
Five day biological oxygen demand	5-day incubation method 5210 B (APHA 1998)	<5
Dissolved organic carbon	Combustion infrared persulphate UV oxidation method (APHA 1998)	<1
Total unfiltered metals, measured to ANZECC 2000 95% Protection limits Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Zn (14 metals)	ICP-MS or ICP-AES methods 3010 A and 3120 B (APHA 1998)	Al, Fe: 0.005 As, Cr, Co, Cu, Pb, Mg, Mo, Ni, Se, Zn: <0.001 Cd, Hg: < 0.0001
Faecal (thermo-tolerant) coliforms (presumptive thermo coliforms (count <10–1 000 000 cfu/100mL)	Enumeration followed by enzyme assays (APHA 1998)	NA
Enterococci (confirmed enterococci (count <10–24 000 MPN/100mL))	Enumeration followed by enzyme assays (APHA 1998)	NA
Sulphate as SO_4^{2-} (filtered)	Ion chromatography method 4110 (APHA 1998)	<2
Chloride (filtered)	Ion chromatography method 4110 (APHA 1998)	<10
Fluoride (filtered)	Ion selective electrode method 4500-F- C (APHA 1998)	<0.2

Table 5 Parameter group 3: surface water – organic compounds and metals

Parameter	Method	Limit of reporting µg/L	
Polycyclic aromatic hydrocarbons (PAHs)	GC-MS, GC-ECD analysis (USEPA 8080/8140 1996e; APHA 1998)	Naphthalene	0.01
		Acenaphthylene	0.01
		Acenaphthene	0.01
		Fluorene	0.01
		Phenanthrene	0.01
		Anthracene	0.01
		Fluoranthene	0.01
		Pyrene	0.01
		Benz(a)anthracene	0.01
		Chrysene	0.01
		Benzo(b)&(k)fluoranthene	0.02
		Benzo(a)pyrene	0.01
		Indeno(1,2,3-cd)pyrene	0.01
		Dibenzo(ah)anthracene	0.01
		Benzo(ghi)perylene	0.01
Organochlorine (OC) and organo phosphorus (OP) pesticides	GC-MS, GC-ECD analysis (USEPA 8080/8140 1996e; APHA 1998)	OC pesticides	< 0.01
		OP pesticides	< 0.1
Benzene, toluene, ethylbenzene, xylene (BTEX) and total petroleum hydrocarbon (TPH) fractions: TPH:C6–C9, TPH:C10–C14, TPH:C15–C28, TPH:C29–C36)	Purge and trap technique for extraction with subsequent analysis by GC-FID or GC/PID (USEPA 5030/8020 1996e)	Benzene	<1.0
		Toluene	<1.0
		Ethyl benzene	<1.0
		Xylene	<2.0
		Total TPH	<5.0
Polychlorinated biphenyls (PCBs)	GC-MS, GC-ECD analysis (USEPA 8080/8140 1983; 1996e; APHA 1998)		<0.01
Phenoxy acid herbicides	GC-MS, GC-ECD analysis (USEPA 8080/8140 1983; 1996e; APHA 1998)		<1

Parameter	Method	Limit of reporting µg/L	
Other herbicides	GC-MS, GC-ECD analysis (USEPA 8080/8140 1996e; APHA 1998)	Atrazine	<0.1
		Diuron	<0.1
		Hexazinone	<0.1
		Metolachlor	<0.1
		Molinate	<0.1
		Simazine	<0.1
		Prometryn	<0.1
		Metribuzin	<0.1
		Trifluralin	<0.1
		Dicamba	<1
		MCPA	<1
		Dichlorprop	<1
		2, 4-D	<1
		2, 4, 5-T	<1
		2, 4, 5 – TP	<1
		2, 4 – DB	<1
		MCPP	<1
		Triclopyr	<1
Anionic surfactants as methylene-blue active substances (MBAS) expressed as a mass of linear alkylbenzene sulphonate per volume	Spectrophotometry method (APHA 1998; USEPA 1983)		<100

Table 6 Parameter group 4: sediments

Parameter	**Method**	**Limit of reporting mg/kg**	
Total metals measured to ANZECC 2000 interim sediment quality guideline trigger values Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Zn (14 metals)	ICP-MS method 3010 A and ICP-AES method 3120 B (APHA 1998)		< 0.5
Total nitrogen	Persulphate digestion method 4500-N C (APHA 1998) and cadmium reduction method 4500-NO3- F (APHA 1998)		<50
Total phosphorus	Persulphate digestion method 4500-P B.5 (APHA 1998) and automated ascorbic acid reduction method 4500-P F (APHA 1998)		<5
Organochlorine (OC) and organophosphorus (OP) pesticides	GC-MS and GC-ECD analyses (USEPA 8080/8140 1983; 1996e; APHA 1998)	OC pesticides OP pesticides	< 0.01 < 0.1
Herbicides	GC-MS and GC-ECD analyses (USEPA 8080/8140 1983; 1996e; APHA 1998)		<0.1
Benzene, toluene, ethylbenzene, xylene (BTEX) and total petroleum hydrocarbon (TPH) fractions: TPH:C6–C9, TPH:C10–C14, TPH:C15–C28, TPH:C29–C36)	Purge and trap technique for extraction (USEPA 5030) with subsequent analysis by GC-FID or GC/PID (USEPA 8020)	Benzene Toluene Ethylbenzene Xylenes C6–C9 C10–C14 C15–C28 C29–C36	< 0.5 < 0.5 < 0.5 < 1.0 < 25 < 50 < 100 < 100
Polycyclic aromatic hydrocarbons (PAHs)	GC-MS and GC-ECD analyses (USEPA 8080/8140 1996e; APHA 1998)		< 0.01
Polychlorinated biphenyls (PCBs)	GC-MS and GC-ECD analyses (USEPA 8080/8140 1996e; APHA 1998)		< 0.1
Chromium reducible sulphur suite	Chromium reducible sulphur distillation and iodometric titration (method WL281-22B)		0.01% W/W
Moisture content	Evaporation at 105°C and gravimetric measurement		

2.3 Rainfall

Rainfall data was collected from the nine Bureau of Meteorology (BOM) weather stations throughout the Swan Canning system that most closely corresponded with the sampling locations in order to provide an indication of rainfall events for the sampling periods. Subcatchments sampled and their corresponding BOM weather stations are listed in Table 7.

Table 7 Subcatchments and corresponding BOM weather stations

Subcatchments	Corresponding BOM weather station reference
South Perth Central Business District Bayswater Main Drain Maylands	BOM 009225 (within the Maylands subcatchment)
Helena River	BOM 009180 (within the Helena River subcatchment)
Bennett Brook	BOM 009263 (within the Bennett Brook subcatchment)
Ellen Brook	BOM 009053 (within the Ellen Brook subcatchment)
Jane Brook Susannah Brook	BOM 009030 (within the Jane Brook)
Henley Brook St Leonards Creek Upper Swan Blackadder Creek	BOM 009025 (within the Upper Swan subcatchment)
Upper Canning River	BOM 009214 (within the Upper Canning subcatchment)
Lower Canning Helm Street Bickley Brook Yule Brook Mills Street Main Drain Perth Airport South Perth Airport North South Belmont Belmont Central	BOM 009106 (within the Lower Canning subcatchment)
Southern River / Wungong Bannister Creek Bull Creek	BOM 009257 (within the Southern River / Wungong subcatchment)

2.4 Frequency of sampling

Frequency of sampling was nominally quarterly at each site although this varied for some sites and parameters depending on water flow. Sampling took place over a week long period in February, May, August and November).

2.5 Quality control

Each batch of samples included the following laboratory quality control measures: one duplicate sample in every ten (randomly selected), one blank matrix test per batch of samples and one recovery from a blank reagent (method test). In addition, the following field sampling quality control measures were applied: one field blank per batch of samples and one set of replicates per batch of samples.

2.6 Data analysis

Data were graphed and compared to the most appropriate guidelines available. Data from individual drains were generally pooled into subcatchments for analysis. However, for contaminants that were detected only sporadically for some drains within a subcatchment (for example pesticides, herbicides and anionic surfactants), these were presented on a drain-by-drain basis.

Where data are presented as means, error bars represent +95% confidence intervals (best estimate for non-normal data) to provide an indication of variability.

Statistical analyses were performed (where data sets allowed) to establish whether significant differences in contaminant levels existed between subcatchments. Data were first tested for normality using the Kolmogorov-Smirnov test and the appropriate analysis of variance (ANOVA) test applied. Where a significant difference between subcatchments was detected, a multiple comparisons test (post-hoc) was applied to determine which subcatchments were statistically different.

Graphs and statistical analyses presented in this report used ‘actual’ data as opposed to substitution of zero values with ‘half-detection limit’ because where contaminants were common (for example, faecal coliforms), they were typically present in all samples, whereas, where contaminants were sporadic in their occurrence (for example, methylene blue active substances) they were present on so few occasions that it was considered misleading to apply substitution to the majority of data points within a dataset.

Refer to Appendix B for the number of samples for each parameter group.

3 Results

3.1 Rainfall

Figures 3 to 11 show the rainfall over the year of sampling (2006) measured at nine Bureau of Meteorology (BOM) weather stations throughout the Swan and Canning system. Sampling days are also indicated to illustrate the occurrence of rainfall (or otherwise) for sampling periods.

The year 2006 was the driest on record for the Perth metropolitan area, with annual rainfall of just under 470 mm compared to the long-term annual average for Perth of 860 mm (BOM 2007). Rainfall patterns varied across the catchment through the year. General patterns for the sampling months were:

February sampling period:	Dry period with no rainfall until the second last day of sampling (7 February), when heavy rainfall occurred.
May sampling period:	Rainfall in the week prior but dry throughout sampling period.
August sampling period:	Preceded by heavy rainfall in the weeks prior and light rains continuing throughout.
November sampling period:	Preceded by a long dry spell with very light rainfall occurring in some subcatchments on the first day of sampling (1 November).

Based on these rainfall events, the last sampling days in February and all the August sampling results should be considered for the possible effects of rainfall on the contaminant levels recorded.

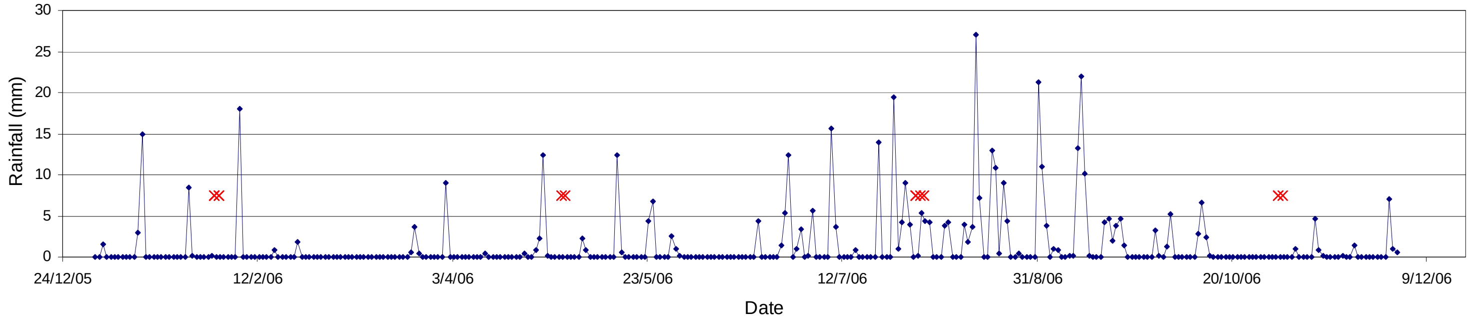

Figure 3 Rainfall data from Maylands weather station (BOM 009225) and corresponding sampling days

X = sampling days for South Perth, Central Business District, Bayswater Main Drain and Maylands subcatchments

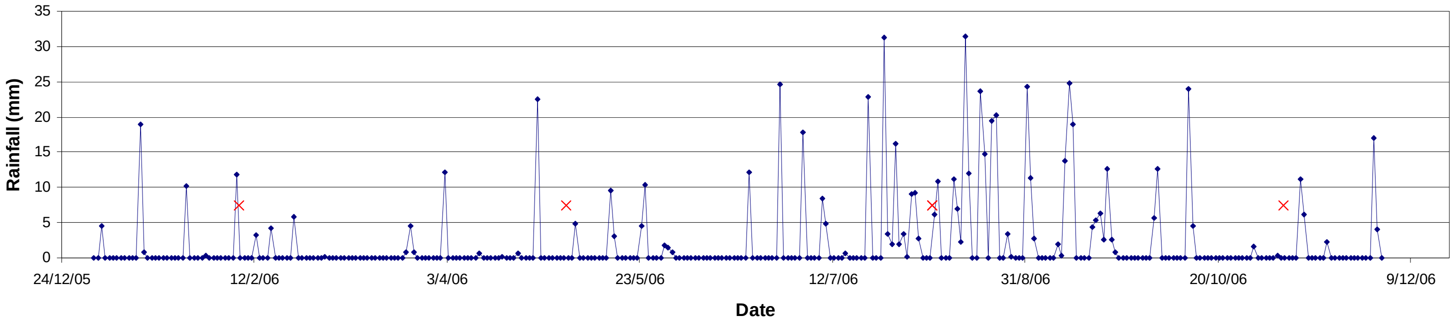

Figure 4 Rainfall data from Helena River weather station (BOM 009180) and corresponding sampling days

X = sampling days for the Helena River subcatchment

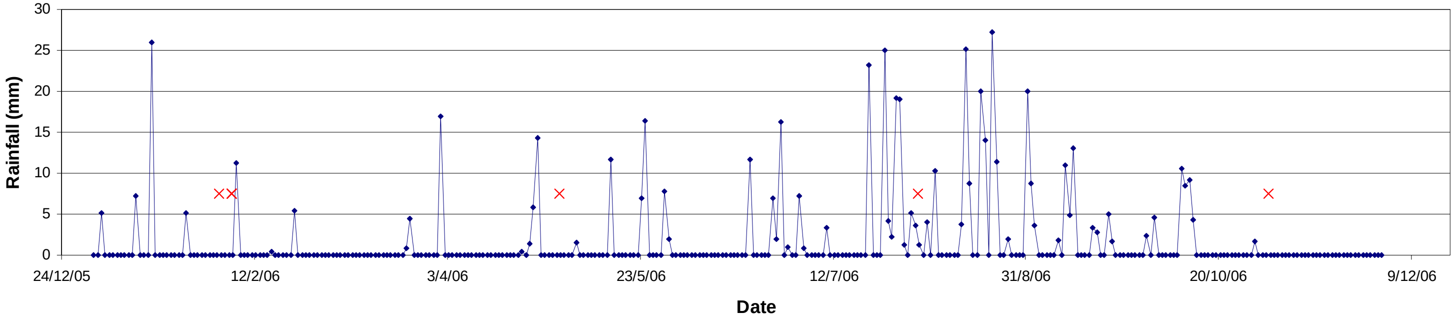

Figure 5 Rainfall data from Bennett Brook weather station (BOM 009263) and corresponding sampling days

X = sampling days for the Bennett Brook subcatchment

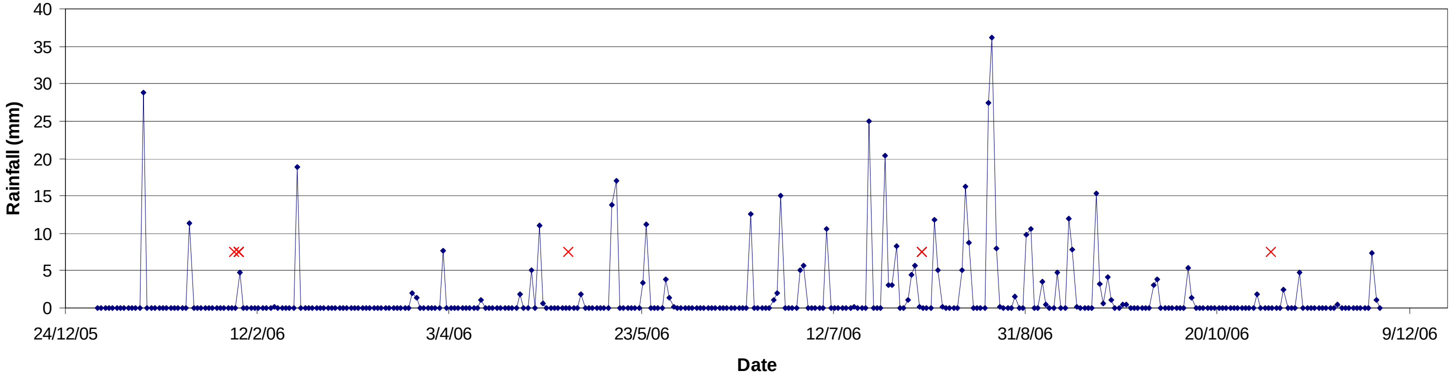

Figure 6 Rainfall data from Ellen Brook weather station (BOM 009053) and corresponding sampling days

X = sampling days for the Ellen Brook subcatchment

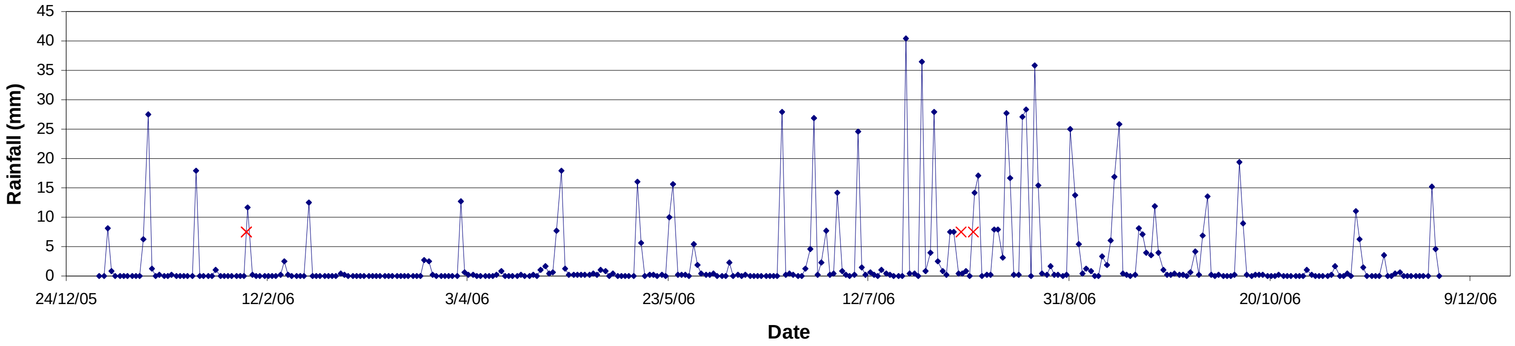

Figure 7 Rainfall data from Jane Brook weather station (BOM 009030) and corresponding sampling days

X = sampling days for the Jane Brook and Susannah Brook subcatchments

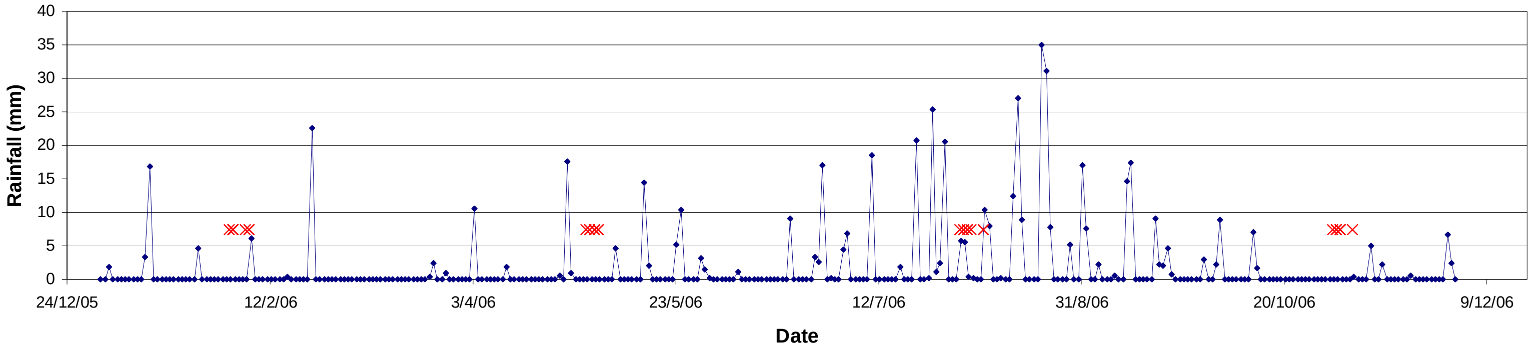

Figure 8 Rainfall data from the Upper Swan weather station (BOM 009025) and corresponding sampling days

X = sampling days for the Henley Brook, St Leonards Creek, Upper Swan and Blackadder Creek subcatchments

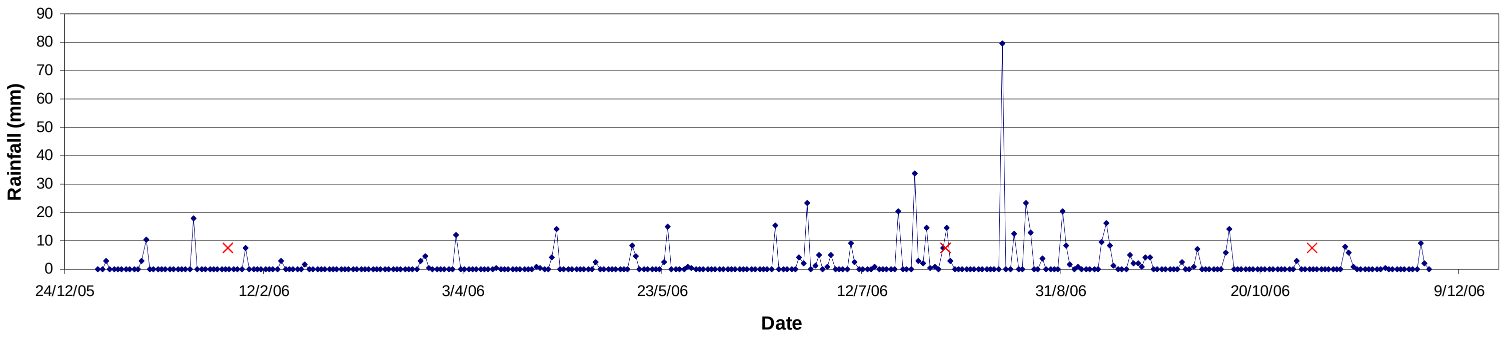

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Figure 9 Rainfall data from the Upper Canning weather station (BOM 009214) and corresponding sampling days

X = sampling days for the Upper Canning subcatchment

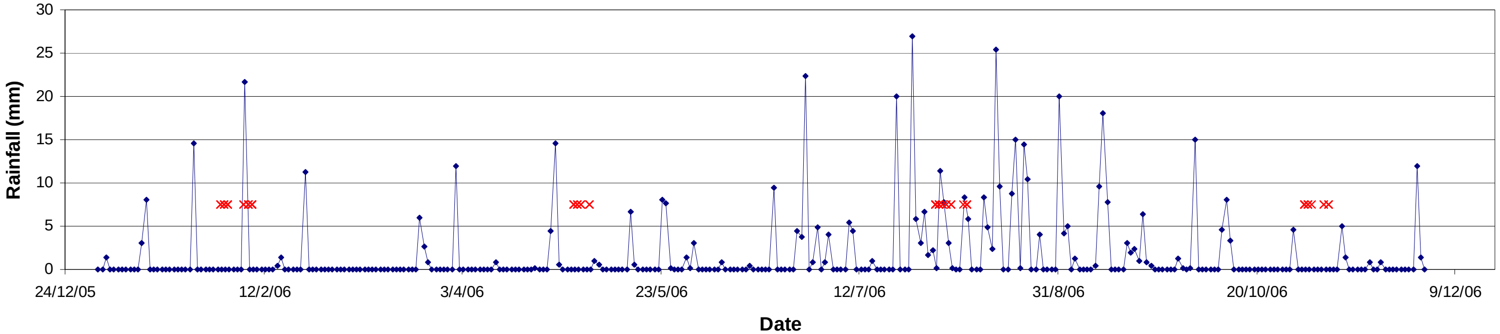

Figure 10 Rainfall data from the Lower Canning weather station (BOM 009106) and corresponding sampling days

X = sampling days for the Lower Canning, Helm Street, Bickley Brook, Yule Brook, Mills Street Main Drain, Perth Airport South, Perth Airport North, South Belmont, Belmont Central subcatchments

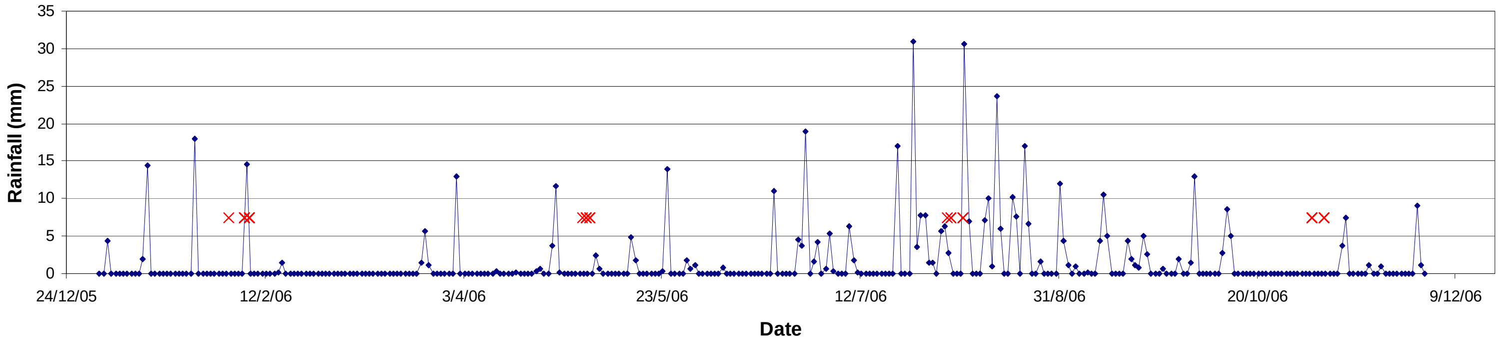

Figure 11   Rainfall data from the Southern River weather station (BOM 009257) and corresponding sampling days

X = sampling days for the Southern River, Bannister Creek and Bull Creek subcatchments

3.2 Physical data

Surface water was sampled for physical parameters including total suspended solids, temperature, pH, electrical conductivity, dissolved oxygen and biological oxygen demand.

Summary

- High total suspended solids appeared to be influenced by rainfall events and were also more evident in the agriculture dominated subcatchments.
- Surface water temperature was higher in the drains in the summer and autumn months.
- Most subcatchments were within the South West Lowland Rivers Freshwater lower (pH 6.5) and upper (pH 8.0) limits for pH except for St Leonards Creek, Susannah Brook and South Perth (where pH was below 6.5).
- Twelve individual drain sites had electrical conductivity greater than 55 mS/cm on one or more occasions suggesting that their water quality may be influenced by estuarine mixing.
- Dissolved oxygen levels were generally below the South West Lowland Rivers Freshwater lower limit (80%) in most subcatchments indicating that there was insufficient dissolved oxygen to maintain a healthy system.
- The biological oxygen demand was below the limit of reporting (5 mg/L) at 62 of the 77 individual drain sites.

Mean physical data for subcatchments are presented.

Total suspended solids

Mean total suspended solids data for subcatchments are presented in Figure 12. Henley Brook had the highest total suspended solids concentrations across subcatchments (but was only sampled on two occasions), followed by the Ellen Brook subcatchment.

At the level of individual drain site, EBN18 (Ellen Brook) and HBBROCK (Henley Brook) in February and MSCWW (Mills Street Main Drain) in August had the highest total suspended solids concentrations. These sampling periods corresponded with significant rainfall events at these sites. No single drain site had consistently high total suspended solids for all sampling occasions.

There are currently no guidelines available for total suspended solids. However, a level of 40 mg/L has been suggested (Liston and Maher 1997) for lowland river systems. From a total of 206 samples, this level was exceeded on nine occasions across seven subcatchments.

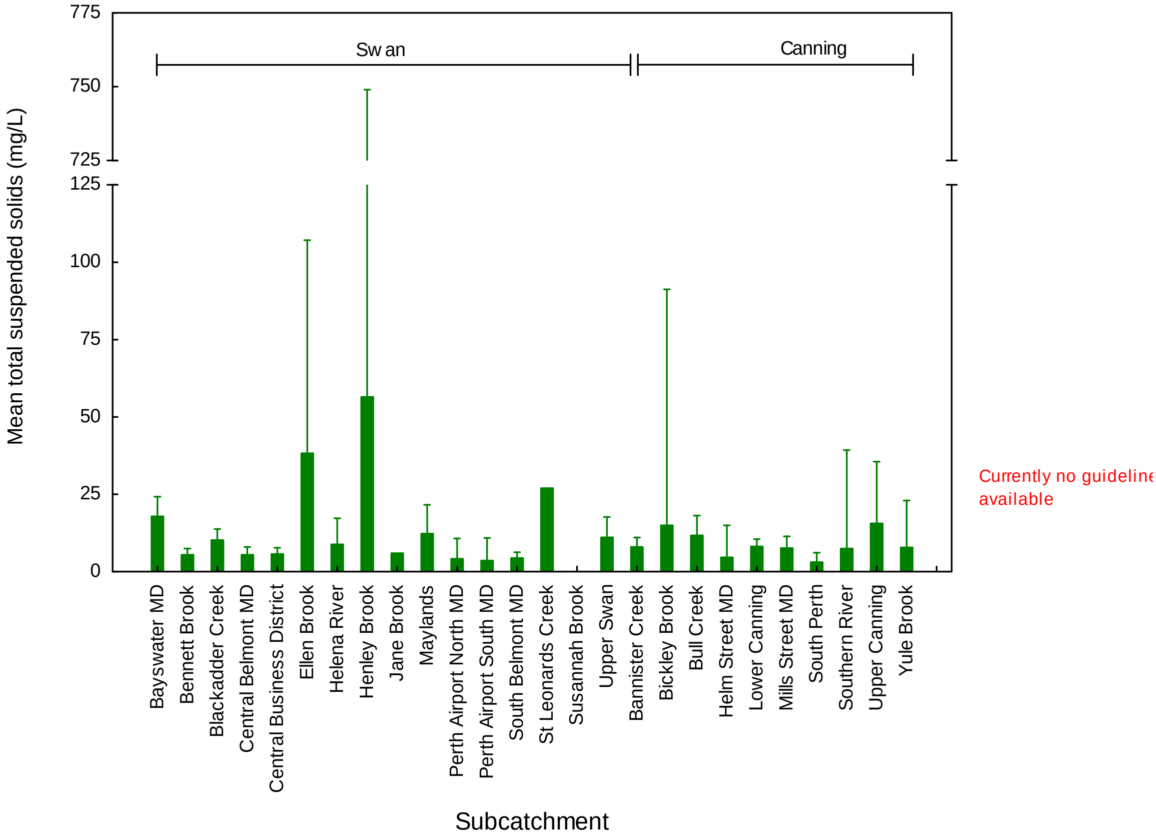

Figure 12 Mean total suspended solids in subcatchments draining into the Swan Canning system. Error bars represent +95% confidence interval.

Temperature

Surface water temperature data are presented in Figure 13. Generally the higher surface water temperatures in the drains coincided with the hotter summer and early autumn months.

The highest surface water temperature recorded in any of the drains was 32.9 °C at the MENDD (Lower Canning) site in February. There are currently no guidelines available for water temperature.

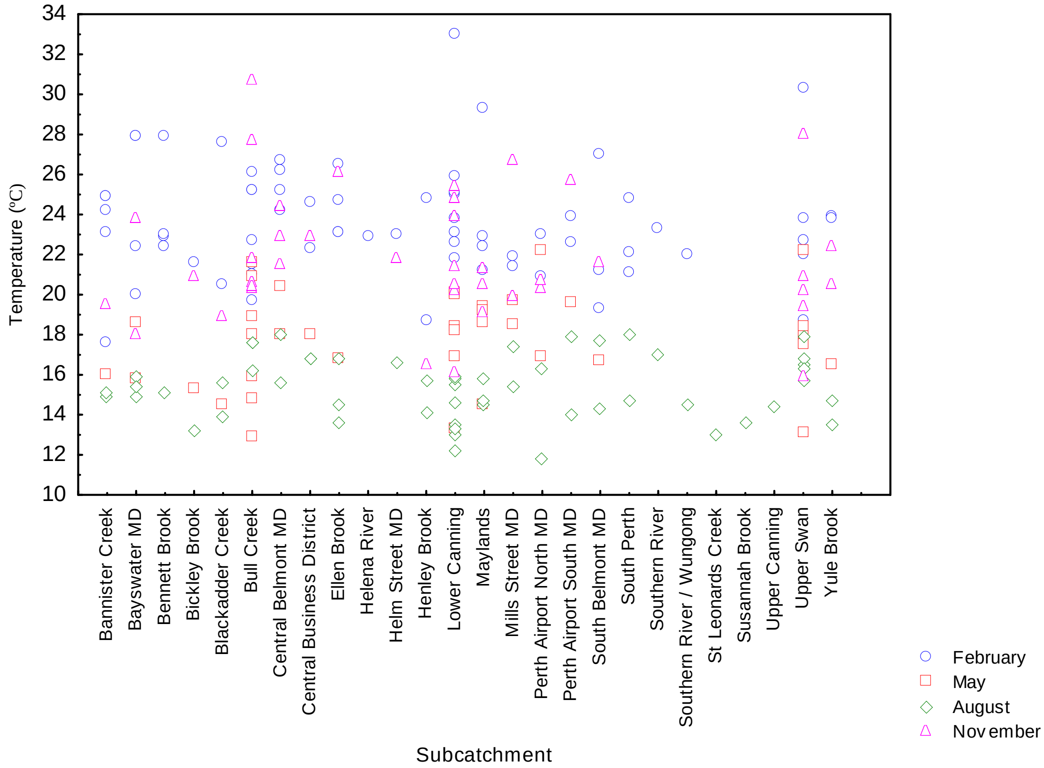

Figure 13 Surface water temperatures in subcatchments draining into the Swan Canning system (for each season).

pH in surface water

Mean pH data for subcatchments are presented in Figure 14.

Mean pH at 18% of individual drain sites was below the lower recreational guideline (pH 6.5) and aquatic ecosystem trigger value (lower limit: pH 6.5) (ANZECC and ARMCANZ 2000). No site exceeded the upper recreational guideline (pH 8.5) or the aquatic ecosystem trigger value (upper limit: pH 8). The St Leonards Creek, Susannah Brook and South Perth subcatchments all had mean pH values below the aquatic ecosystem trigger value (Figure 14).

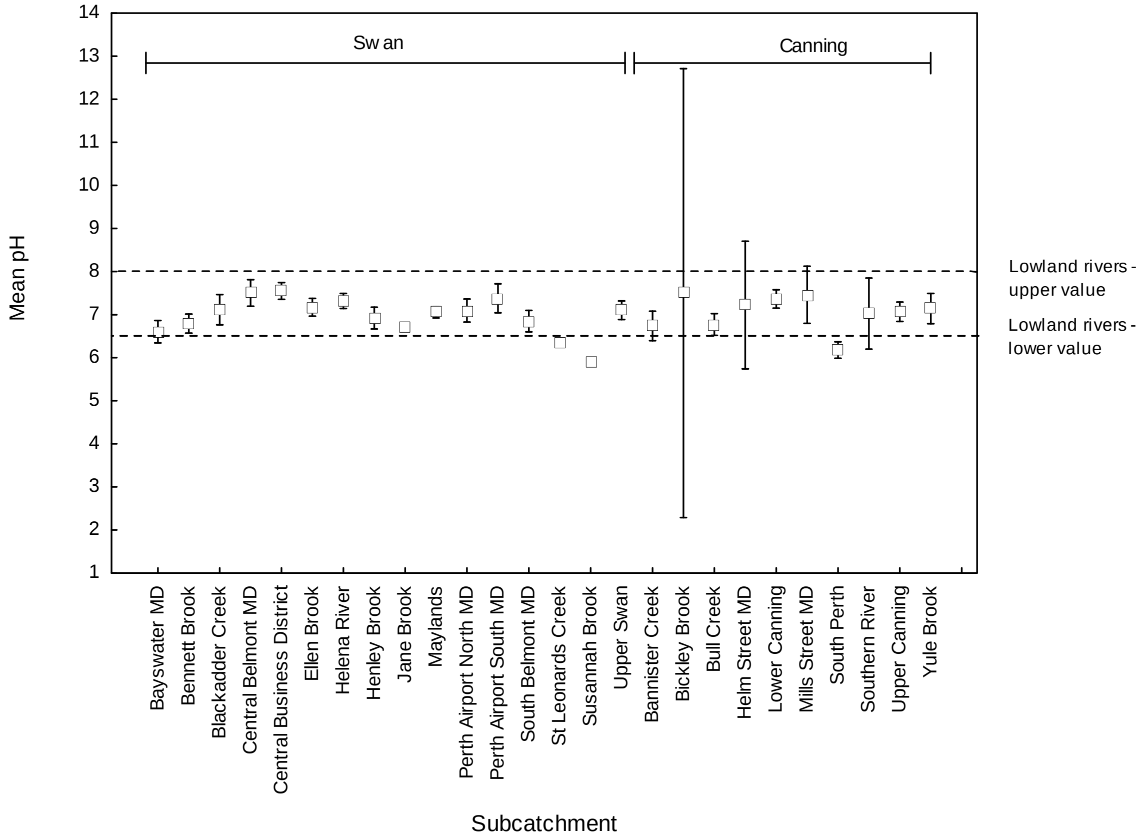

Figure 14 Mean surface water pH in subcatchments draining into the Swan Canning system. Error bars represent +/- 95% confidence interval.

Electrical conductivity in surface water

The mean electrical conductivity data for subcatchments are presented in Figure 15.

Mean electrical conductivity across all subcatchments exceeded the trigger value upper limit of 0.3 mS/cm (ANZECC and ARMCANZ 2000) (Figure 15). Additionally, at the level of individual drains, this limit was exceeded at all drain sites on all sampling occasions except site KYBDO (South Belmont) and site PAS01 (Perth Airport South).

An indicator value of 55 mS/cm was used to indicate saline water. Individual drain sites where this value was exceeded on one or more occasion were BBDSLORD (Bennett Brook), BCWETB (Blackadder Creek), BAMDOUT and SAMDOUT (Bull Creek), MBMDOUTE and MBMDOUTW (Central Business District), EBN20 (Ellen Brook), HRJSB (Helena River), MIMDOUT and MLMDOUT (Maylands), BWD9 and CSMDO (Upper Swan).

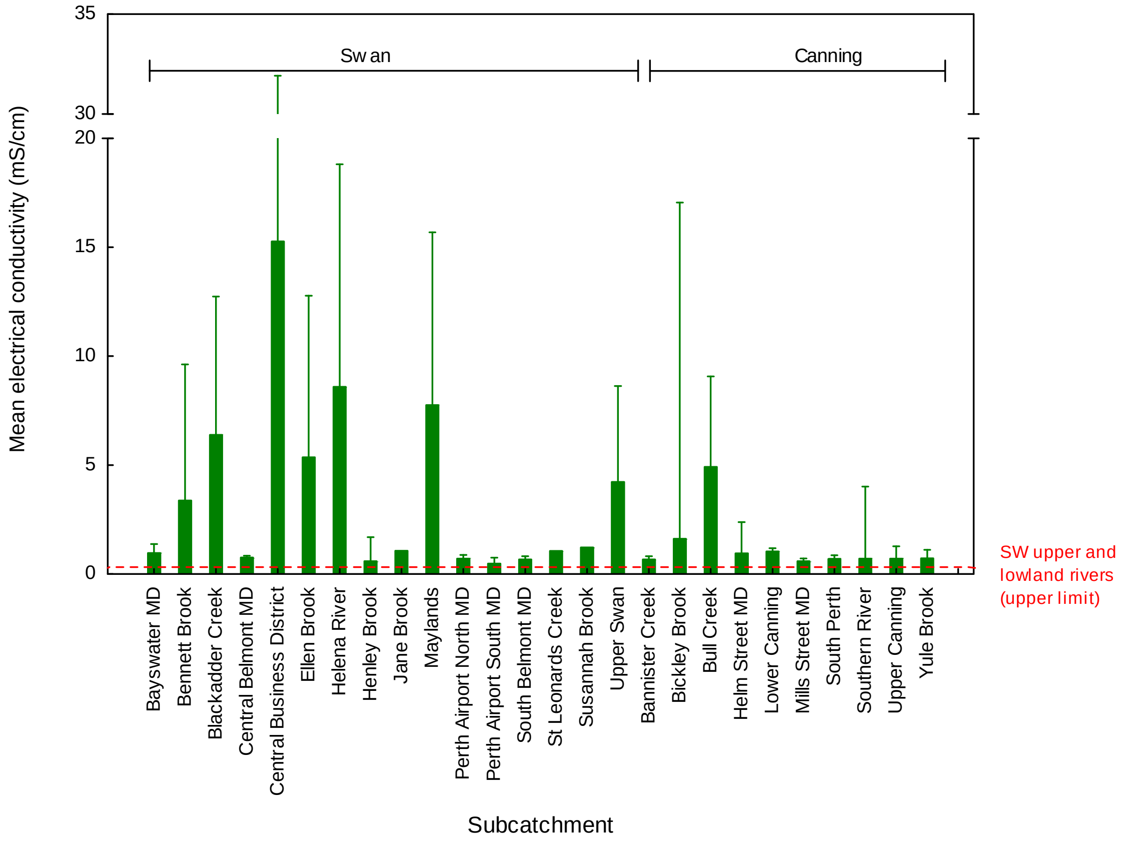

Figure 15 Mean surface water electrical conductivity in subcatchments draining into the Swan Canning system. Error bars represent + 95% confidence interval.

Dissolved oxygen in surface water

Mean dissolved oxygen data for subcatchments are presented in Figure 16. Five subcatchments were within the recommended upper and lower South West Lowland Rivers Freshwater guidelines (80% and 120% respectively). These were the Bayswater Main Drain, Central Belmont, Maylands, Upper Swan and Mills Street Main Drain subcatchments. All other subcatchments were below the recommended lower limit for dissolved oxygen.

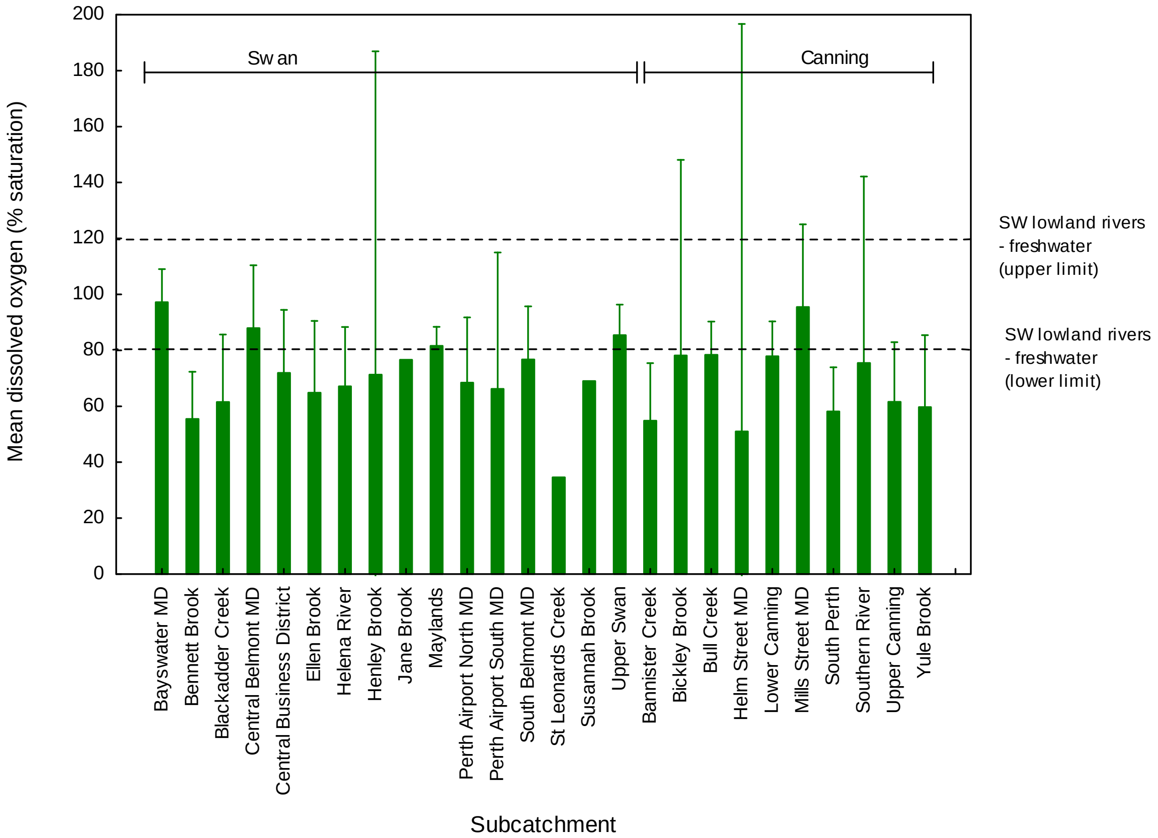

Figure 16 Mean dissolved oxygen (% saturation) across subcatchments draining into the Swan Canning system. Error bars represent + 95% confidence interval.

Biological oxygen demand in surface water

Mean biological oxygen demand data are presented at the level of individual drain site for those drains where biological oxygen demand exceeded the limit of reporting of 5 mg/L (Figure 17).

Fifteen sites had biological oxygen demand levels above the detection limit of 5 mg/L on one or more occasion (Figure 17). CBCPO (Central Belmont Main Drain) and BWDESOUT (Bayswater Main Drain) were the only sites where levels were consistently above 5 mg/L.

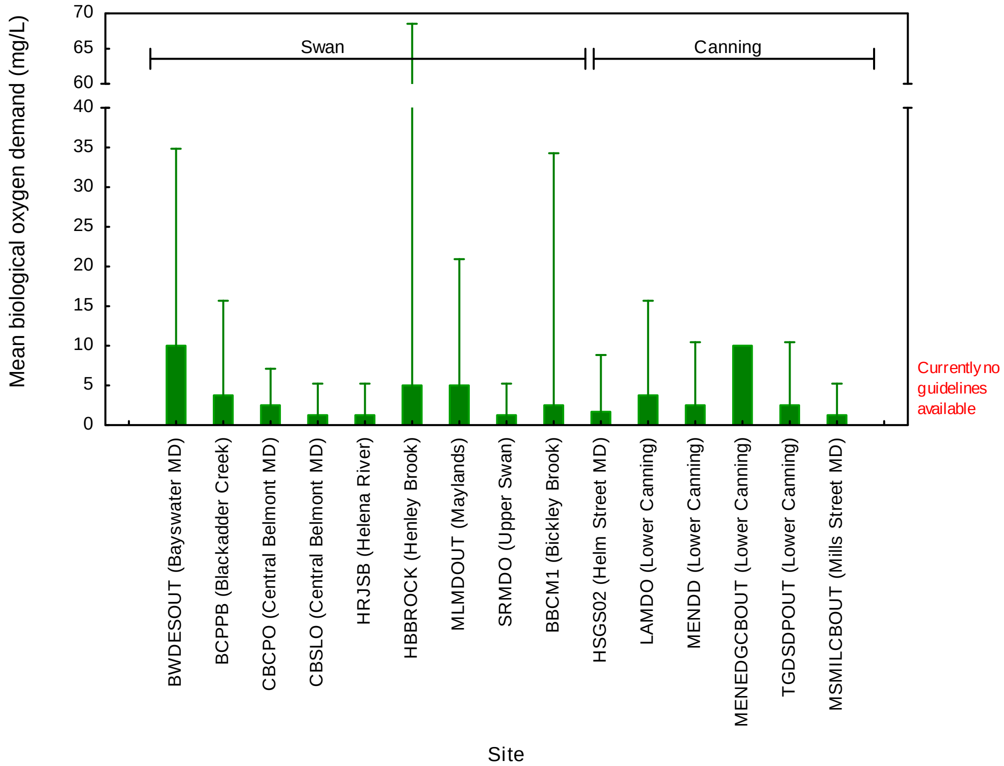

Figure 17 Mean biological oxygen demand in individual drains. Error bars represent + 95% confidence interval. Only drains where biological oxygen demand was above the limit of reporting (5 mg/L) are represented.

3.3 Microbial water quality

Microbial organisms (faecal coliforms and enterococci) were investigated in surface water only.

Summary

- Faecal coliform and enterococci bacteria counts are used as an indication of faecal contamination of water in relation to the suitability of a waterbody for recreational activities. These bacterial organisms are not exclusive to humans, being produced by almost all warm blooded animals. High levels of bacteria indicate an increased risk of illness when in contact with the water through activities such as swimming, wading, fishing or boating. Some potential illnesses due to pathogen contaminated recreational waters include ear, eye, nose, throat and skin diseases as well as gastrointestinal disorders (ANZECC and ARMCANZ 2000).

For subcatchments draining into the Swan River:

- Faecal coliforms and enterococci were detected in all subcatchments.
- Enterococci levels at Jane Brook were significantly lower than those at Blackadder Creek. However, there was no significant difference in enterococci levels between all other subcatchments.
- There was no significant difference in faecal coliform levels between subcatchments.
- The Primary Contact Recreational Guideline was exceeded for both parameters at all subcatchments except Jane Brook, which only exceeded this guideline for enterococci.
- The Secondary Contact Recreational Guideline was exceeded at Blackadder Creek, Central Business District, Helena River, Henley Brook, Maylands, Perth Airport North and Perth Airport South for either or both parameters.

For subcatchments draining into the Canning River:

- Faecal coliforms and enterococci were detected in all subcatchments.
- There was no significant difference between subcatchments for either parameter.
- The Primary Contact Recreational Guideline was exceeded at all sites for either or both parameters.
- The Secondary Contact Recreational Guideline was exceeded at Bannister Creek, Bickley Brook, Lower Canning River, Mill Street Main Drain and Upper Canning River for either or both parameters.

Mean microbial water quality data are presented for subcatchments in Figures 18 to 21.

Swan River – faecal coliforms

Faecal coliforms were detected in all subcatchments sampled. There was no significant difference in mean faecal coliform numbers between subcatchments (Kruskal-Wallis test: $H_{(13, N=80)} = 17.92$; $p > 0.05$). However, when compared with guideline levels for primary and secondary contact respectively (150 and 1000 faecal coliform organisms per 100 mL), Jane Brook was the only subcatchment where neither guideline level was exceeded.

In the Bayswater Main Drain, Belmont Central, Bennett Brook, Ellen Brook, Henley Brook, Maylands, Perth Airport South, South Belmont and Upper Swan subcatchments, faecal coliform levels were between the guidelines for primary and secondary contact. However, in the Blackadder Creek, Central Business District, Helena River and Perth Airport North subcatchments, both guideline levels were exceeded (Figure 18).

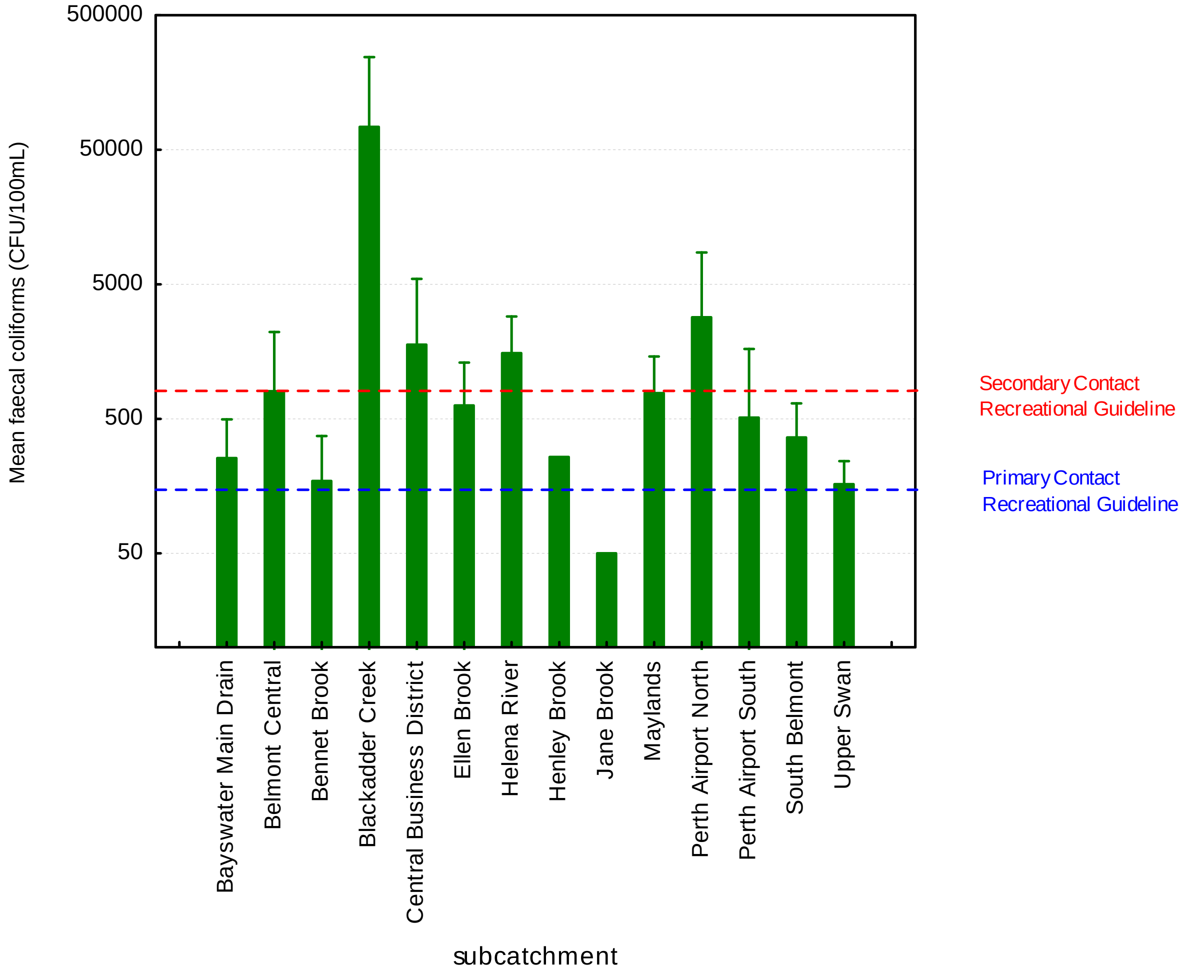

Figure 18 Mean faecal coliform levels in subcatchments draining into the Swan River. Error bars represent + 95% confidence interval.

Swan River - enterococci

Enterococci were detected in all subcatchments sampled and there was a significant difference between subcatchments in enterococci numbers (Kruskal-Wallis test: $H_{(13, N=82)} = 23.52$; $p < 0.05$). Levels at Jane Brook were statistically lower than Blackadder Creek ($p < 0.05$). Enterococci levels were not statistically different between the other subcatchments ($p > 0.05$).

All subcatchments exceeded Primary Contact Recreational Guideline levels (35 and 230 enterococci organisms per 100 mL respectively) and Blackadder Creek, Central Business District, Helena River, Henley Brook, Maylands and Perth Airport South exceeded Secondary Contact Recreational Guidelines (Figure 19).

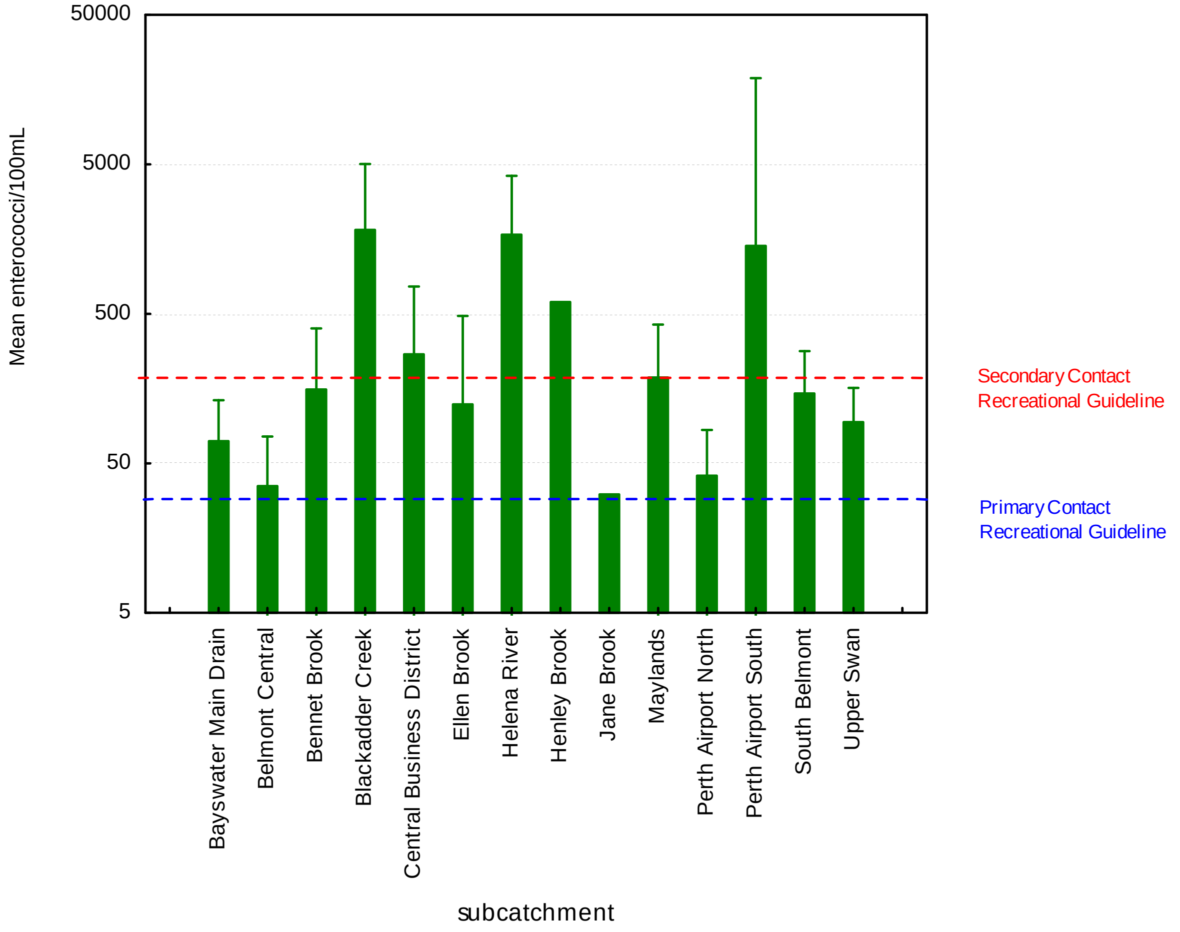

Figure 19 Mean enterococci levels in subcatchments draining into the Swan River. Error bars represent +95% confidence interval.

Canning River – faecal coliforms

Faecal coliforms were detected in all subcatchments sampled. There was no significant difference in mean faecal coliform numbers between subcatchments (Kruskal-Wallis test: $H_{(9, N=69)} = 5.4$; $p > 0.05$). However, when compared with guideline levels for primary and secondary contact (150 and 1000 faecal coliform organisms per 100 mL respectively), Bickley Brook was the only subcatchment where neither guideline level was exceeded. In the Bull Creek, Helm St, South Perth, Southern River and Yule Brook subcatchments, faecal coliform levels were between the guidelines for primary and secondary contact. However, in Bannister Creek, Lower Canning River, Mills Street Main Drain and Upper Canning River subcatchments, both guideline levels were exceeded (Figure 20).

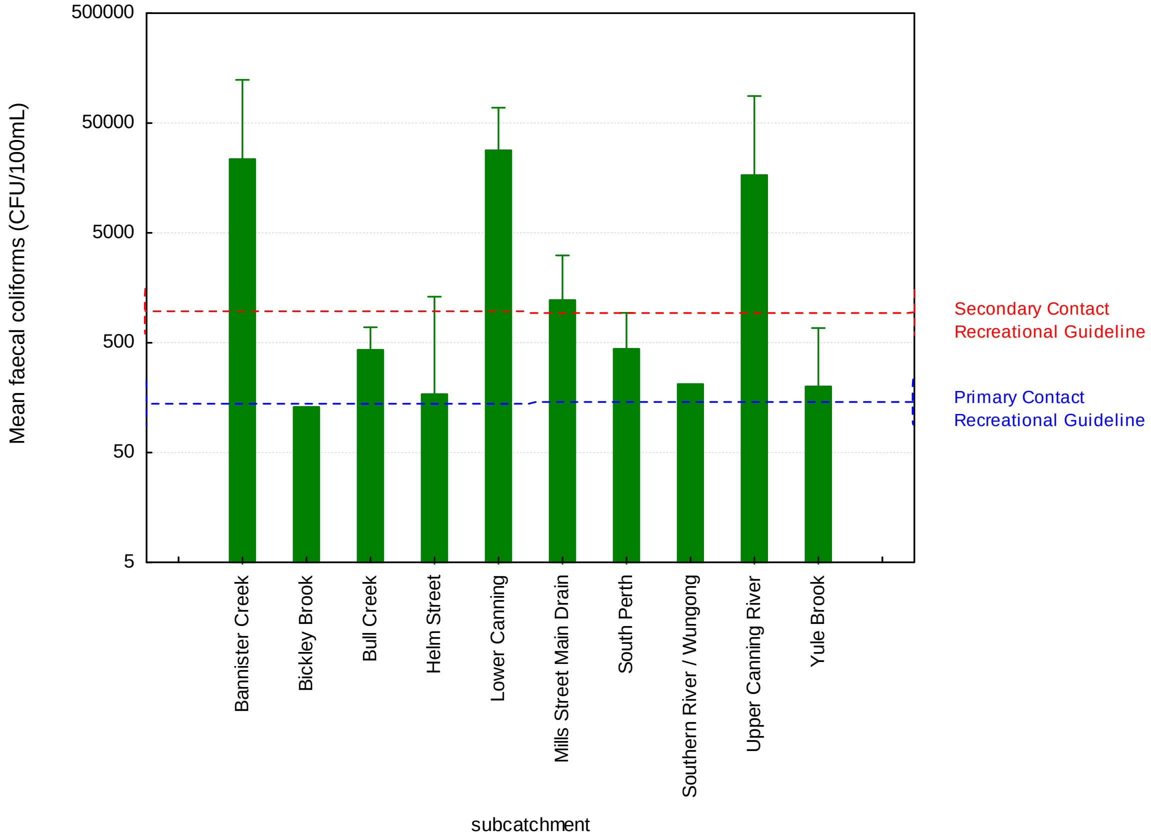

Figure 20 Mean faecal coliform levels in subcatchments draining into the Canning River. Error bars represent + 95% confidence interval.

Canning River - enterococci

Enterococci were detected in all subcatchments. As for the faecal coliform data, there was no significant difference in enterococci numbers between subcatchments (Kruskal-Wallis test: $H_{(9,\ N=69)} = 12.17$; $p > 0.05$). However, when compared with guidelines for primary and secondary contact (35 and 230 enterococci organisms per 100 mL respectively), Helm Street and Southern River were the only subcatchments where neither guideline level was exceeded. At Bull Creek, South Perth, Upper Canning River and Yule Brook, enterococci numbers fell between the guidelines for primary and secondary contact. However, at Bannister Creek, Bickley Brook, Lower Canning and Mills Street Main Drain subcatchments, both guideline levels were exceeded (Figure 21).

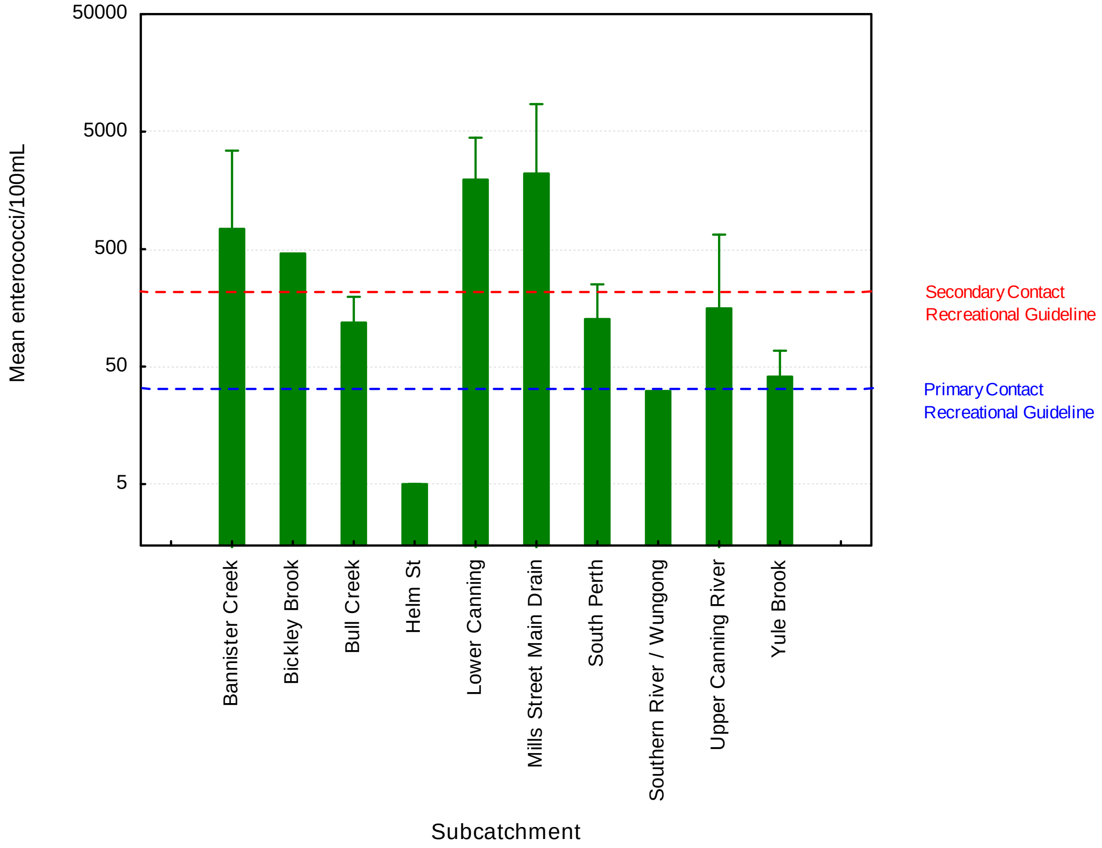

Figure 21 Mean enterococci levels in subcatchments draining into the Canning River. Error bars represent + 95% confidence interval.

3.4 Polycyclic aromatic hydrocarbons (PAHs)

Both surface water and sediment samples were analysed for polycyclic aromatic hydrocarbons (PAHs).

Summary

- PAHs are formed during the incomplete combustion of fuels and domestic wastes. They are also typical components of asphalts, oils, greases, creosote and roofing tar. Some are also used in medicines, dyes, plastics and pesticides.
- PAHs were typically only found in sediments (PAHs were detected in 44% of sediment samples compared with less than 7% of surface water samples).
- Individual PAHs consistently exceeded the Low Trigger Value for ecosystem health at sites sampled within the Helena River, Perth Airport South and Central Business District subcatchments (all draining into the Swan River).
- At Perth Airport South the PAH, dibenzo(a,h,)anthracene also exceeded the High Trigger Value for ecosystem health on one occasion.
- PAHs were also occasionally above the Low Trigger Value for Blackadder Creek, Maylands and Belmont Central subcatchments (draining into the Swan River) and Bull Creek, Mills Street Main Drain and Lower Canning subcatchments (draining into the Canning River) but did not exceed the High Trigger Value at these locations.
- Of the low molecular weight PAHs phenanthrene was consistently present in the highest concentrations.
- Of the high molecular weight PAHs fluoranthene, pyrene and benzo(b)&(k) flouranthene were consistently present in the highest concentrations.

PAHs in sediments versus surface water

PAHs were only detected on a few occasions in the surface water and concentrations were below guideline levels. The subcatchments where this occurred (albeit sporadically) were Bull Creek and Lower Canning (draining into the Canning River) and Bayswater Main Drain, Upper Swan, South Belmont and Perth Airport North (draining into the Swan River).

Figure 22 shows the relative proportion of samples where PAHs were detected in sediment compared with surface water samples. PAHs were detected in 44% of sediment samples compared with less than 7% of surface water samples.

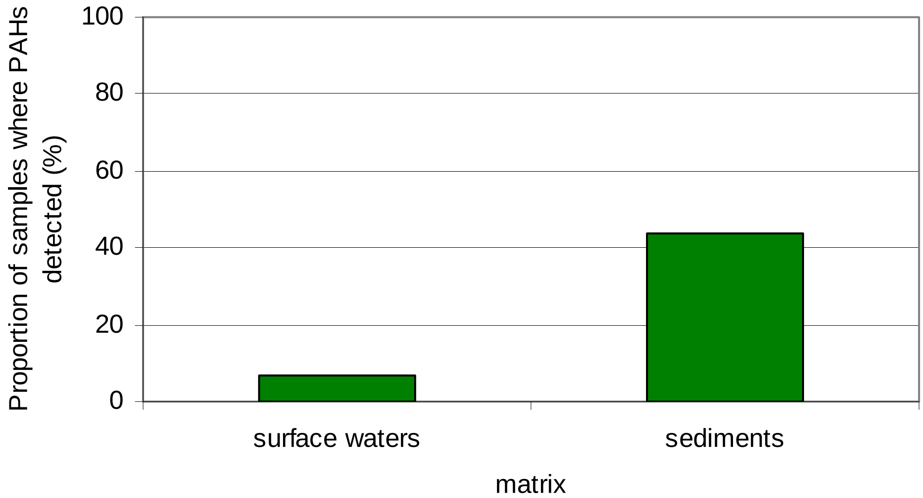

Figure 22 Proportion of samples in which PAHs were detected in surface waters and sediments (across all samples). n = 151 for surface water and 158 for sediments.

PAHs in sediments

Data are presented for the Helena River, Perth Airport South and Central Business District subcatchments, because at these sites the Low Trigger Values for ecosystem health were consistently exceeded for individual PAHs as shown in Figures 23 to 28. All concentrations were normalised to 1% organic carbon according to the *Interim Sediment Quality Guidelines* (ISQG) (Simpson et al. 2005; ANZECC and ARMCANZ 2000).

The number of samples (n) for Helena River and Perth Airport South was four. However, Central Business District was only sampled for PAHs once during this study.

At Helena River, all 15 PAHs (both low and high molecular weight) were present. All PAHs except napthalene were present in concentrations that exceeded the Low Trigger Values for ecosystem health (where these exist). At Perth Airport South, acenaphthylene, phenanthrene and anthracene (of the low molecular weight PAHs) and all high molecular weight PAHs exceeded the Low Trigger Values for ecosystem health (where these exist). Similarly at Central Business District acenaphthylene, phenanthrene and anthracene (of the low molecular weight PAHs) exceeded the Low Trigger Values for ecosystem Health. All the high molecular weight PAHs were detected in this subcatchment and all exceeded the Low Trigger Values (where these exist) except benzo(a)pyrene. Of the low molecular weight PAHs, naphthalene, acenapthene and fluorene were not detected in the Perth Airport South and Central Business District subcatchments.

Helena River

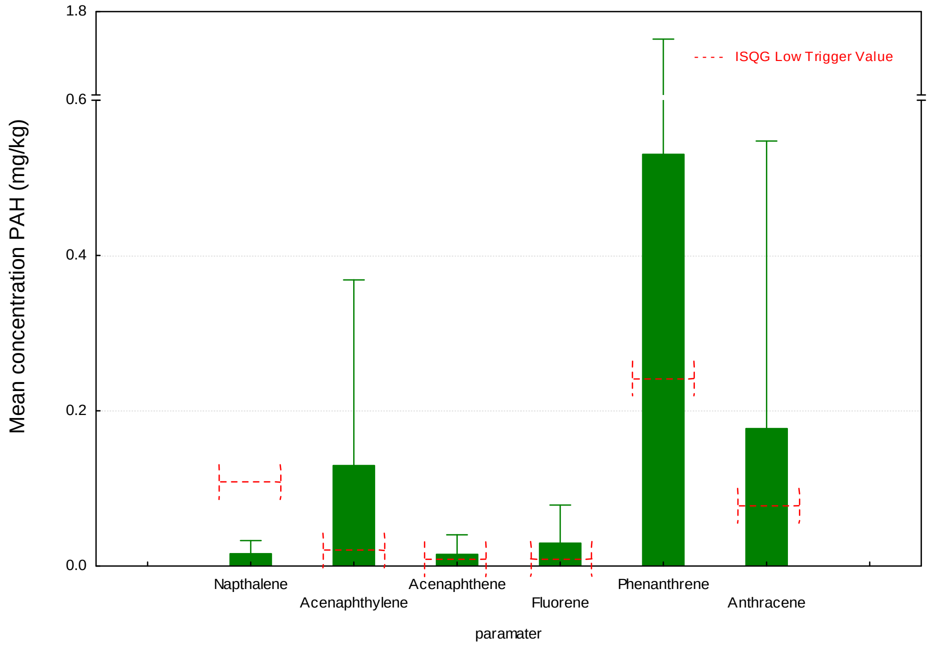

Figure 23 Mean low molecular weight PAH concentrations in sediments of the Helena River. Error bars represent + 95% confidence interval. n = 4.

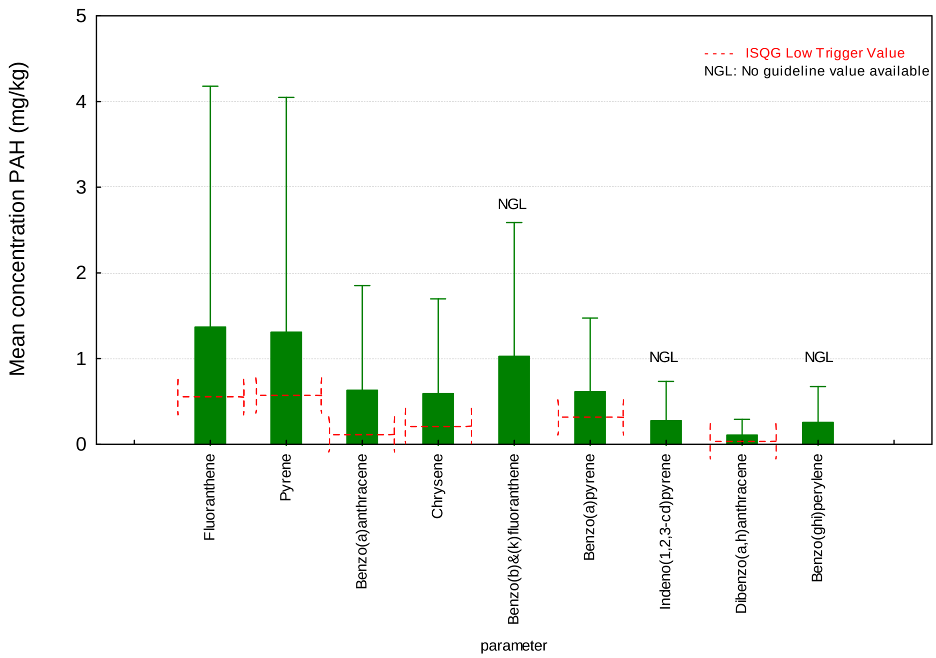

Figure 24 Mean high molecular weight PAH concentrations in sediments of the Helena River. Error bars represent + 95% confidence interval. n = 4.

Perth Airport South

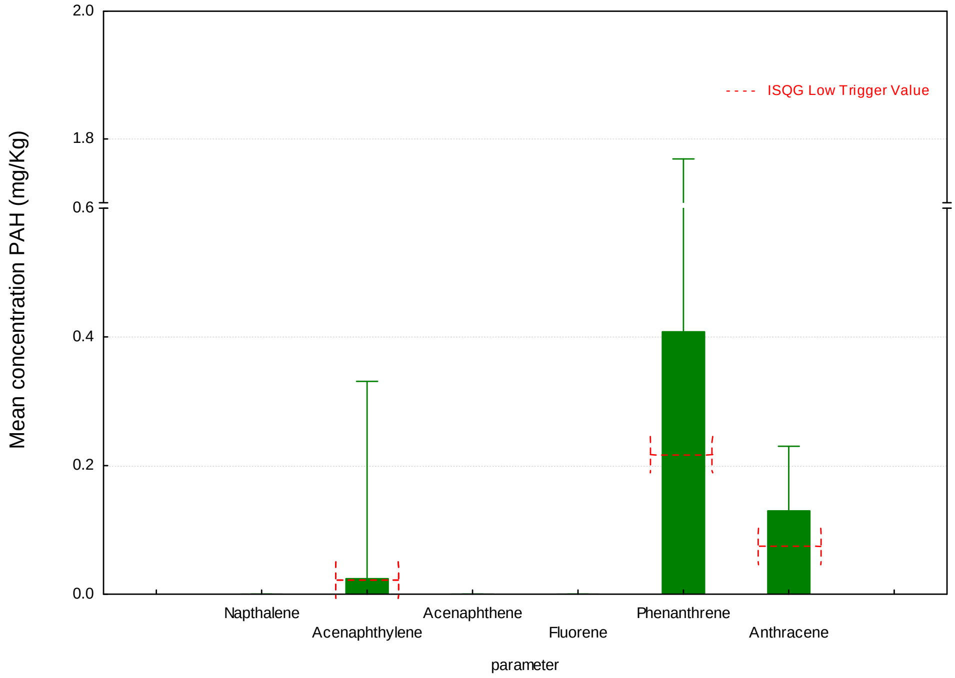

Figure 25 Mean low molecular weight PAH concentrations in sediments of the Perth Airport South drain. Error bars represent + 95% confidence interval. n = 4.

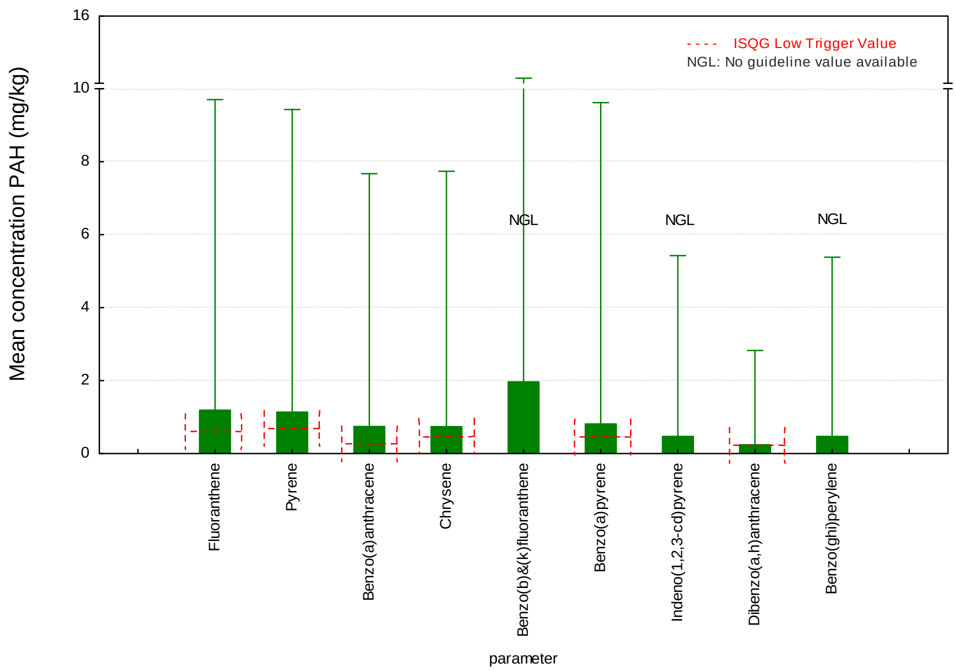

Figure 26 Mean high molecular weight PAH concentrations in sediments of the Perth Airport South drain. Error bars represent + 95% confidence interval. n = 4.

Central Business District

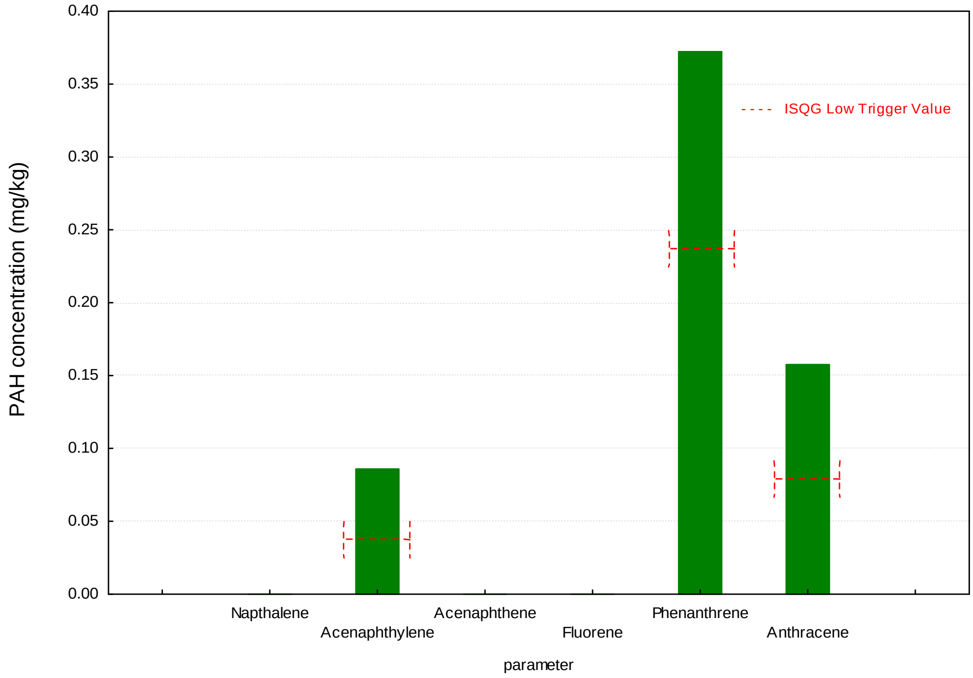

Figure 27 Low molecular weight PAH concentrations in sediments of Central Business District drain.

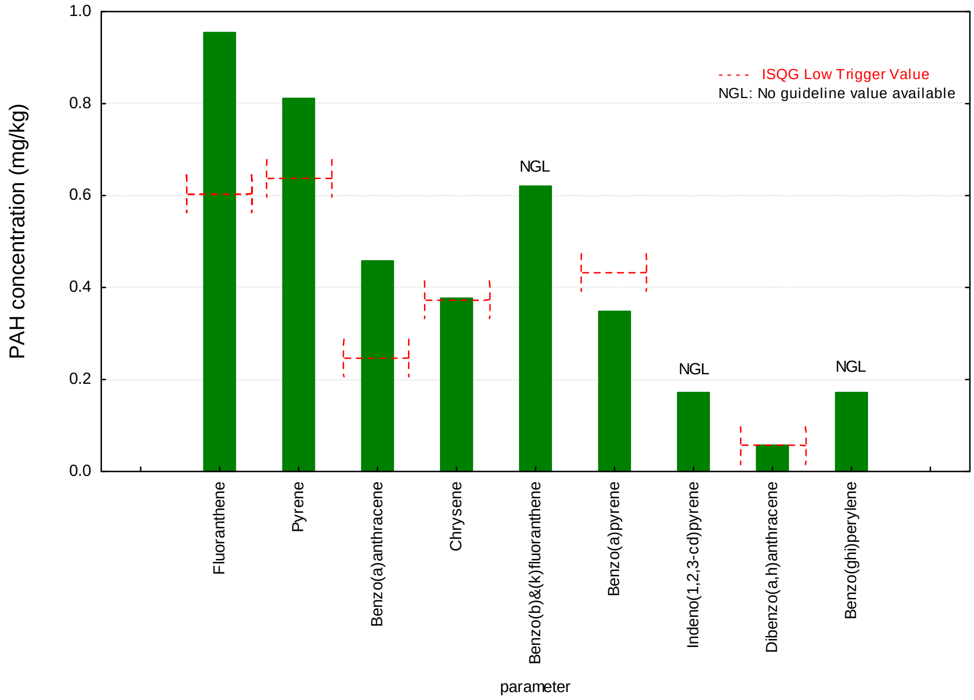

Figure 28 High molecular weight PAH concentrations in sediments of Central Business District drain.

Note: this location was only sampled on one occasion.

3.5 Petroleum hydrocarbons

Both surface water and sediment samples were analysed for the group of petroleum hydrocarbons known as BTEX (comprising benzene, toluene, ethylbenzene and xylenes). In addition, total petroleum hydrocarbon (TPH) analyses were performed on both surface water and sediment samples.

Summary

- The petroleum hydrocarbons comprise a broad family of several hundred chemical compounds that originate from crude oil. Almost all of them are composed entirely from hydrogen and carbon atoms. The BTEX petroleum hydrocarbons (benzene, toluene, ethylbenzene, and xylenes) are relatively volatile and make up part of the C6 – C9 petroleum hydrocarbons (i.e. they have between 6 and 9 carbon atoms per molecule). The C10 – C14 petroleum hydrocarbons have between 10 and 14 carbon atoms per molecule, the C15 – C28 petroleum hydrocarbons have between 15 and 28 carbon atoms per molecule and the C29 – C36 petroleum hydrocarbons have between 29 and 36 carbon atoms per molecule. The relative volatility of these compounds decreases with increasing carbon chain length. They are most likely to enter the environment as a result of road runoff containing vehicle fuel and oils.
- Benzene, toluene, ethylbenzene, and xylenes (BTEX) were not detected in any surface water or sediment samples.
- TPHs were not detected in any surface water samples.
- All four TPH fractions tested for were detected in sediment with nine C6 – C9 detections, three C10 – C14 detections, fourteen C15 – C28 detections, and four C29 – C36 detections.

TPHs in sediments versus surface water

Petroleum hydrocarbons (including BTEX compounds) were not detected in surface water. However, TPH were detected at 15 individual drain sites (within ten subcatchments) in the sediment. These subcatchments were: Maylands, Upper Swan, Bennett Brook, Central Belmont Main Drain, Lower Canning, Mills Street Main Drain, Ellen Brook, Susannah Brook, Bayswater Main Drain and Bull Creek (Table 8).

Figure 29 shows the relative proportion of samples where TPH were detected in sediment compared with surface water. Petroleum hydrocarbons were detected in 13% of sediment samples compared with no detections in surface water samples.

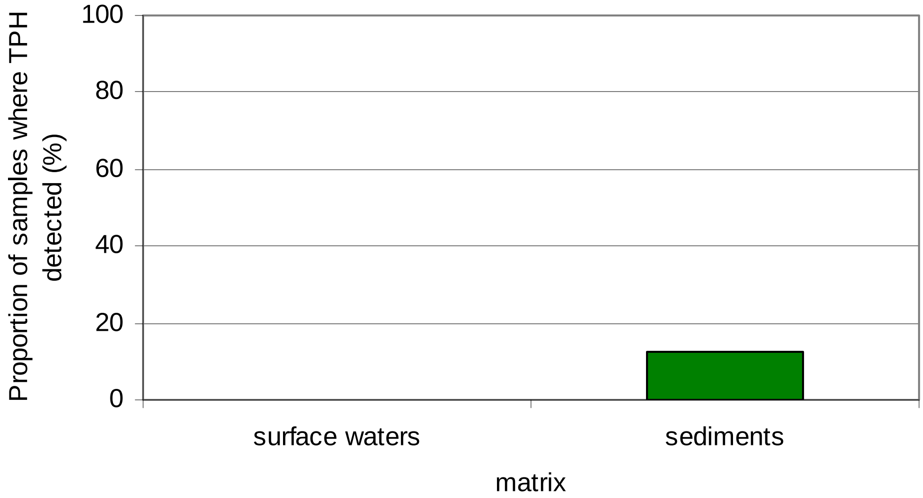

Figure 29 Proportion of samples in which total petroleum hydrocarbons were detected in surface waters and sediments (across all samples). n = 151 for surface water and 158 for sediments.

Table 8 TPH concentrations in sediments

		February				May		August				November		
Subcatchment	**Site Code**	**C6 - C9 concentration (mg/Kg)**	**C10 - C14 concentration (mg/Kg)**	**C15 - C28 concentration (mg/Kg)**	**C29 - C36 concentraiton (mg/Kg)**	**C6 - C9 concentration (mg/Kg)**	**C15 - C28 concentration (mg/Kg)**	**C6 - C9 concentration (mg/Kg)**	**C10 - C14 concentration (mg/Kg)**	**C15 - C28 concentration (mg/Kg)**	**C29 - C36 concentraiton (mg/Kg)**	**C6 - C9 concentration (mg/Kg)**	**C10 - C14 concentration (mg/Kg)**	**C15 - C28 concentration (mg/Kg)**
		LOR < 25 mg/Kg	LOR < 50 mg/Kg	LOR < 100 mg/kg	LOR < 100 mg/kg	LOR < 25 mg/Kg	LOR < 100 mg/kg	LOR < 25 mg/Kg	LOR < 50 mg/Kg	LOR < 100 mg/kg	LOR < 100 mg/kg	LOR < 25 mg/Kg	LOR < 50 mg/Kg	LOR < 100 mg/kg
Maylands	SLMBAIGIN				140			63						
Upper Swan	SRMDO	130	58	1200	610		740							
Upper Swan	BSMDO			310										
Upper Swan	CSMDO					39								
Upper Swan	BWD9											25		
Central Belmont	CBCPO						130	89		430				
Central Belmont	CBSLO									160				
Bennett Brook	BBDSLORD						380		150	550				
Lower Canning	LAMDO											26		
Lower Canning	BWAMDO							26						
Mills Street Main Drain	MSILCBOUT									100	130			
Ellen Brook	EBN18									270				
Susannah Brook	SBRRB									490	110			
Bayswater Main Drain	BWDESOUT											28		280
Bull Creek	SAMDOUT												75	170

Note: this table only shows those sites where TPH were detected.

TPH concentrations in sediments

TPH data are presented for individual drains (Figures 30 to 33). Each of the four TPH fractions were detected at site SRMDO (Upper Swan). This site also had the highest concentrations recorded for three out of four TPH fractions. Site BBDSLORD (Bennett Brook) had the highest concentrations of the C10 – C14 fraction. Six sites had detections of two out of four TPH fractions and the remainder had detections for only one of the fractions. No site had detections on all four sampling occasions. Five sites had detections in two consecutive months. Ten sites had detections in only one sampling month.

There are currently no guideline values for TPH concentrations in sediment.

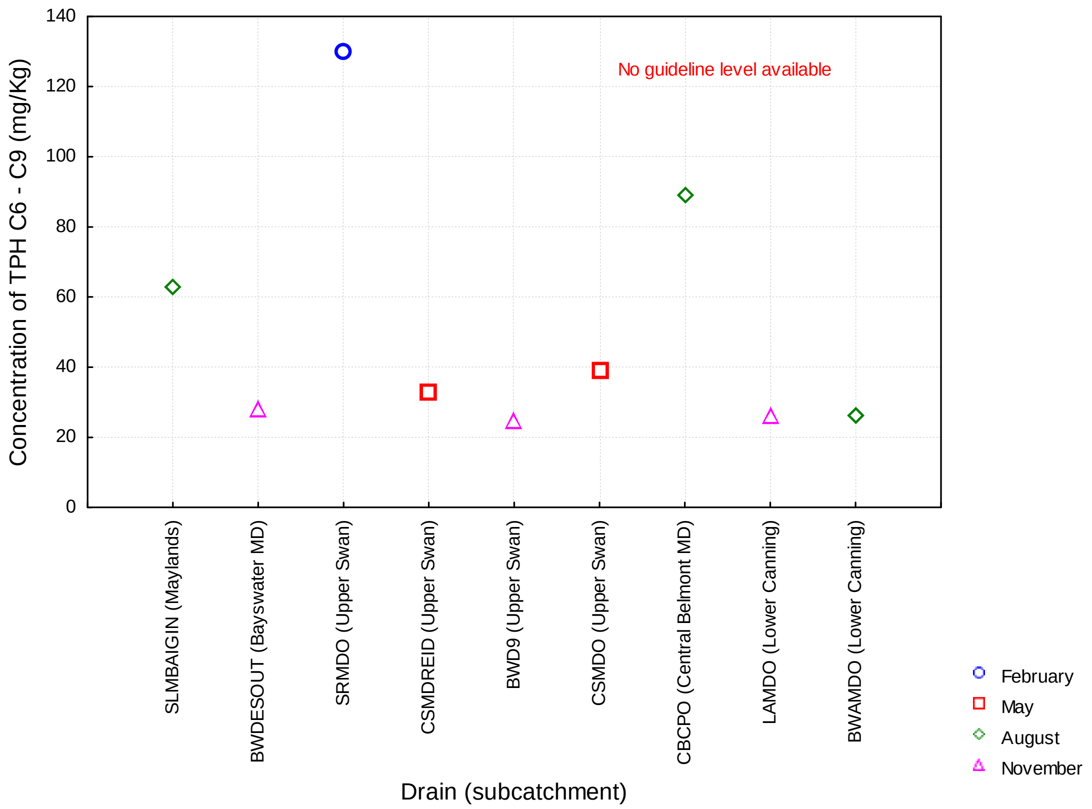

Figure 30 TPH (C6–C9) concentration in sediments at individual drain sites

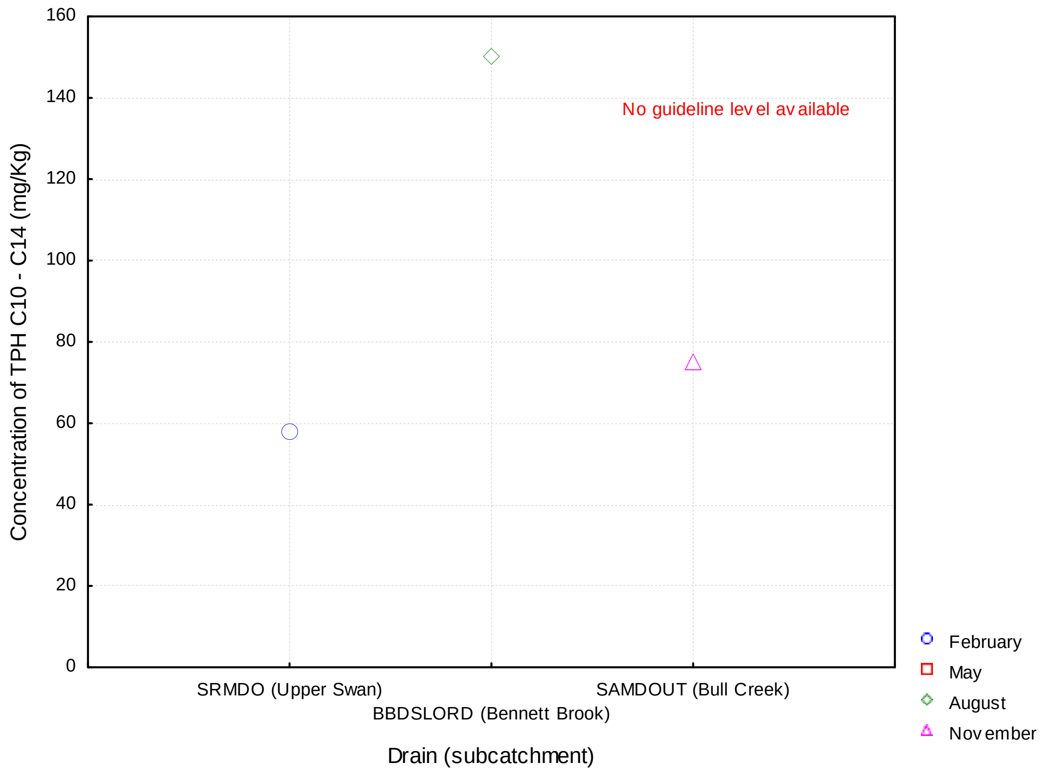

Figure 31   TPH (C10–C14) concentration in sediments at individual drain sites

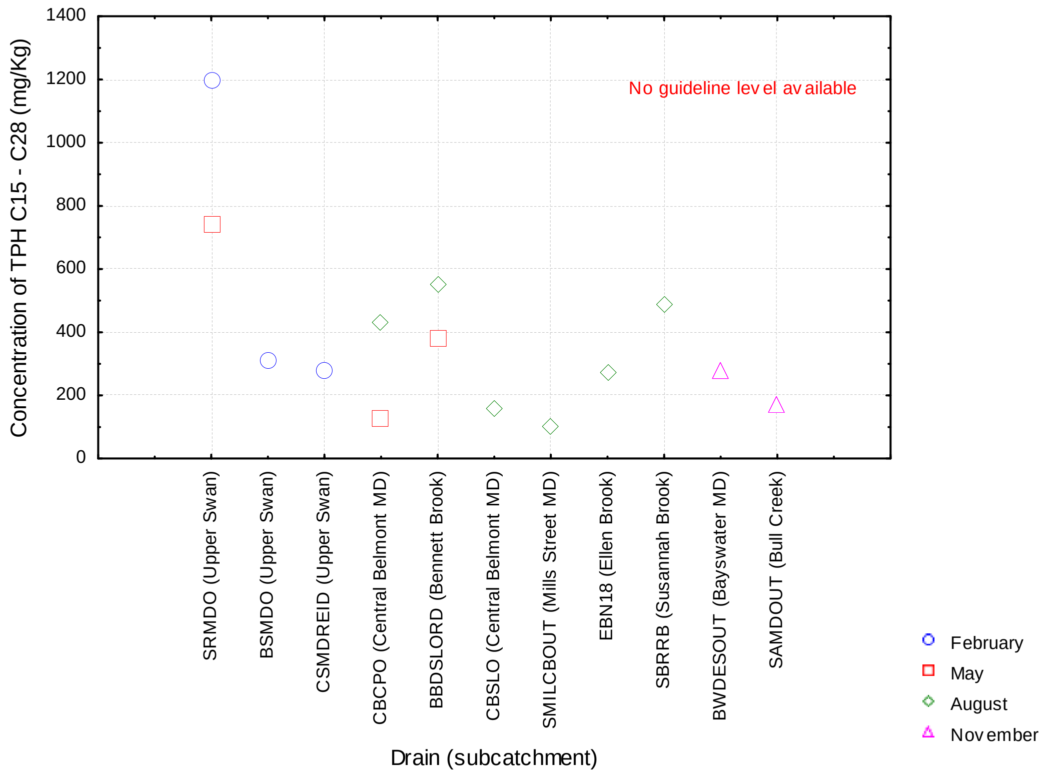

Figure 32   TPH (C15–C28) concentration in sediments at individual drain sites

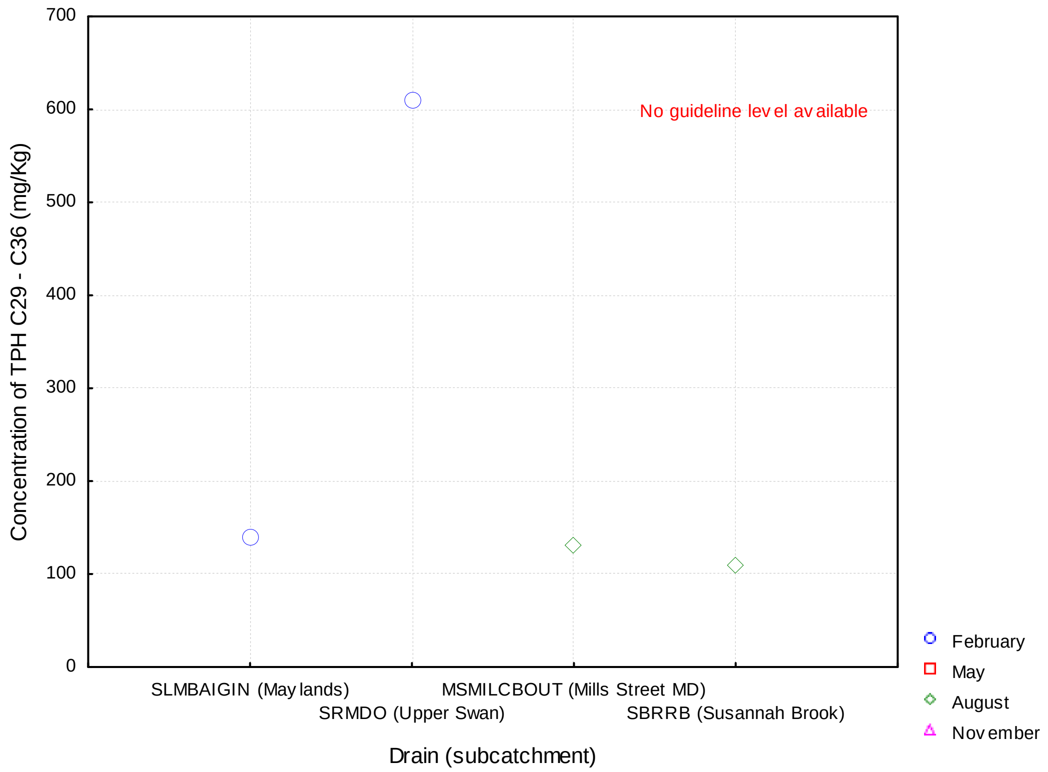

Figure 33 TPH (C29–C36) concentration in sediments at individual drain sites

3.6 Polychlorinated biphenyls

Both surface water and sediment samples were analysed for polychlorinated biphenyls (PCBs).

Summary

- PCB mixtures have been used for a variety of applications including dielectric fluids for capacitors and transformers, heat transfer and hydraulic fluids, lubricating and cutting oils, and as additives in pesticides, paints, adhesives, sealants, plastics, and reactive flame retardants. They have also been generated and released into the environment as by-products of chemical manufacturing and incineration. A ban on the importation of PCBs into Australia has been in place since 1979.
- PCBs were not detected in any of the surface water or sediment samples collected.
- Note that the limit of reporting was 0.1 µg/L and 0.1 mg/kg respectively. However, most of the 95% Ecosystem Protection guidelines (ANZECC and ARMCANZ 2000) that exist for these compounds are lower (in some cases orders of magnitude lower) than the limits of reporting in the current study. Therefore non-detect data should be treated with caution. Refer to *comment on limits of reporting* in section 2.

3.7 Organochlorine (OC) pesticides

Both surface water and sediment samples were analysed for organochlorine (OC) pesticides.

Summary

- OC pesticides were produced to control pests. They were used extensively in the agriculture industry for the protection of crops, livestock, buildings and households from the damaging effects of insects. The importation, manufacture and use of OC pesticides has been phased out in Australia. However, they are often still present in soils and sediments due to their persistent nature. These compounds are composed primarily of carbon, hydrogen and chlorine atoms.
- OC pesticides were more common in sediments than surface water. They were detected in 17% of sediment samples compared with 1.3% of surface water samples.
- Few guideline values exist for OC pesticides in sediments (6 out of 16 pesticides tested have guidelines). Where these are available and the particular parameter was detected, it was consistently above guideline levels. This is because laboratory reporting limits were higher than all Low Trigger Value guideline values available (for sediments). Therefore non-detect data should be treated with caution. Refer to the *comment on limits of reporting* in section 2.
- OC pesticides were detected at the following locations: Bayswater Main Drain, Blackadder Creek, Central Belmont Main Drain, South Belmont Main Drain, Helena River, Maylands and Upper Swan draining into the Swan River; and Mills Street Main Drain and the Lower Canning draining into the Canning River.
- Chlordane and dieldrin were the most frequently reported OC pesticides.
- Helena River had the highest number of individual OC pesticides detected and typically the highest concentrations (exceeding both Low and High Trigger Values) on the majority of occasions that OC pesticides were detected.
- OC pesticides were not detected in any samples collected during November.

OC pesticides in sediments versus surface water

OC pesticides were only detected on two sampling occasions in surface waters (1.3%) (Figure 34). These were for the OC pesticide dieldrin during August at the Upper Swan and Helena River subcatchments. Both exceeded the guideline level for Ecosystem Protection of 0.01 µg/L. (Helena River: 0.012 µg/L; Upper Swan: 0.019 µg/L). OC pesticides were detected in 17% of sediment samples.

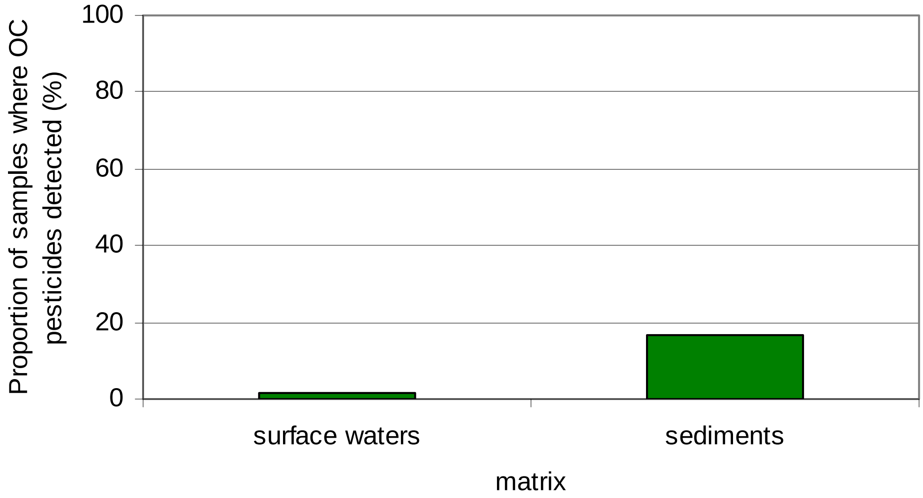

Figure 34 Proportion of samples in which OC pesticides were detected in surface waters and sediments (across all samples). n = 151 for surface water and 158 for sediments.

OC pesticides in sediments

Guidelines only exist for six of the 16 OC pesticides tested for. Wherever a guideline exists for a particular OC pesticide and that compound was detected in this study, it was consistently present in concentrations above the guideline level because the laboratory's limit of reporting was above the guideline level. As such, all OC data will be presented here; and because there was high variability between sampling months for OC pesticides in sediments, the data will be presented over time for each of the subcatchments where detections occurred. All concentrations were normalised to 1% total organic carbon according to the *Interim Sediment Quality Guidelines* (Simpson et al. 2005; ANZECC and ARMCANZ 2000).

Note that the following graphs (Figures 35 to 43) show only those OC pesticides that were detected. Refer to Appendix A for the full suite of OC pesticides analysed. The limit of reporting was 0.01 mg/kg for all OC pesticides analysed. Some graphed values are lower than the limit of reporting due to post-conversion of data to 1% total organic carbon (ANZECC and ARMCANZ 2000).

Sites draining into the Swan River

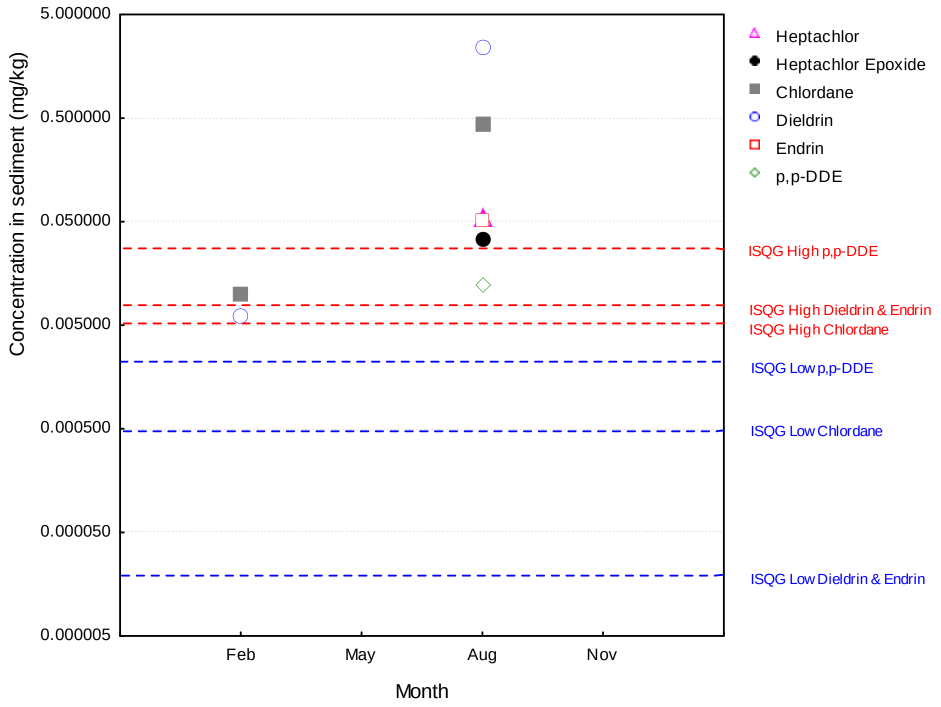

Figure 35 OC pesticides in sediments of the Helena River subcatchment (data from drain site HRJSB).

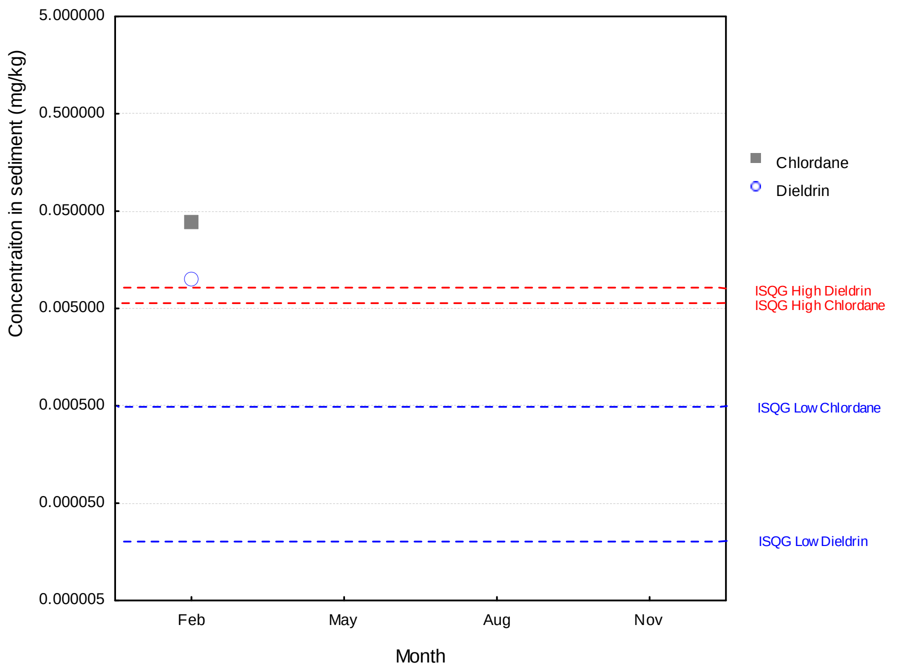

Figure 36 OC pesticides in sediments of South Belmont Main Drain subcatchment (data from drain site SBMD1).

Note: ISQG Low: Interim Sediment Quality Guideline Low Trigger Value;
ISQG High: Interim Sediment Quality Guideline High Trigger Value.

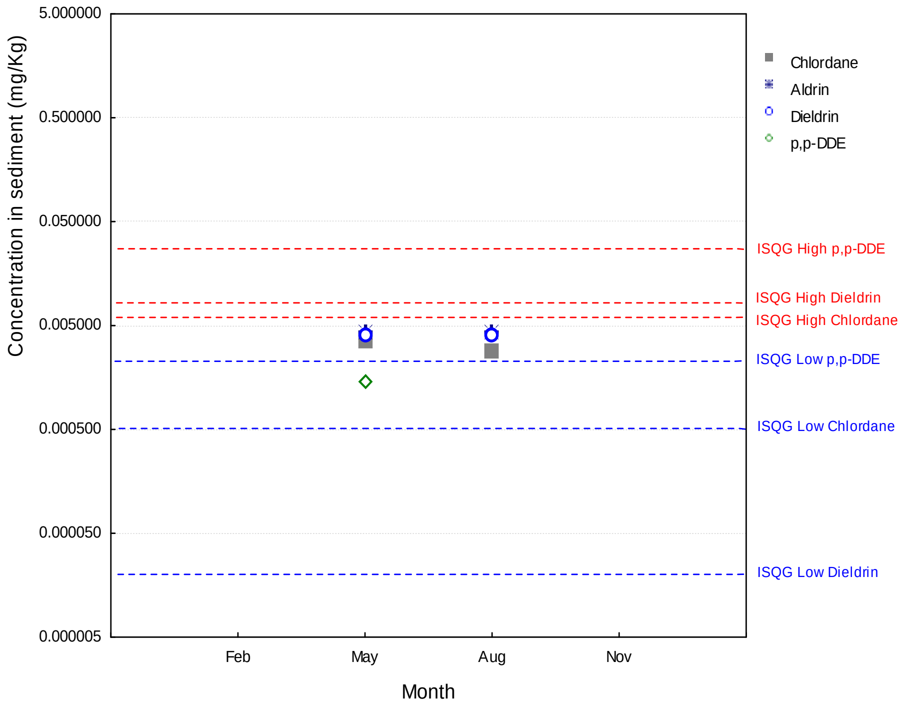

Figure 37 OC pesticides in sediments of Central Belmont Main Drain subcatchment (data from drain site CBCPO).

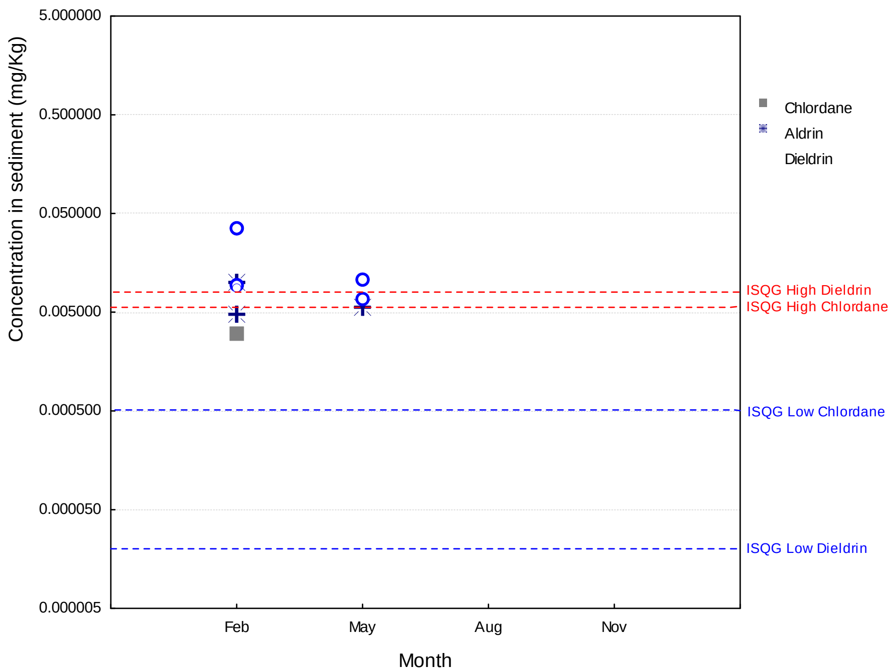

Figure 38 OC pesticides in sediments of the Upper Swan subcatchment (comprising data from drain sites BSMDO, CSMDREID and CSMDO).

Note: **ISQG Low: Interim Sediment Quality Guideline Low Trigger Value;**
ISQG High: Interim Sediment Quality Guideline High Trigger Value.

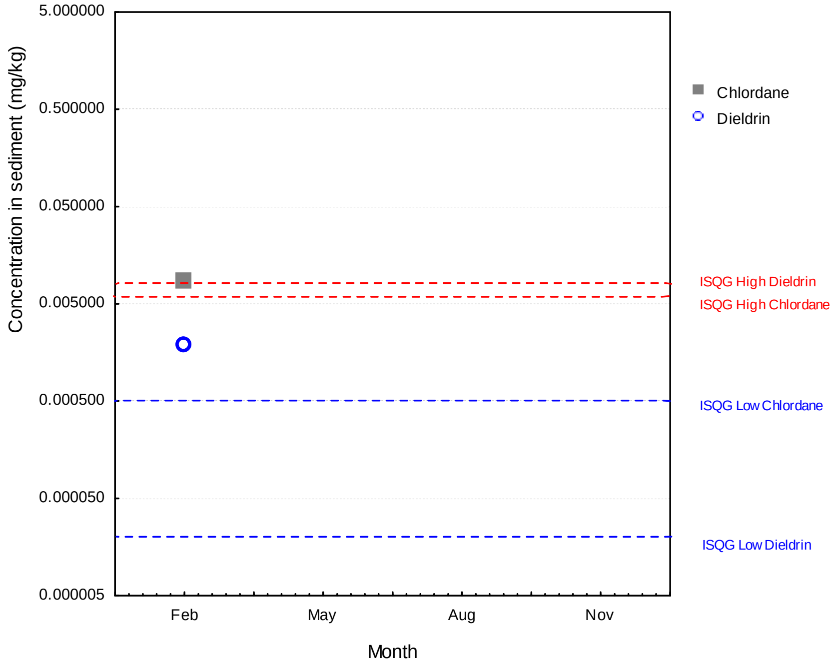

Figure 39 OC pesticides in sediments of Blackadder Creek subcatchment (data from drain site BCWETB).

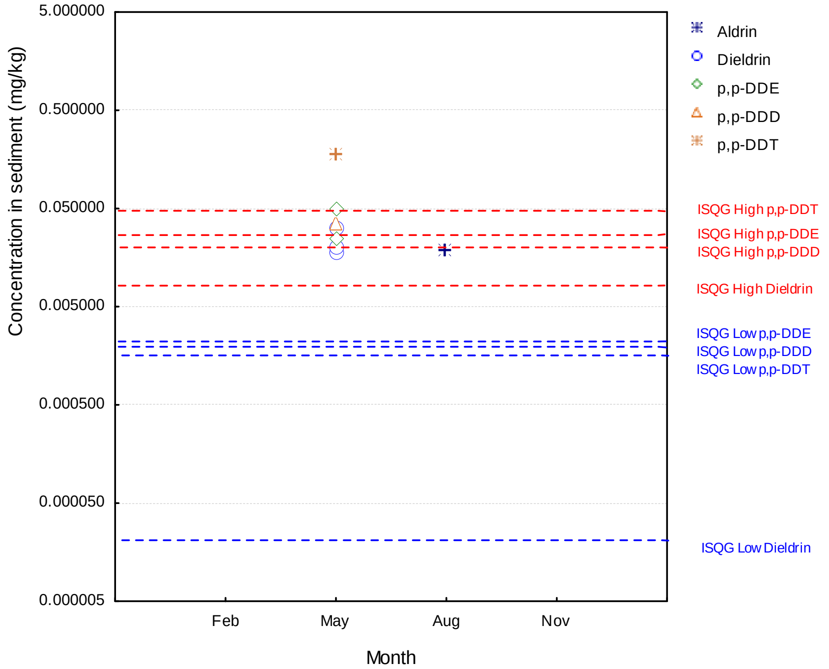

Figure 40 OC pesticides in sediments of Maylands subcatchment (comprising data from drain sites CAMDOUT, SLMBAIGIN, MIMDOUT and MLMDOUT).

Note: **ISQG Low: Interim Sediment Quality Guideline Low Trigger Value;**
ISQG High: Interim Sediment Quality Guideline High Trigger Value.

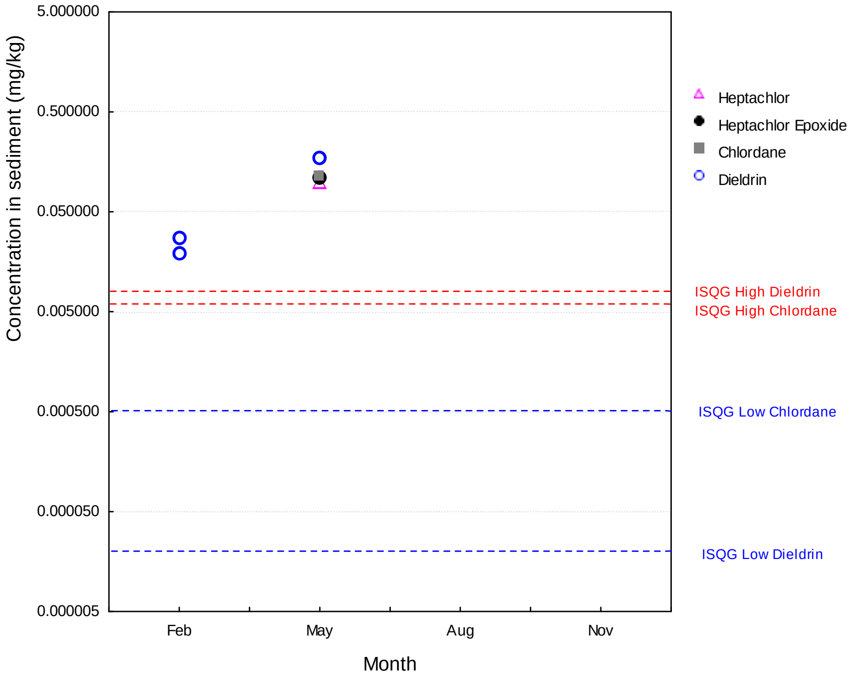

Figure 41 OC pesticides in sediments of Bayswater Main Drain subcatchment (comprising data from drain sites BWDRPBD and BWDESOUT).

Note: **ISQG Low: Interim Sediment Quality Guideline Low Trigger Value; ISQG High: Interim Sediment Quality Guideline High Trigger Value.**

Sites draining into the Canning River

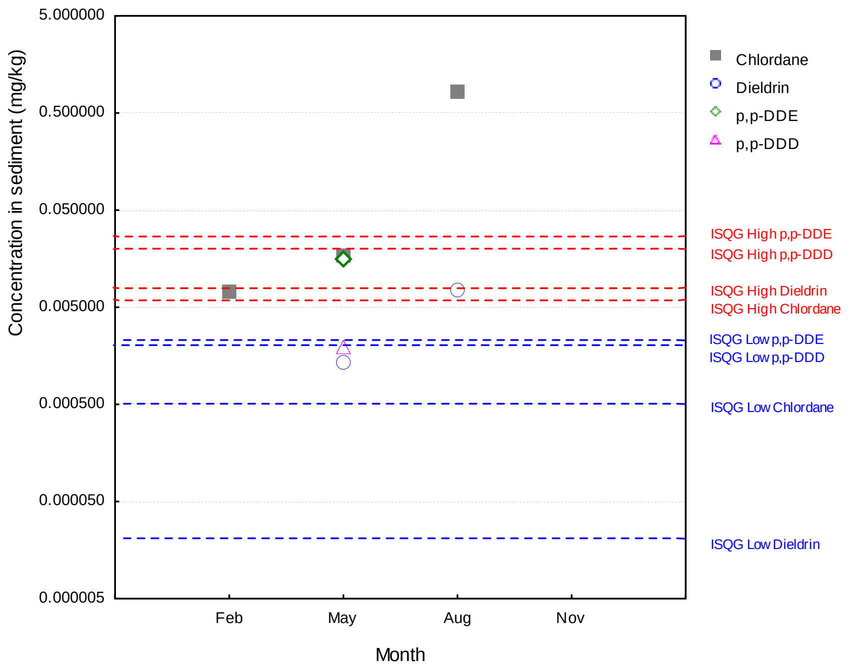

Figure 42 OC pesticides in sediments of Mills Street Main Drain subcatchment (data from drain site MSMILCBOUT).

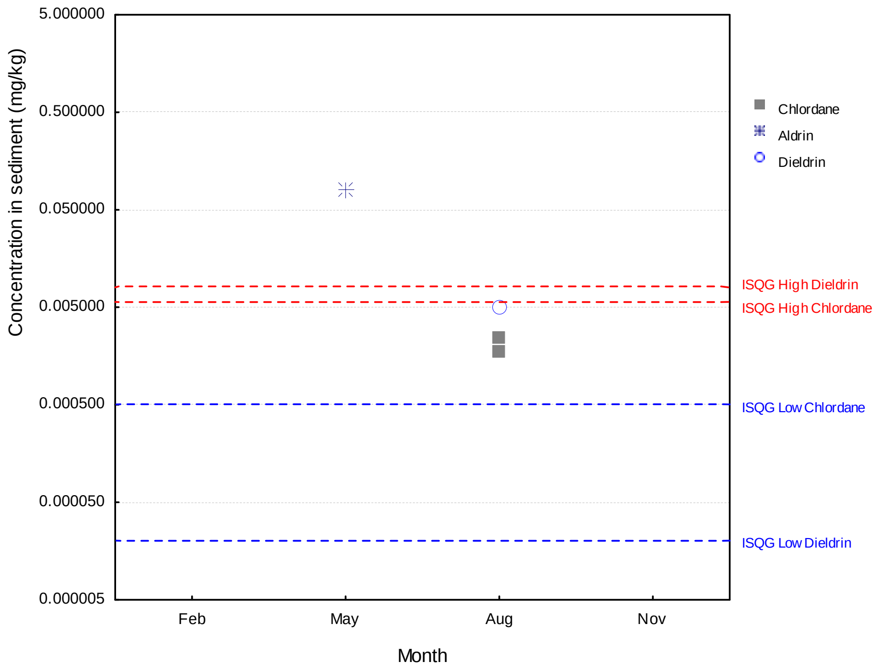

Figure 43 OC pesticides in sediments of the Lower Canning subcatchment (comprising data from drain sites TGDSDPOUT, LAMDO and BWAMDO).

Note: **ISQG Low: Interim Sediment Quality Guideline Low Trigger Value;**
ISQG High: Interim Sediment Quality Guideline High Trigger Value.

3.8 Organophosphorus (OP) pesticides

Both surface water and sediment samples were analysed for organophosphorus (OP) pesticides.

Summary

- OP pesticides are produced to control pests. They are used in the protection of crops, buildings, lawns and household pets from pests such as insects.
- OP pesticides were not detected in any of the surface water or sediment samples collected.
- Note that the limit of reporting for surface water and sediments was 0.1 µg/L and 0.1 mg/kg respectively. However, all of the 95% Ecosystem Protection guidelines (ANZECC and ARMCANZ 2000) that exist for these compounds in surface water are lower (in some cases orders of magnitude lower) than the limit of reporting in the current study. Therefore non-detect data should be treated with caution. There are currently no sediment quality guidelines for OP pesticides. Refer to the *comment on limits of reporting* in section 2.

3.9 Herbicides

Both surface water and sediment samples were analysed for herbicides.

Summary

- Herbicides are a group of compounds that are used to control or inhibit the growth of plant environmental pests (weeds).
- Herbicides were more commonly found in surface water than the sediments.
- Herbicides were detected in just one sample in February, ten in May, 27 in August and none in November, suggesting a possible seasonal pattern.
- Simazine was detected in the sediment in May at the SLMBAIGIN drain (Maylands subcatchment) and was the only herbicide detected in the sediment.
- Simazine exceeded the guideline for 95% Ecosystem Protection in surface waters in May at drain SRMDO (Upper Swan subcatchment).
- Metolachlor exceed the guideline for 95% Ecosystem Protection in surface waters at drain YBMD25 (Yule Brook subcatchment) in August.

Herbicides in sediments versus surface water

Simazine was the only herbicide detected in the sediment. This occurred on a single occasion at drain SLMBAIGIN (Maylands subcatchment) in May.

Herbicides were detected at 23 sites in surface water. Concentrations were below guideline levels with the exception of simazine at the SRMDO (Upper Swan) site during May and metolachlor at the YBMD25 (Yule Brook) site during August. The subcatchments where herbicides were detected were Bayswater Main Drain, Bennett Brook, Blackadder Creek, Central Belmont Main Drain, Helena River, Jane Brook, Maylands, St Leonards Creek, Upper Swan, Bannister Creek, Bickley Brook, Helm Street Main Drain, Lower Canning, Mills Street Main Drain and Yule Brook (Table 9).

Herbicides were detected in less than 1% of sediment samples and 20% of surface water samples (Figure 44).

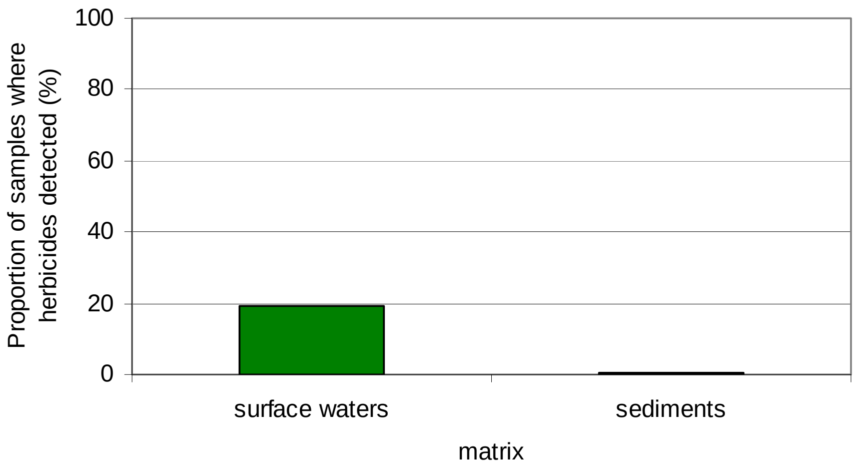

Figure 44 Proportion of samples in which herbicides were detected in surface waters and sediments. n = 151 for surface water and 158 for sediments.

Table 9 Herbicide concentrations in sediment and surface water

		February		May				August				November	
		Water	Sediment	Water			Sediment	Water			Sediment	Water	Sediment
Sub-Catchment	**Site Code**	**Simazine concentration (ug/L)**	**No detections**	**Simazine concentration (ug/L)**	**Atrazine concentration (ug/L)**	**Trifluralin concentration (ug/L)**	**Simazine concentration normalised (mg/Kg)**	**Simazine concentration (ug/L)**	**Atrazine concentration (ug/L)**	**Metolachlor concentration (ug/L)**	**No detections**	**No detections**	**No detections**
		LOR < 0.1ug/L		LOR < 0.1ug/L	LOR < 0.1ug/L	LOR < 0.1ug/L	LOR < 0.1mg/Kg	LOR < 0.1ug/L	LOR < 0.1ug/L	LOR < 0.1ug/L			
Bayswater MD	BWDESOUT			0.78				1.6					
Bayswater MD	BWDESOUT			1.2									
Bayswater MD	PSDTBMD							0.11	0.3				
Bayswater MD	BWDRPBD								0.31				
Bayswater MD	BWDRPBD								0.23				
Bennett Brook	BBCSVBRD								0.14				
Blackadder Creek	BCWETB							1.1	0.28				
Blackadder Creek	BCPPB							0.12					
Central Belmont MD	CBSLO			0.89									
Helena River	HRJSB			0.14					2.4				
Jane Brook	JBGNH							1.2					
Maylands	SLMBAIGIN						1.18	0.46					
Maylands	CAMDOUT							1.3					
St Leonards Creek	STLEONCG							0.6					
Upper Swan	SRMDO			3.7				0.23					
Upper Swan	CSMDO								0.22				
Bannister Creek	BNCADEN			0.42				0.11					
Bickley Brook	BBCM1							0.13	0.15				
Helm St MD	HSGS02	0.34											
Lower Canning	LAMDO			0.67									
Lower Canning	LACDD							0.15					
Mills Street MD	MSMILCBOUT				3.1	0.12		2.7	1.3				
Mills Street MD	MSCWW							1.4	0.43				
Yule Brook	YBMD25							0.15	0.16	0.28			

Note: this table shows those sites where herbicides were detected. Sediment concentrations were normalised to 1% organic carbon according to the *Interim Sediment Quality Guidelines* (Simpson et al. 2005; ANZECC and ARMCANZ 2000).

Herbicides in sediments

One herbicide (simazine) was detected in the sediment. This occurred in May and only at drain site SLMBAIGIN (Maylands subcatchment). The concentration of simazine was 1.18 mg/kg (normalised to 1% total organic carbon). There are no guidelines for simazine in sediment.

Note: The February sediment sample was not tested for dicamba, MCPA, dichlorprop, 2 4D, 2 4 5-T, 2 4 5-TP, 2 4-DB, MCPP, and triclopyr.

Herbicides in surface water

Four herbicides were detected in surface water. These were simazine, atrazine, trifluralin and metolachlor. Metolachlor and trifluralin were both detected at only one site on one occasion. Simazine and atrazine were detected at multiple sites on multiple occasions.

Metolachlor was detected at YBMD25 (Yule Brook) in August. The concentration was 0.28 µg/L which exceeded (by an order of magnitude) the 95% Ecosystem Protection value of 0.02 µg/L.

Trifluralin was detected at MSMILCBOUT (Mills Street Main Drain) in May. The concentration was 0.12 µg/L which is below the 95% Ecosystem Protection value of 2.6 µg/L.

Simazine was detected at one site in February, seven in May, fifteen in August and was not detected in November (Figure 45). The results suggest that there may be a temporal pattern with more of the herbicide present in the drains in autumn and winter. A simazine concentration of 3.7 µg/L during May at site SRMDO (Upper Swan) exceeded the 95% Ecosystem Protection value for simazine (3.2 µg/L) (ANZECC and ARMCANZ 2000). All other values were below the guideline level.

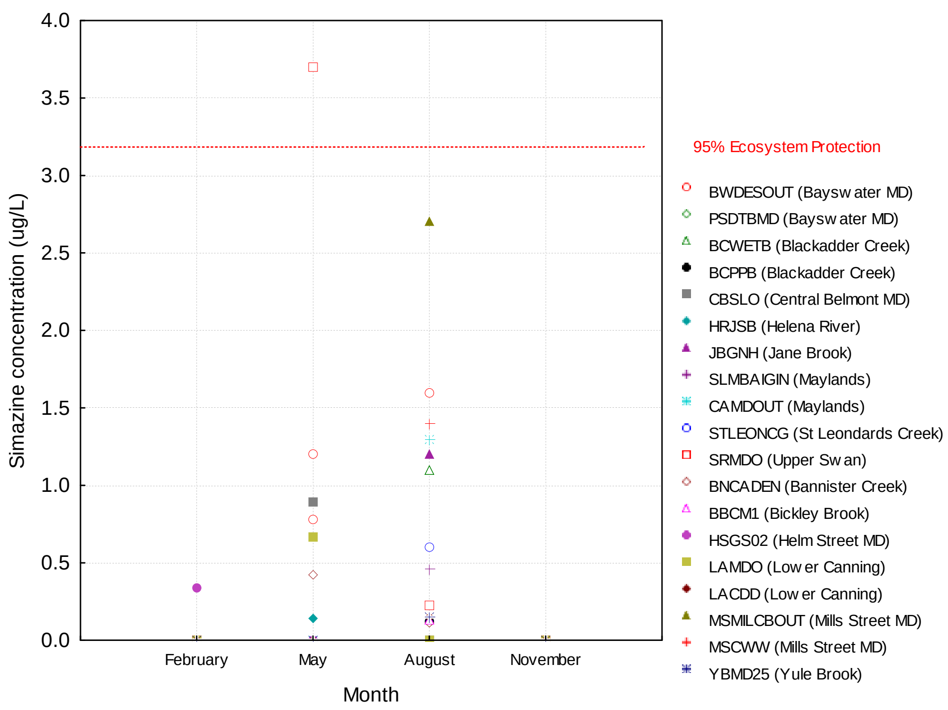

Figure 45 Simazine concentrations in surface water at individual drain sites

Atrazine was not detected in February, was detected at one site in May, ten in August and not detected in November (Figure 46). Again this suggests a possible temporal pattern with more of the herbicide present in the drains in the middle of the year around the autumn and winter months.

The atrazine guideline for 95% Ecosystem Protection of 13 µg/L (ANZECC and ARMCANZ 2000) was not exceeded at any time. The highest level detected was 3.1 µg/L in MSMILCBOUT (Mills Street Main Drain) in May.

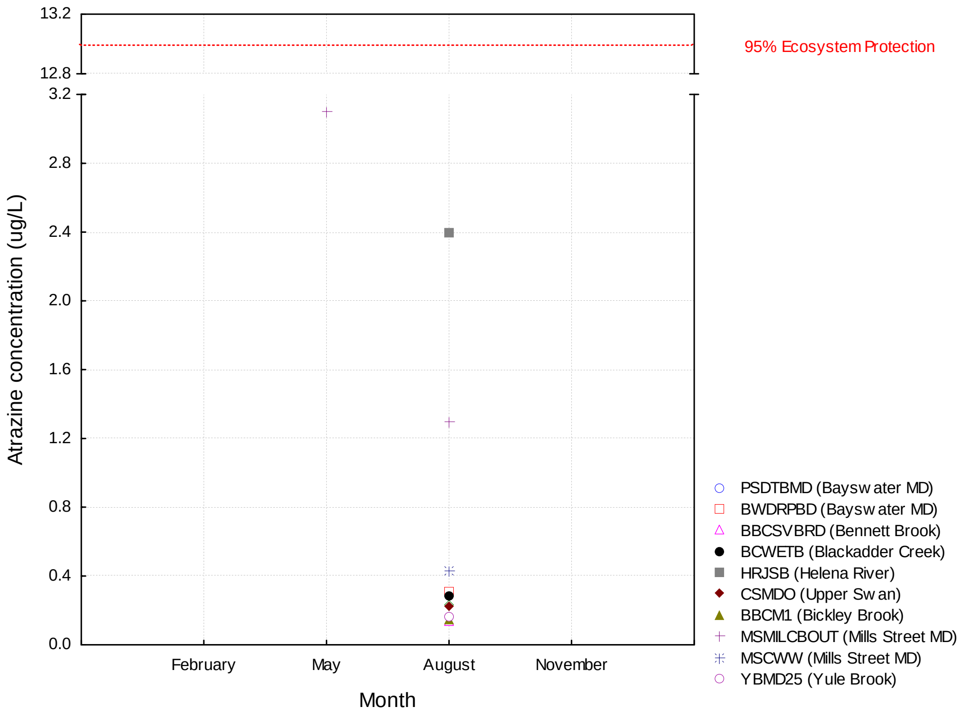

Figure 46 Atrazine concentrations in surface water at individual drain sites.

3.10 Anionic surfactants (methylene blue active substances)

Only surface water samples were analysed for methylene blue active substances (MBAS).

Summary

- Anionic surfactants enter waterways mainly by discharge of aqueous wastes from household and industrial cleansing operations.
- The concentration of MBAS provides a measure of anionic surfactants within a sample.
- MBAS were only detected at six sites with no single site having more than one detection over the four sampling periods.
- MBAS were detected during the February, May and August sampling periods but were not detected during November.
- MBAS concentrations at Individual drain site BCPPB in the Blackadder Creek subcatchment (February) exceeded the recreational guideline value, and individual drain site LIEP6 in the Lower Canning subcatchment (August) was equal to the recreational guideline value of 0.2 mg/L (ANZECC and ARMCANZ 2000).

MBAS in surface water

MBAS were detected at six sites in four subcatchments (Table 10). The subcatchments were Lower Canning, Blackadder Creek, Bull Creek, and Upper Swan. There were three detections in February, one in May, two in August, and none in November.

The highest concentration of MBAS was 0.3 mg/L at drain site BCPPB (Blackadder Creek) during February. This exceeds the recreational guideline value of 0.2 mg/L (ANZECC and ARMCANZ 2000). Site LIEP6 (Lower Canning) had a detection of 0.2 mg/L in August. Currently there is no guideline level for ecosystem health.

Table 10 MBAS concentrations in surface water

Subcatchment	Site code	MBAS concentration mg/L (LOR < 0.1 mg/L)			
		February	May	August	November
Blackadder Creek	BCPPB	0.3			
Bull Creek	BAMDOUT	0.1			
Upper Swan	CSMDO		0.1		
Lower Canning	LACDD			0.1	
Lower Canning	LIEP6			0.2	
Lower Canning	LAMDO	0.1			

Note: this table only shows the sites where MBAS were detected

3.11 Metals

Summary

In general,

- Metals were detected in sediments and surface water of all subcatchments (measured as total metals).
- Of the suite of 14 metals, all were detected in both sediment and surface water samples with the exception of mercury, which was only detected in sediment samples.
- Significant differences were found between subcatchments for most metals.

Subcatchments draining into the Swan River:

- Bayswater Main Drain consistently had significantly higher metal concentrations in the surface water than other subcatchments for the majority of metals. Whereas Blackadder Creek consistently had significantly higher metal concentrations in the sediments than other subcatchments for the majority of metals.
- Sediment concentrations of cadmium, lead and zinc exceeded guideline levels at Central Belmont. Sediment concentrations of copper, lead and zinc exceeded the guideline levels at Upper Swan. Sediment concentrations of lead and zinc exceeded the guideline levels at Blackadder Creek. Sediment concentrations of lead exceeded the guideline levels at Helena River, Maylands and Perth Airport South. Sediment copper concentrations exceeded the guideline levels at Central Business District.
- Surface water concentrations of aluminium, iron, zinc and copper exceeded the guidelines for the majority of subcatchments. Additionally, surface water concentrations of chromium, cobalt and lead exceeded the guidelines at Bayswater Main Drain. Surface water concentrations of chromium exceeded the guideline at South Belmont. Surface water cobalt concentrations exceeded the guideline at Upper Swan.

Subcatchments draining into the Canning River:

- The variability in metal concentrations in the surface water within subcatchments was generally greater than for the Swan. As such, there were fewer significant differences between subcatchments. Those subcatchments that were found to be significantly higher in surface water metal concentration were Bannister Creek and Mills Street Main Drain for chromium and nickel. Additionally, Mills Street Main Drain and the Upper Canning subcatchments consistently had significantly higher metal concentrations in the sediments than other subcatchments.
- Sediment concentrations of copper, lead and zinc exceeded the guidelines at Mills Street Main Drain. Sediment lead concentrations exceeded the guidelines at Helm Street and Lower Canning.
- Surface water concentrations of aluminium, iron and zinc exceeded the guidelines at all subcatchments. Surface water copper concentrations exceeded the guidelines for most subcatchments. Surface water lead and chromium concentrations exceeded the guidelines at Mills Street Main Drain and Bickley Brook. Surface water chromium concentrations exceeded the guidelines at Bannister Creek and Bull Creek.

Supporting graphs and detailed analyses follow:

Metals in sediments

Figures 47 to 60 show the mean total metal concentrations in sediments in subcatchments draining into the Swan Canning system.

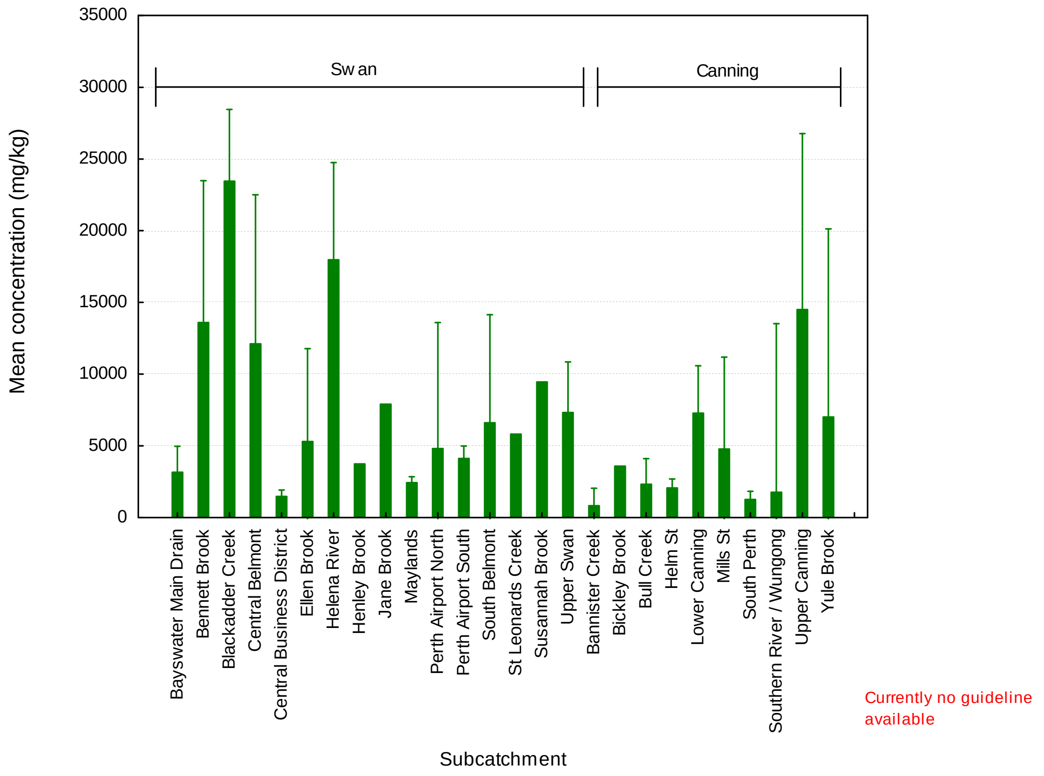

Figure 47 Mean total aluminium concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

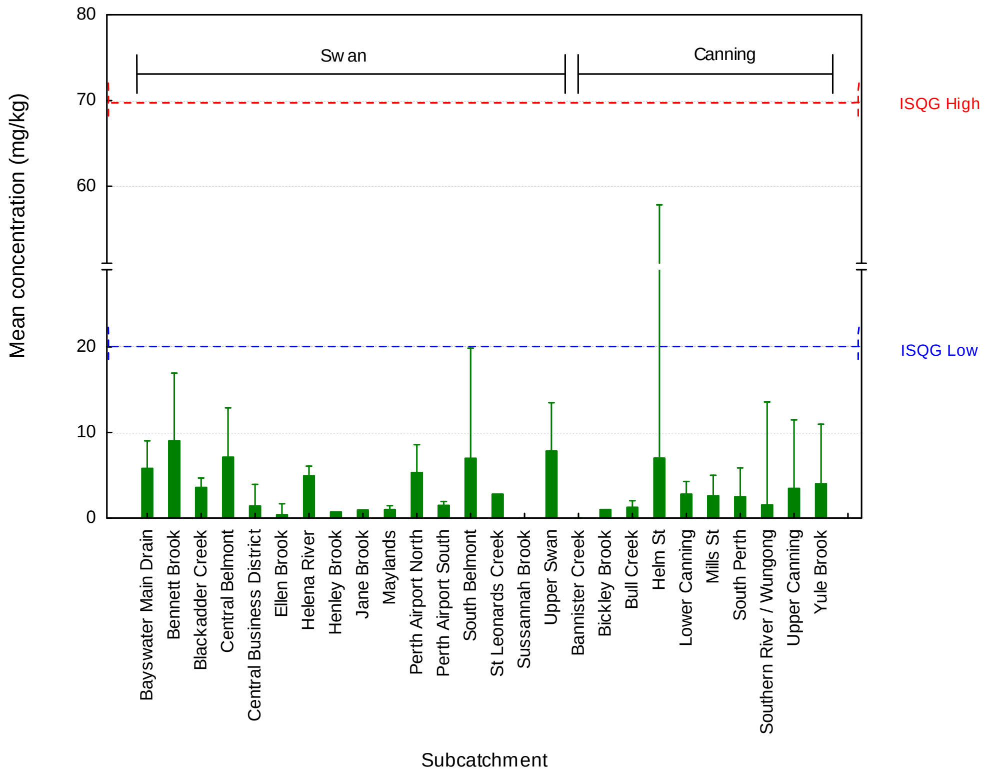

Figure 48 Mean total arsenic concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

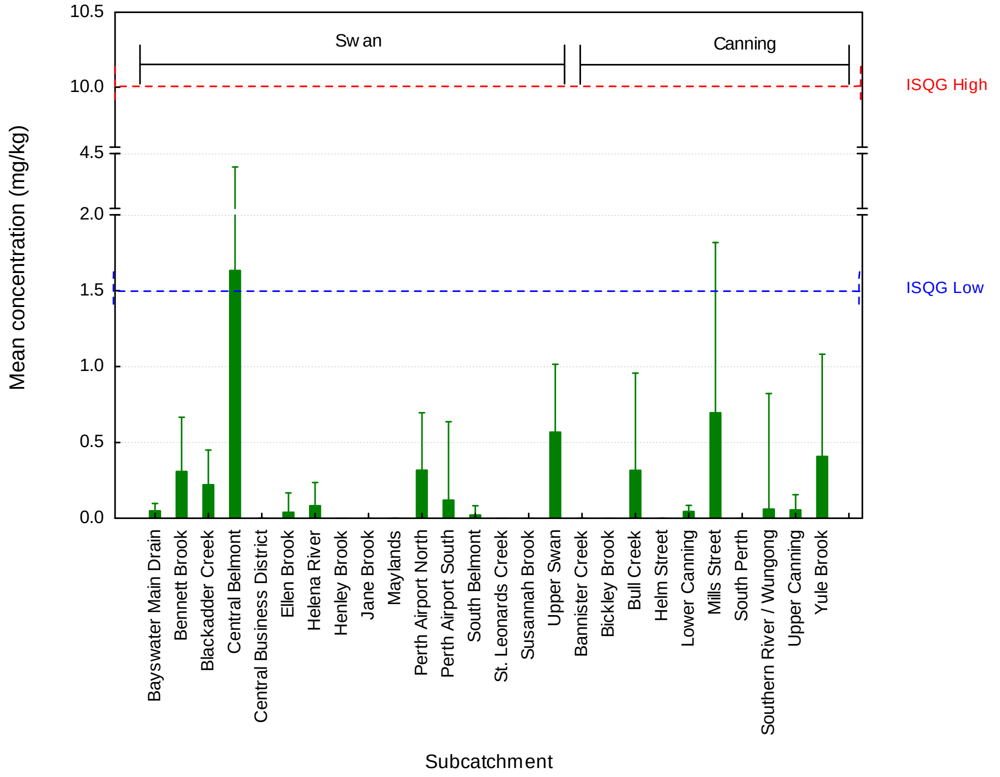

Figure 49 Mean total cadmium concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

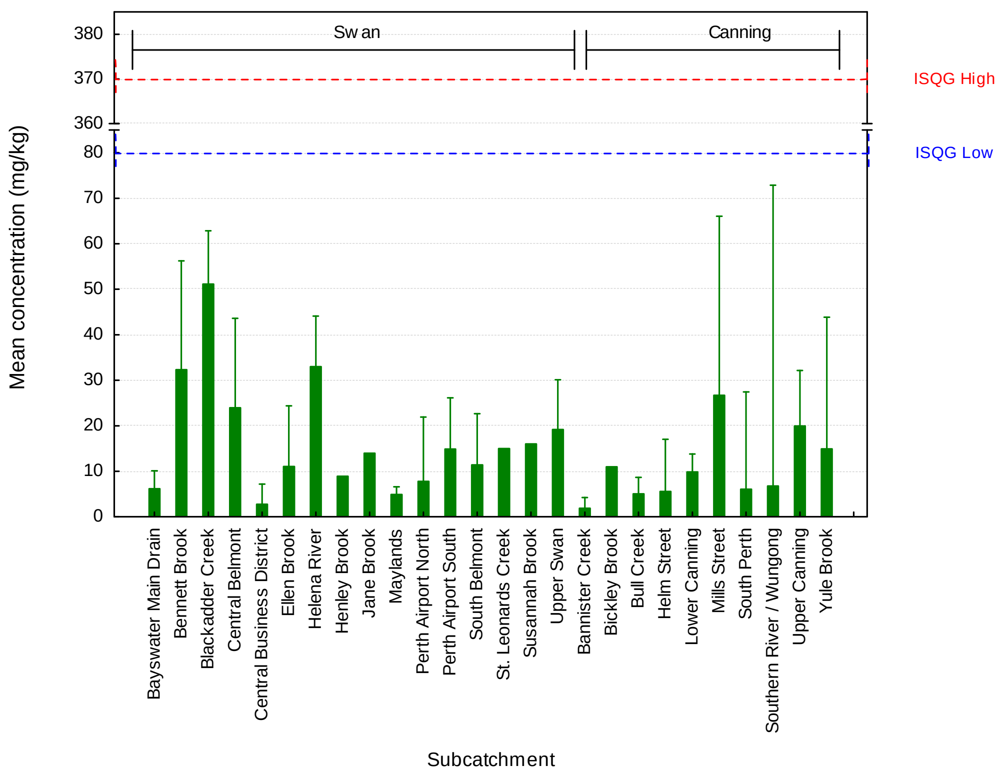

Figure 50 Mean total chromium concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

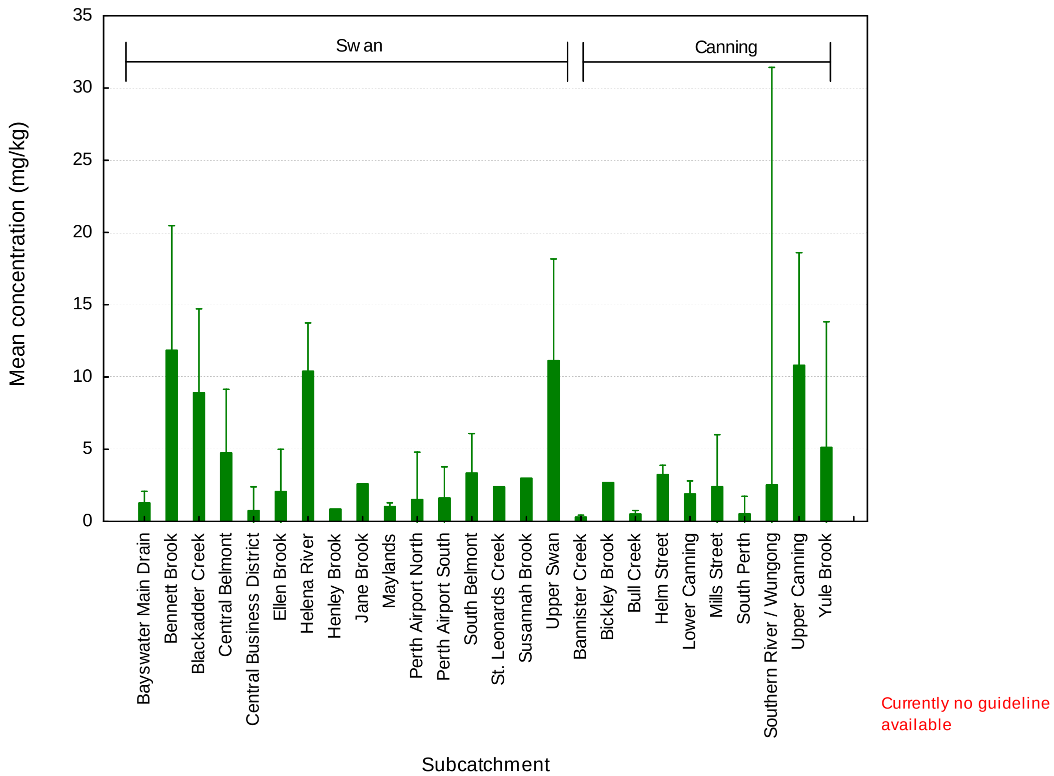

Figure 51 Mean total cobalt concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

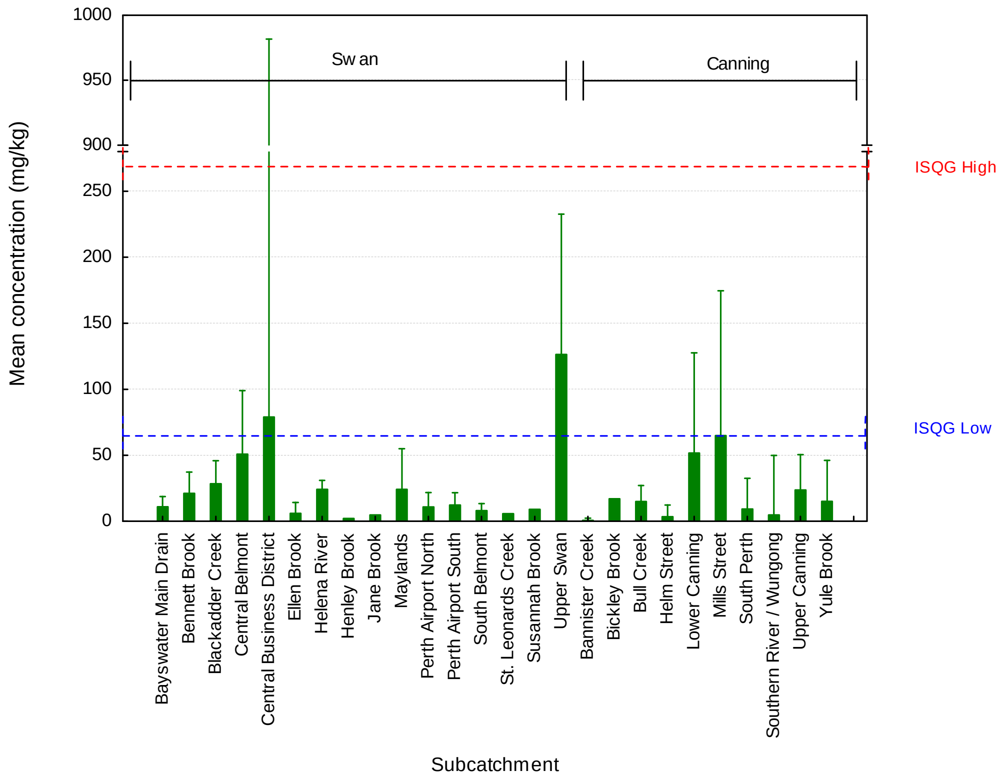

Figure 52 Mean total copper concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

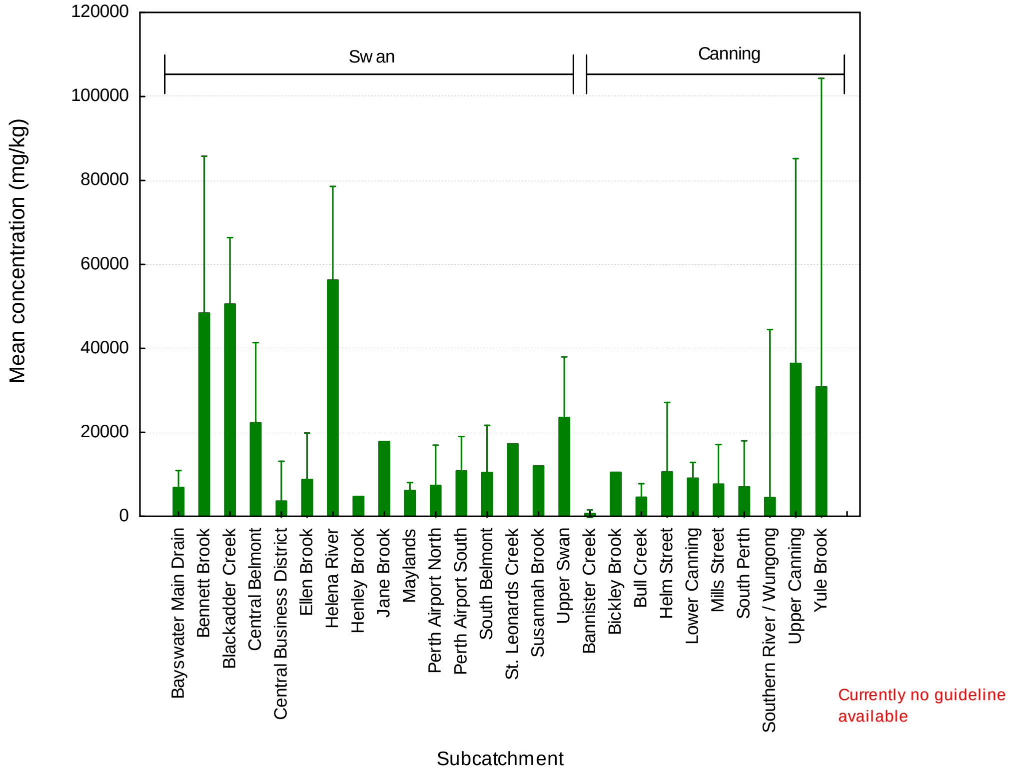

Figure 53 Mean total iron concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

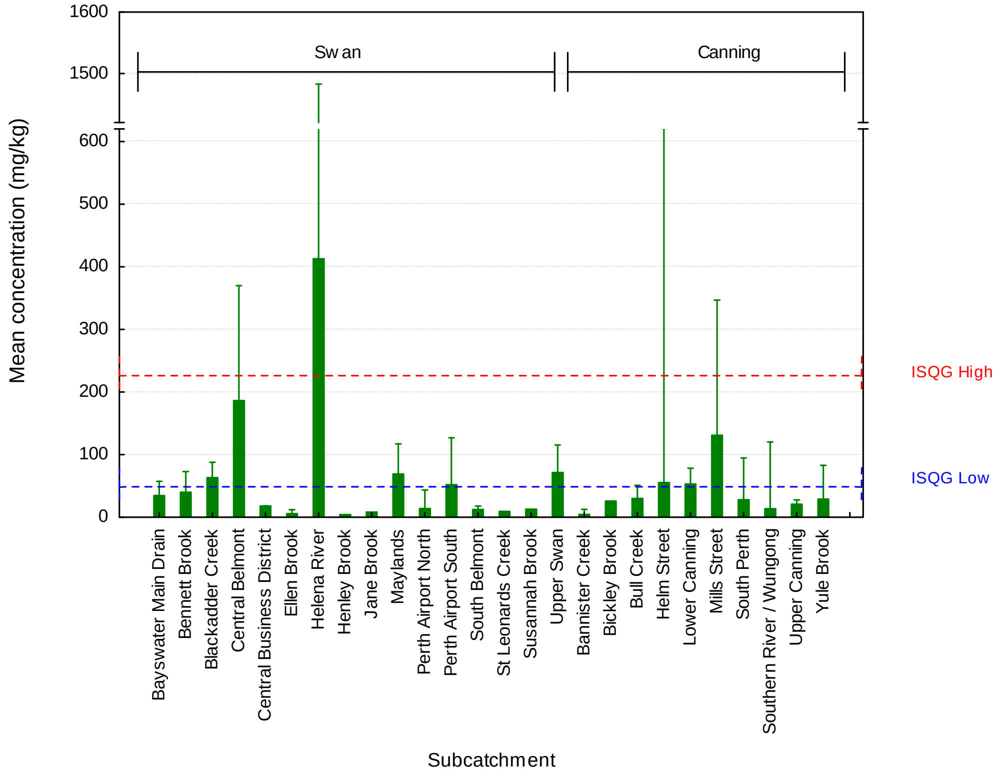

Figure 54 Mean total lead concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

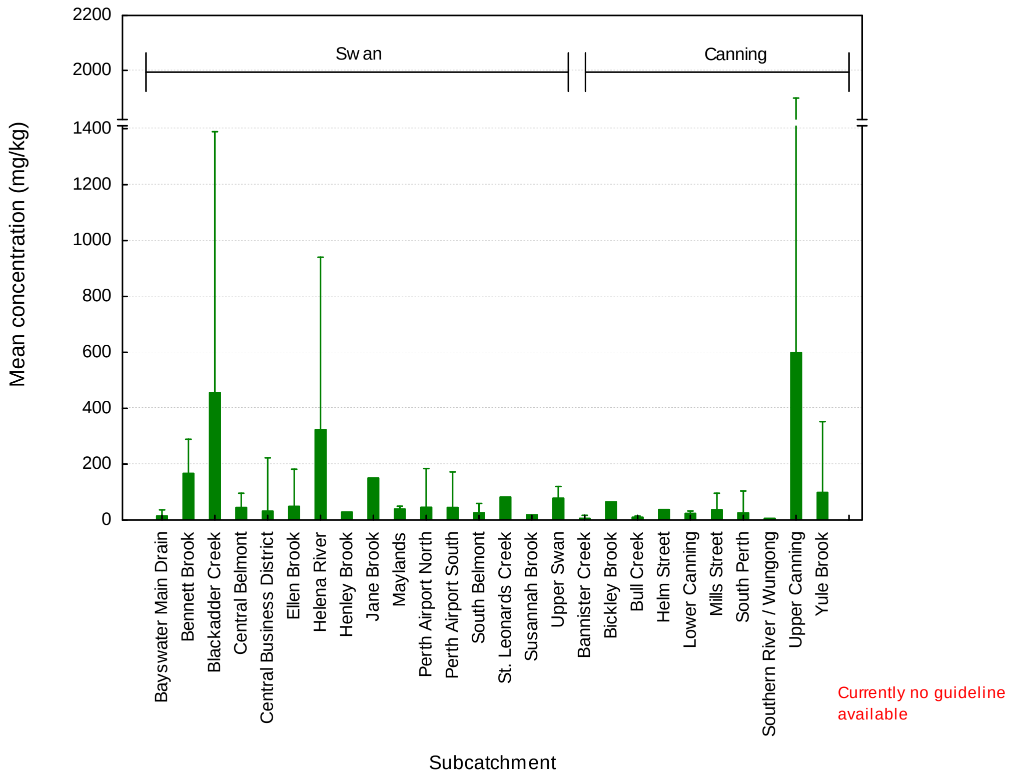

Figure 55 Mean total manganese concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

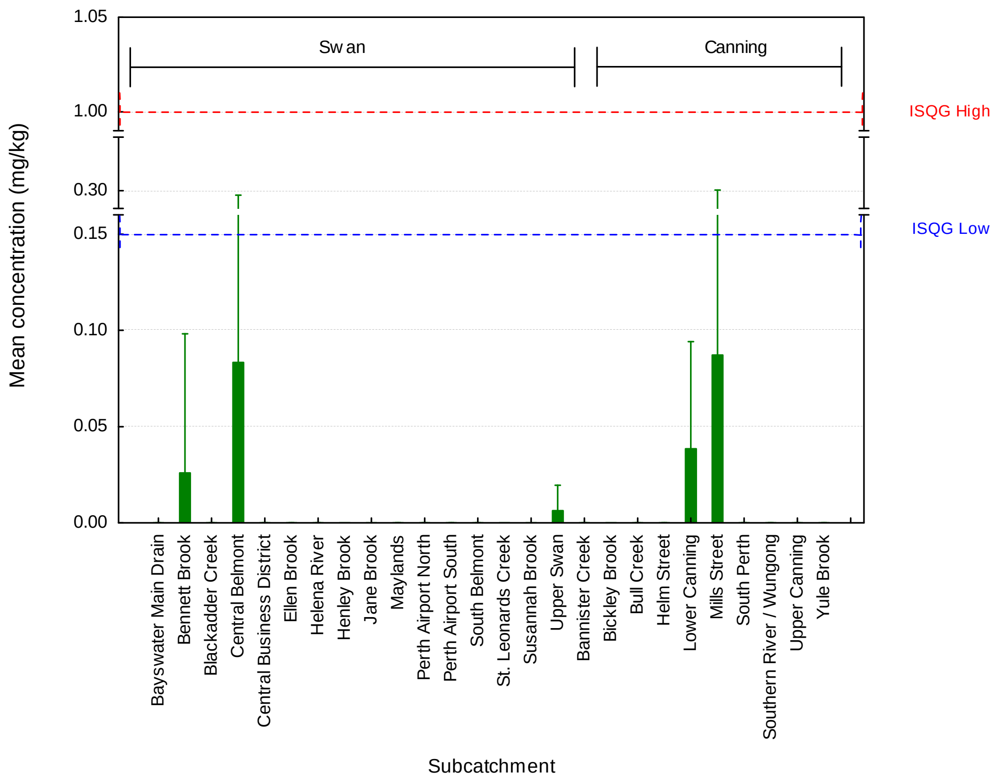

Figure 56 Mean total mercury concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

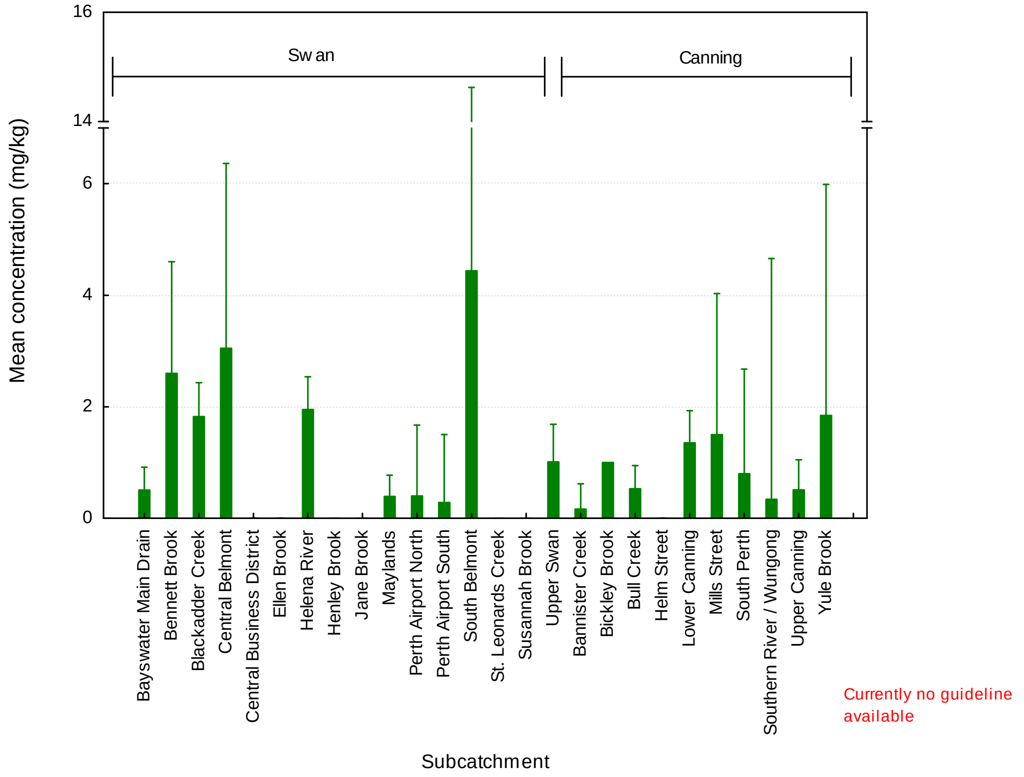

Figure 57 Mean total molybdenum concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

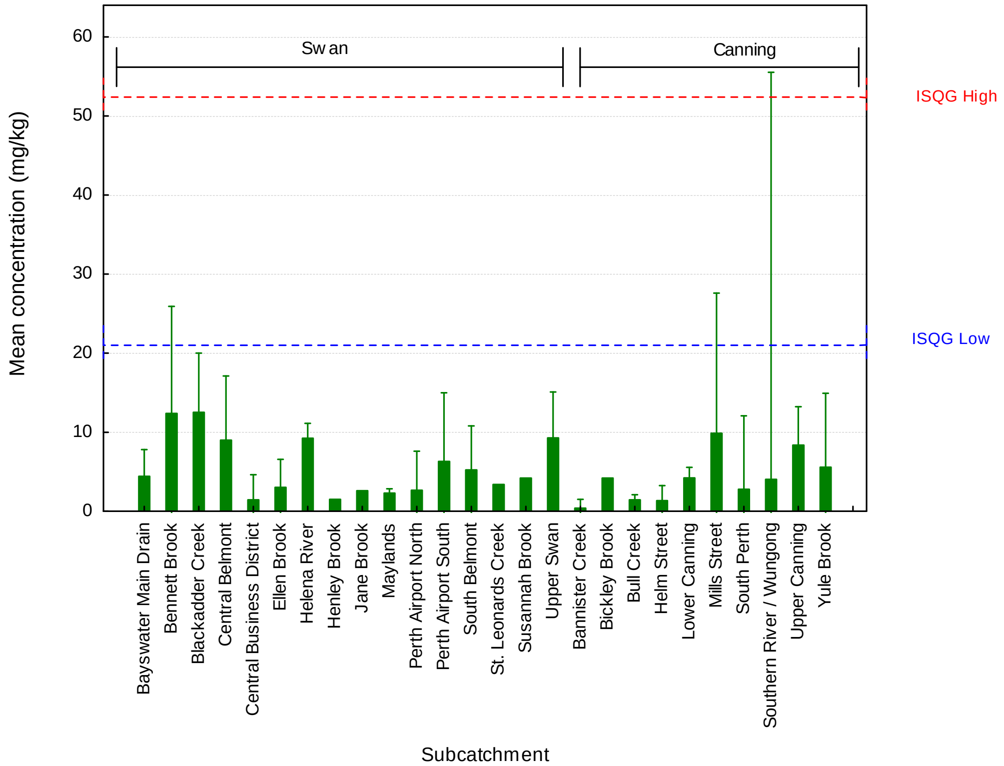

Figure 58 Mean total nickel concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

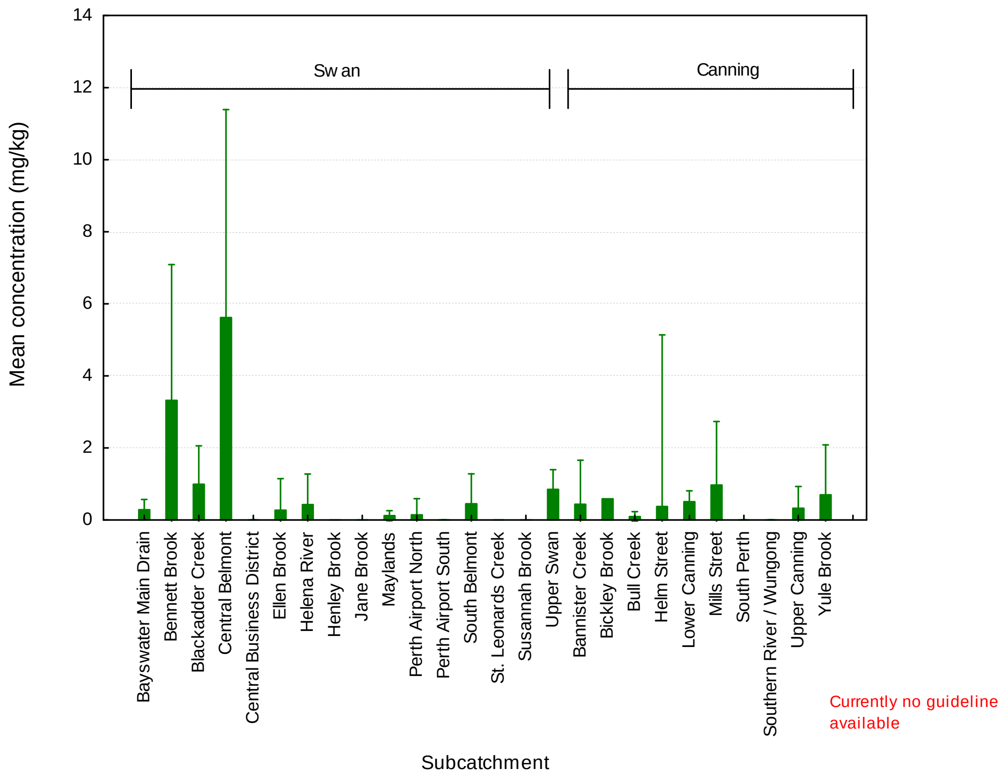

Figure 59 Mean total selenium concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

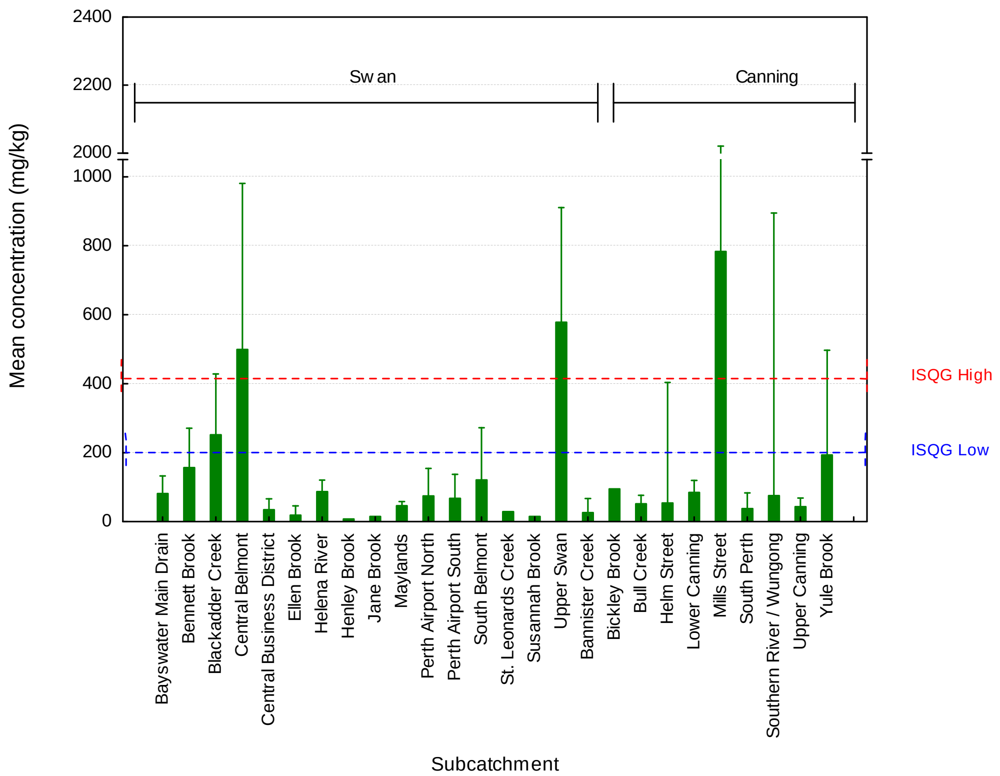

Figure 60 Mean total zinc concentration in sediments across subcatchments. Error bars represent + 95% confidence interval.

Generally, the data were quite variable within subcatchments as indicated by the large 95% confidence intervals on the graphs. However, where significant differences were detected between subcatchments, these were generally consistent across the metals (Tables 11 and 12).

Of the subcatchments draining into the Swan River, Blackadder Creek had consistently significantly higher metal concentrations in the sediments than other subcatchments for the majority of metals.

Of the subcatchments draining into the Canning River, Mills Street Main Drain and the Upper Canning subcatchments generally had consistently significantly higher metal concentrations in the sediments than other subcatchments.

Swan River – sediment metal concentrations

Table 11 A comparison of metal concentrations in sediments of subcatchments draining into the Swan River

Metal	**Kruskal-Wallis test: H statistic**	**p**	**Multiple comparisons test (post-hoc)**	**p**
Aluminium	$H_{(15, N = 91)} = 40.54$	**< 0.001**	Blackadder Creek > Bayswater Main Drain Blackadder Creek > Maylands	**< 0.001** **< 0.001**
Arsenic	$H_{(15, N = 91)} = 33.61$	**< 0.01**	No significant differences detected	> 0.05
Cadmium	$H_{(15, N = 91)} = 25.03$	= 0.05		
Chromium	$H_{(15, N = 91)} = 39.04$	**< 0.001**	Blackadder Creek > Bayswater Main Drain Blackadder Creek > Maylands	**< 0.01** **< 0.001**
Cobalt	$H_{(15, N = 91)} = 25.03$	**< 0.001**	Blackadder Creek > Bayswater Main Drain	**< 0.05**
Copper	$H_{(15, N = 91)} = 22.62$	> 0.05		
Iron	$H_{(15, N = 91)} = 36.12$	**< 0.01**	Blackadder Creek > Bayswater Main Drain Blackadder Creek > Maylands	**< 0.05** **< 0.05**
Lead	$H_{(15, N = 91)} = 30.82$	**< 0.01**	No significant differences detected	> 0.05
Mercury	$H_{(15, N = 91)} = 10.10$	> 0.05		
Manganese	$H_{(15, N = 74)} = 33.34$	**< 0.01**	Blackadder Creek > Bayswater Main Drain Bennett Brook > Bayswater Main Drain Helena River > Bayswater Main Drain	**< 0.01** **< 0.05** **< 0.01**
Molybdenum	$H_{(15, N = 91)} = 31.33$	**< 0.01**	No significant differences detected	> 0.05
Nickel	$H_{(15, N = 91)} = 19.47$	> 0.05		
Selenium	$H_{(15, N = 91)} = 23.67$	> 0.05		
Zinc	$H_{(15, N = 91)} = 40.85$	**< 0.001**	Upper Swan > Ellen Brook Upper Swan > Maylands	**< 0.05** **< 0.01**

Canning River – sediment metal concentrations

Table 12 A comparison of metal concentrations in sediments of subcatchments draining into the Canning River

Metal	**Kruskal-Wallis test: H statistic**	**p**	**Multiple comparisons test (post-hoc)**	**p**
Aluminium	$H_{(9, N = 67)} = 21.84$	**< 0.01**	Upper Canning > Bannister Creek	**< 0.05**
Arsenic	$H_{(9, N = 68)} = 17.20$	**< 0.05**	No significant differences detected	> 0.05
Cadmium	$H_{(9, N = 67)} = 20.38$	**< 0.05**	No significant differences detected	> 0.05
Chromium	$H_{(9, N = 67)} = 17.74$	**< 0.05**	Upper Canning > Bannister Creek	**< 0.05**
Cobalt	$H_{(9, N = 67)} = 30.23$	**< 0.001**	Upper Canning > Bannister Creek Upper Canning > Bull Creek	**< 0.05** **< 0.01**
Copper	$H_{(9, N = 67)} = 18.44$	**< 0.05**	Lower Canning > Bannister Creek Mills Street Main Drain > Bannister Creek	**< 0.05** **< 0.05**
Iron	$H_{(9, N = 67)} = 25.79$	**< 0.01**	Upper Canning > Bannister Creek Upper Canning > Bull Creek	**< 0.01** **< 0.05**
Lead	$H_{(9, N = 67)} = 13.04$	> 0.05		
Mercury	$H_{(9, N = 67)} = 4.86$	> 0.05		
Manganese	$H_{(9, N = 55)} = 26.01$	**< 0.01**	Upper Canning > Bannister Creek Upper Canning > Bull Creek	**< 0.01** **< 0.05**
Molybdenum	$H_{(9, N = 67)} = 11.25$	> 0.05		
Nickel	$H_{(9, N = 67)} = 22.25$	**< 0.01**	Upper Canning > Bannister Creek	**< 0.05**
Selenium	$H_{(9, N = 67)} = 10.62$	> 0.05		
Zinc	$H_{(9, N = 67)} = 18.75$	**< 0.05**	Mills Street Main Drain > Bannister Creek Mills Street Main Drain > Bull Creek	**< 0.05** **< 0.05**

There are currently no guidelines available for aluminium concentrations in sediments. The highest concentrations were observed in the Blackadder Creek, Helena River and Upper Canning subcatchments (Figure 47).

The Low ISQG value was not exceeded for arsenic at any of the subcatchments sampled (Figure 48).

Mean cadmium concentrations from the Central Belmont subcatchment exceeded the Low ISQG (Figure 49).

Chromium was detected in all subcatchments. However, the Low ISQG for chromium was not exceeded at any subcatchment (Figure 50).

Cobalt was detected in the sediment in all subcatchments (Figure 51). There are currently no guidelines available for cobalt in sediments. The highest mean concentrations were experienced in the Bennett Brook, Helena River, Upper Swan and Upper Canning subcatchments.

The Low ISQG for copper was exceeded in both the Central Business District and Upper Swan subcatchments (Figure 52). The Mills Street Main Drain subcatchment had a mean copper concentration that was equal to the Low ISQG.

There are currently no guidelines available for iron concentrations in sediments. Bennett Brook, Blackadder Creek and Helena River had the highest mean iron concentrations of those subcatchments draining into the Swan River; and Upper Canning and Yule Brook subcatchments had the highest mean iron concentrations of those draining into the Canning River (Figure 53).

For those subcatchments draining into the Swan River, the High ISQG for lead was exceeded in sediments from the Helena River subcatchment, while Blackadder Creek, Central Belmont, Maylands, Perth Airport South and Upper Swan sediments exceeded the Low ISQG. Of those subcatchments draining into the Canning River, the Helm Street, Lower Canning and Mills Street Main Drain sediments exceeded the Low ISQG (Figure 54).

There are currently no guidelines for manganese in sediments. The highest mean sediment concentration for manganese was detected in the Blackadder Creek subcatchment draining into the Swan River and the Upper Canning subcatchment draining into the Canning River (Figure 55).

The mean concentration of mercury in sediments did not exceed the low ISQG, (Figure 56) for any subcatchment. Mercury was only detected in the Bennett Brook, Central Belmont, Upper Swan, Lower Canning and Mills Street Main Drain subcatchments.

There are currently no guidelines for molybdenum in sediments. Comparatively high concentrations of molybdenum were detected in the sediments at the South Belmont subcatchment (Figure 57).

The mean concentration of nickel in sediments did not exceed the Low ISQG in any of the subcatchments (Figure 58).

There is currently no Australian guideline for selenium concentrations in sediments. However, the trigger level proposed in the United States by Hamilton and Buhl (2003) of 3 to 4 mg/kg (with a moderate to high hazard of negative environmental impacts) was exceeded at the Central Belmont and Bennett Brook subcatchments, both draining into the Swan River (Figure 59).

Both ISQGs for zinc were exceeded by sediments from Central Belmont and Upper Swan subcatchments (draining into the Swan River), and sediments from Mills Street Main Drain (draining into the Canning River) (Figure 60). Sediments from Blackadder Creek (Swan River) exceeded the low ISQG for zinc.

Metals in surface water

Figures 61 to 73 show the mean total metal concentrations in surface water in subcatchments draining into the Swan Canning system.

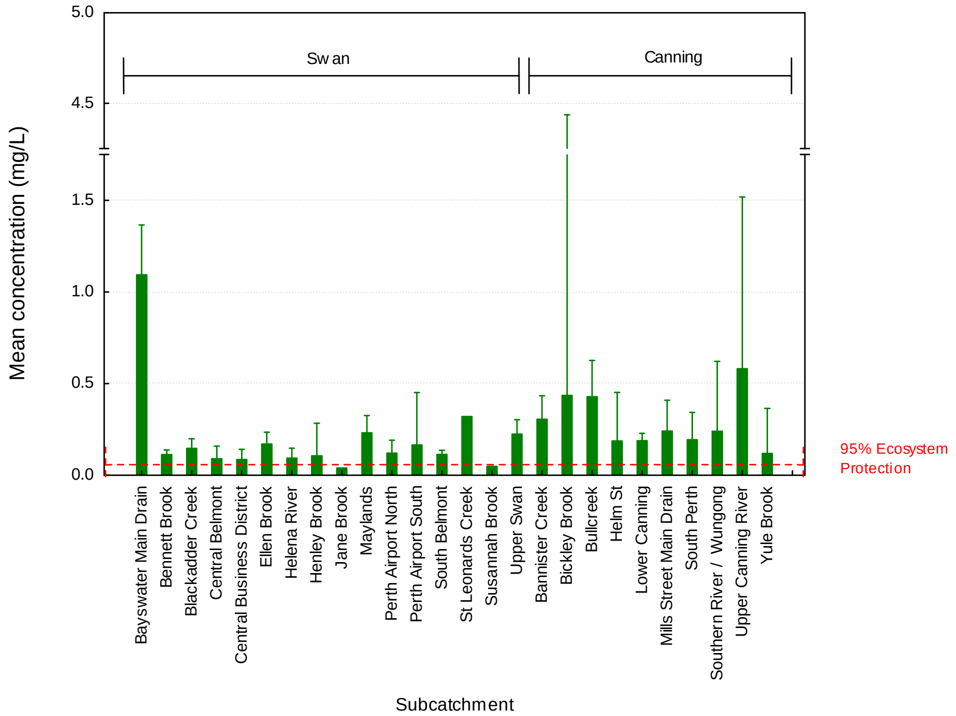

Figure 61 Mean total aluminium concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

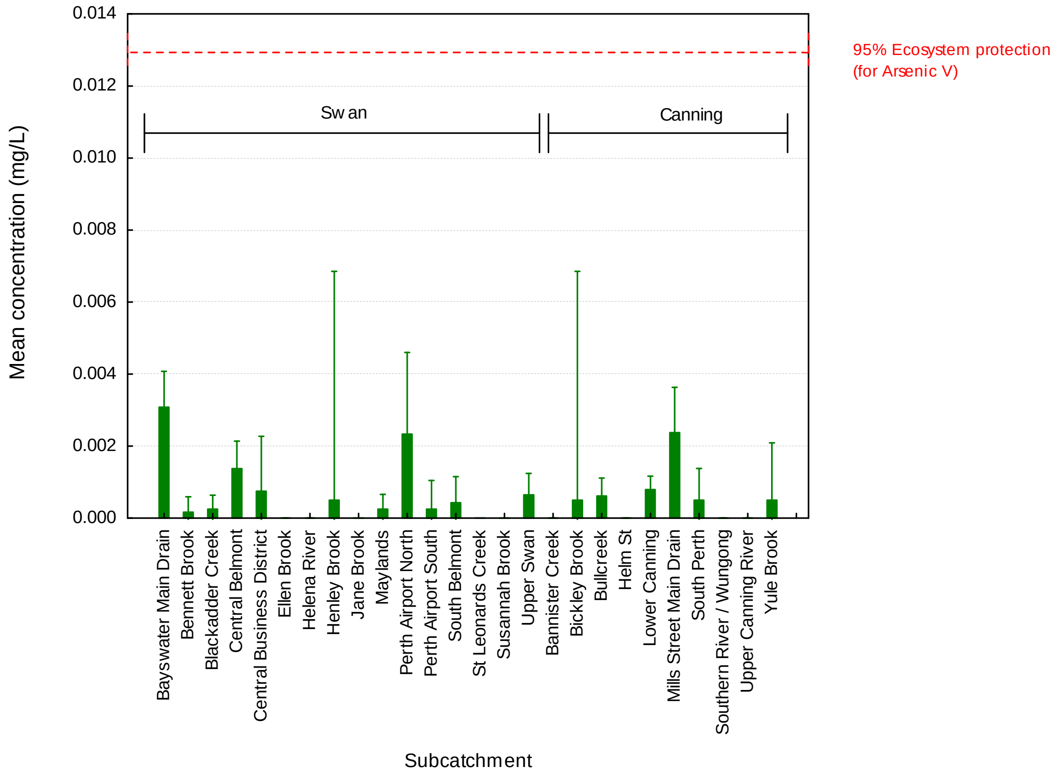

Figure 62 Mean total arsenic concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

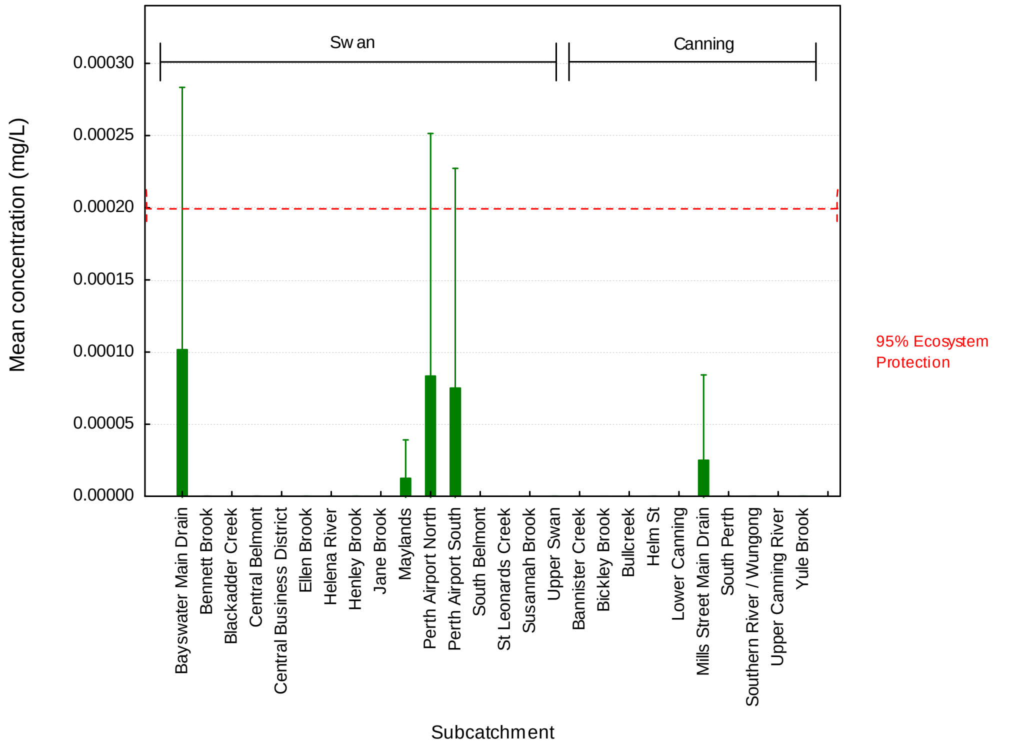

Figure 63 Mean total cadmium concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

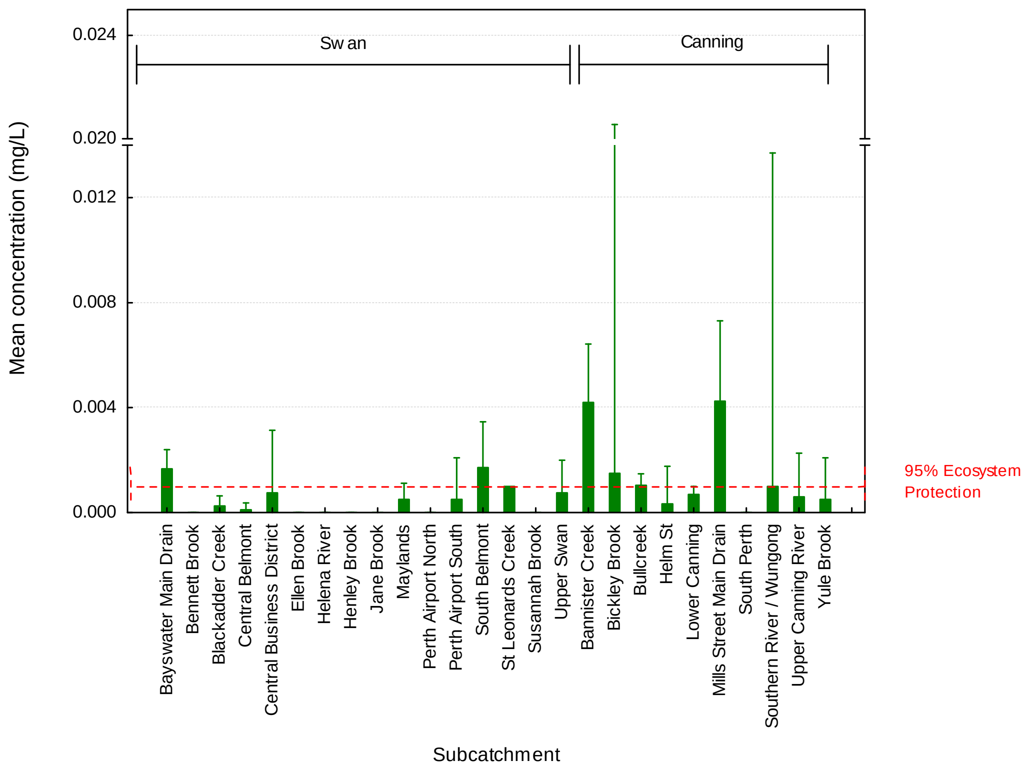

Figure 64 Mean total chromium concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

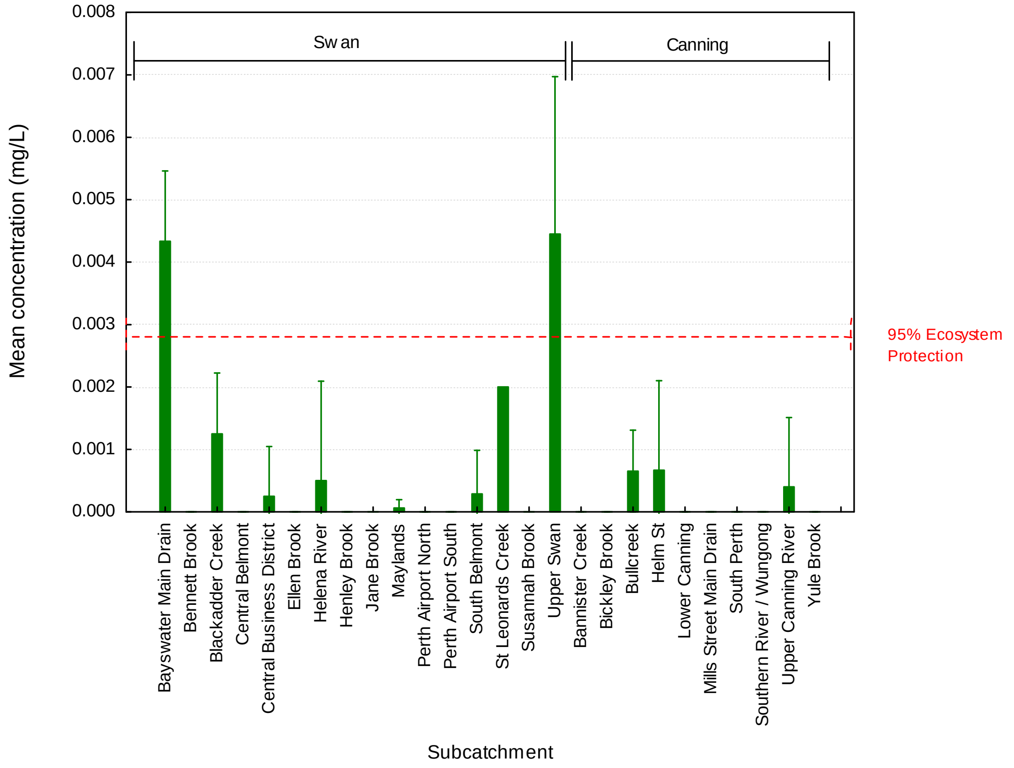

Figure 65 Mean total cobalt concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

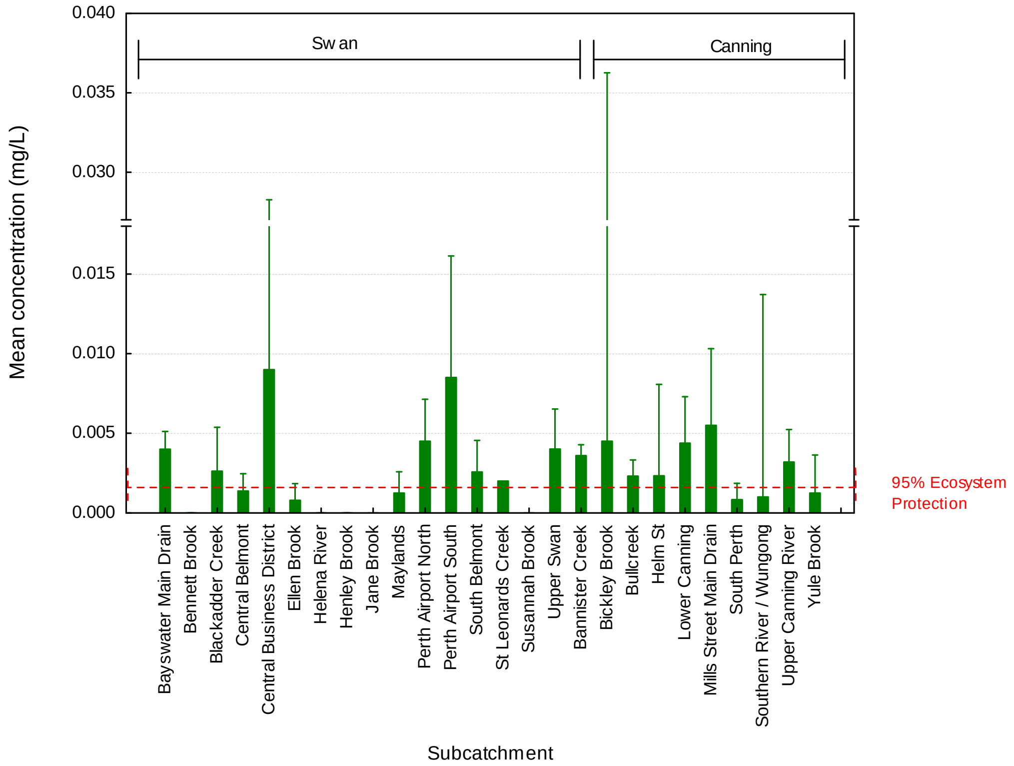

Figure 66 Mean total copper concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

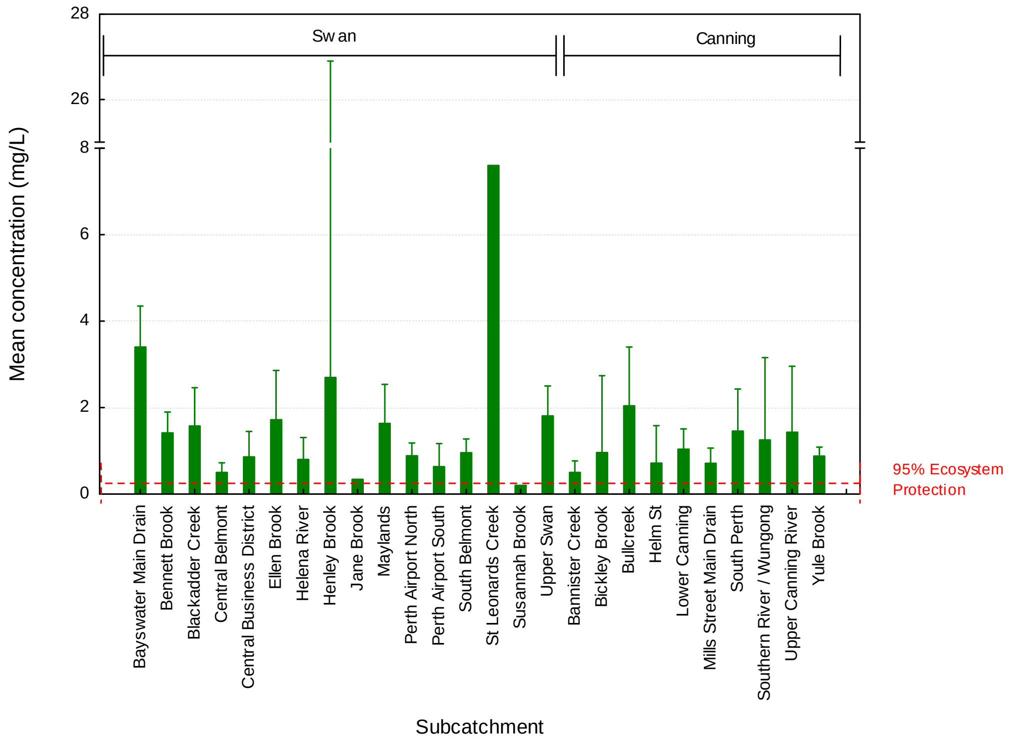

Figure 67 Mean total iron concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

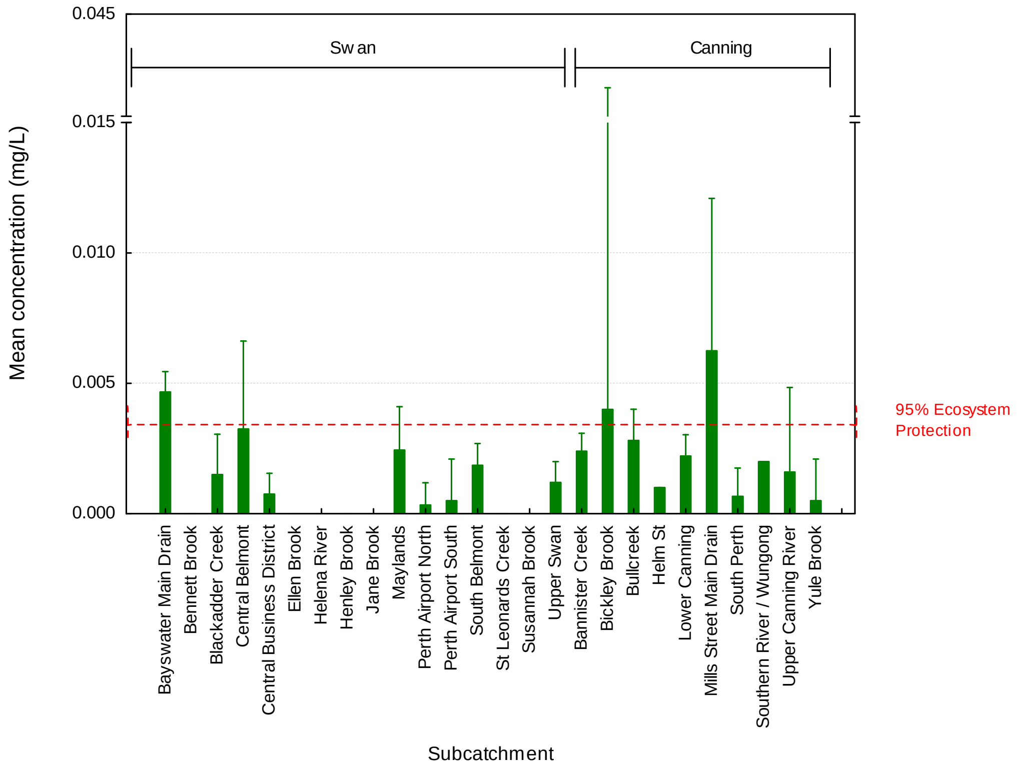

Figure 68 Mean total lead concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

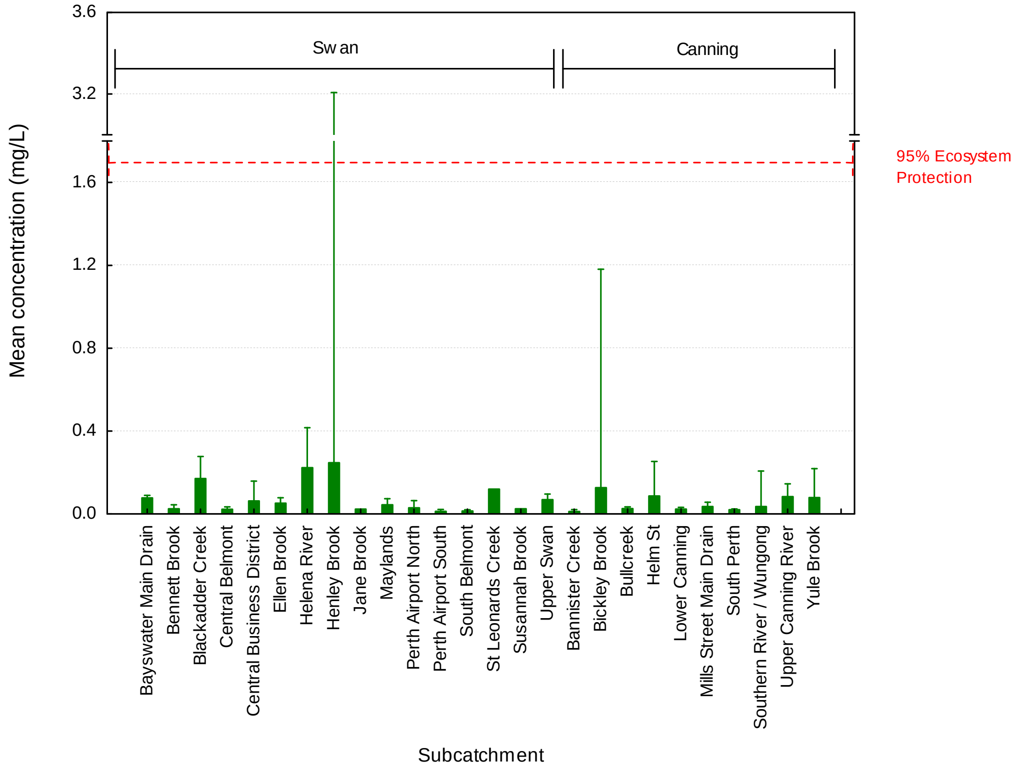

Figure 69 Mean total manganese concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

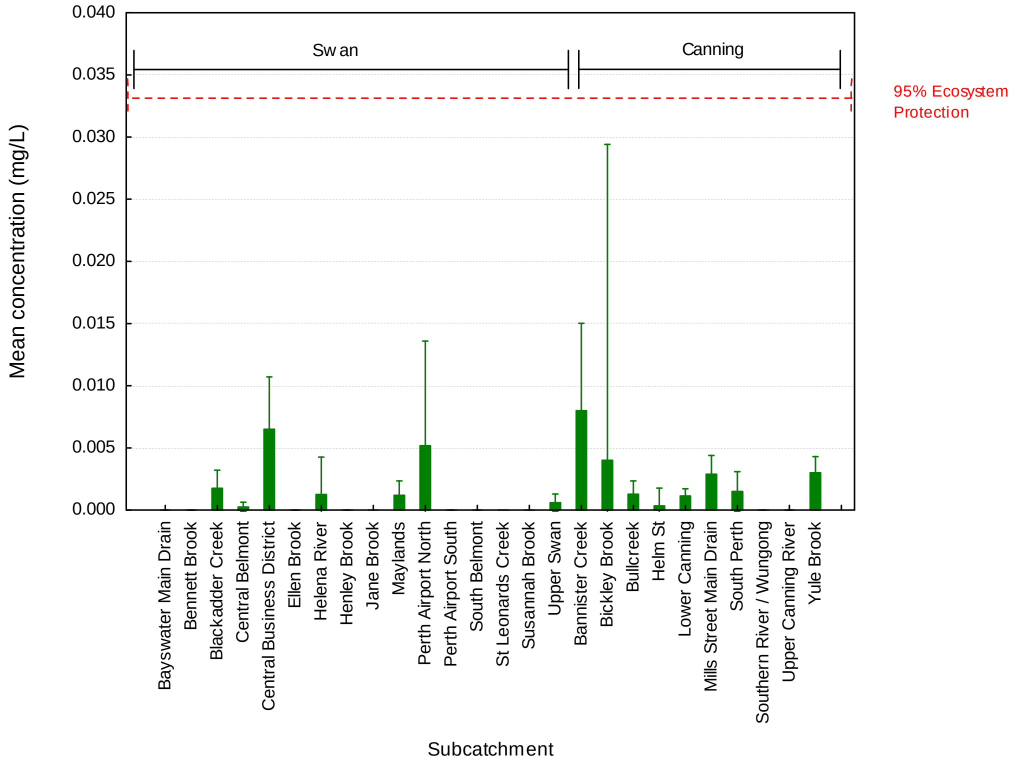

Figure 70 Mean total molybdenum concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

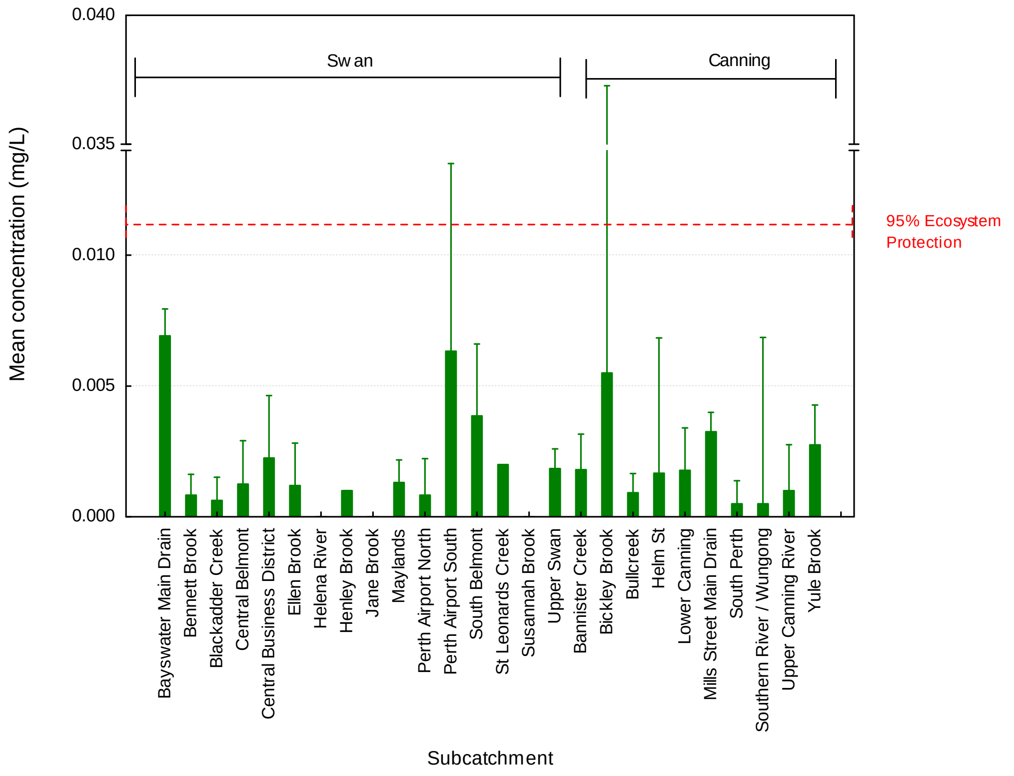

Figure 71 *Mean total nickel concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.*

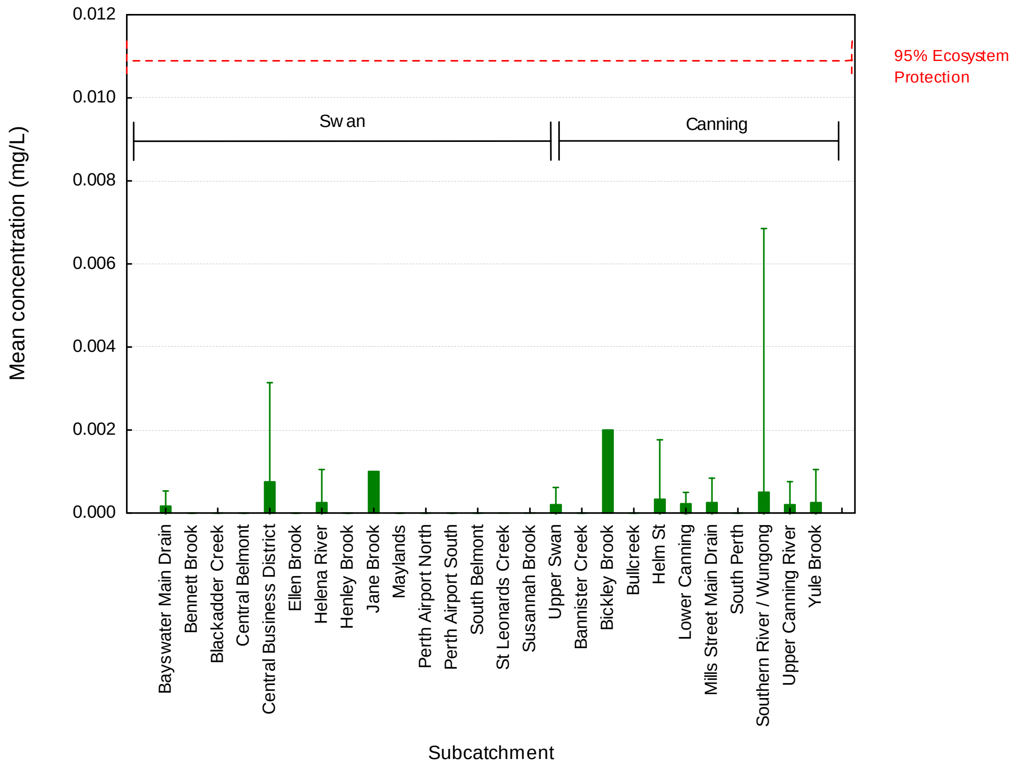

Figure 72 Mean total selenium concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

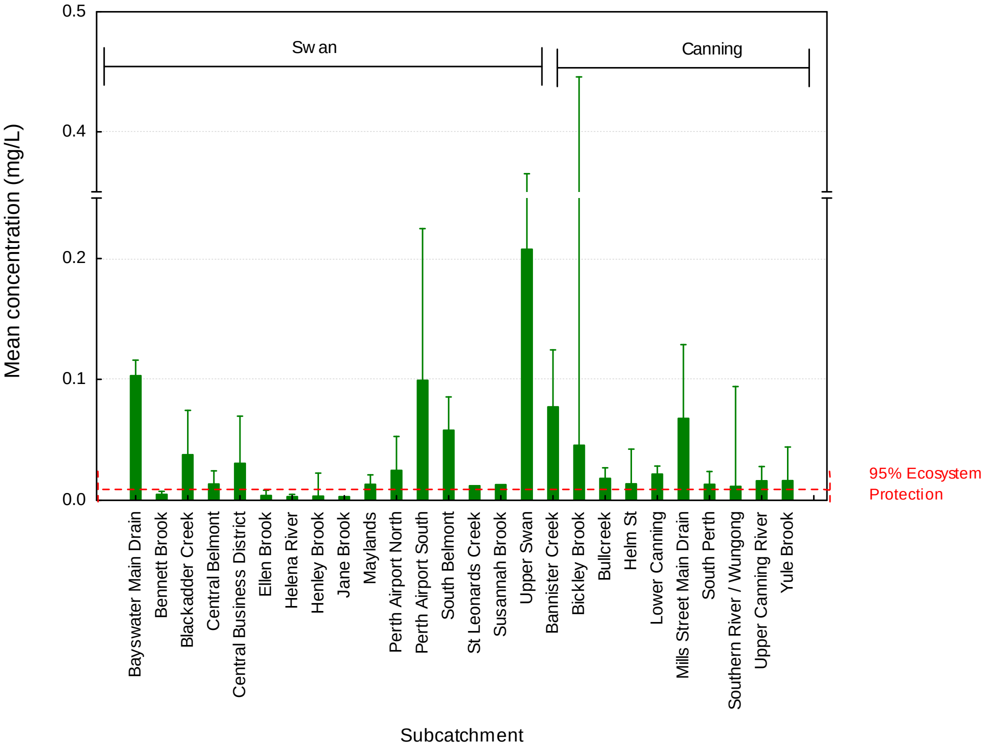

Figure 73 Mean total zinc concentration in surface water across subcatchments. Error bars represent + 95% confidence interval.

Swan River– surface water metal concentrations

Table 13 A comparison of metal concentrations in surface waters of subcatchments draining into the Swan River

Metal	Kruskal-Wallis test: H statistic	p	Multiple comparisons test (post-hoc)	p
Aluminium	$H_{(15, N = 105)} = 52.94$	**< 0.001**	Bayswater Main Drain > South Belmont	**< 0.01**
			Bayswater Main Drain > Maylands	**< 0.05**
			Bayswater Main Drain > Perth Airport North	**< 0.01**
			Bayswater Main Drain > Central Business District	**< 0.01**
			Bayswater Main Drain > Helena River	**< 0.05**
			Bayswater Main Drain > Bennett Brook	**< 0.05**
			Bayswater Main Drain > Central Belmont	**< 0.001**
Arsenic	$H_{(15, N = 105)} = 47.53$	**< 0.001**	Bayswater Main Drain > Maylands	**< 0.01**
			Bayswater Main Drain > Upper Swan	**< 0.05**
Cadmium	Not enough data to perform statistical analysis			
Chromium	$H_{(15, N = 105)} = 33.93$	**< 0.05**	No significant differences detected	> 0.05
Cobalt	$H_{(15, N = 105)} = 56.67$	**< 0.001**	Bayswater Main Drain > Central Belmont	**< 0.05**
			Bayswater Main Drain > Maylands	**< 0.01**
Copper	$H_{(15, N = 105)} = 49.63$	**< 0.001**	Perth Airport South > Bennett Brook	**< 0.05**
			Bayswater Main Drain > Bennett Brook	**< 0.01**
			Bayswater Main Drain > Maylands	**< 0.05**
Iron	$H_{(15, N = 105)} = 45.58$	**< 0.001**	Bayswater Main Drain > Central Belmont	**< 0.001**
			Bayswater Main Drain > Perth Airport South	**< 0.05**
Lead	$H_{(15, N = 105)} = 54.22$	**< 0.001**	Bayswater Main Drain > Perth Airport North	**< 0.01**
			Bayswater Main Drain > Ellen Brook	**< 0.01**
			Bayswater Main Drain > Upper Swan	**< 0.01**
			Bayswater Main Drain > Bennett Brook	**< 0.001**
			Bayswater Main Drain > Helena River	**< 0.05**
Mercury	Was not detected in any surface water samples			
Manganese	$H_{(15, N = 105)} = 47.46$	**< 0.001**	Blackadder Creek > Perth Airport South	**< 0.05**
			Blackadder Creek > South Belmont	**< 0.05**
			Bayswater Main Drain > South Belmont	**< 0.05**
			Helena River > South Belmont	**< 0.05**
Molybdenum	$H_{(15, N = 105)} = 45.70$	**< 0.05**	No significant differences detected	> 0.05
Nickel	$H_{(15, N = 104)} = 51.32$	**< 0.001**	Bayswater Main Drain > Perth Airport North	**< 0.01**
			Bayswater Main Drain > Central Belmont	**< 0.05**
			Bayswater Main Drain > Upper Swan	**< 0.05**
			Bayswater Main Drain > Bennett Brook	**< 0.05**
			Bayswater Main Drain > Blackadder Creek	**< 0.001**
			Bayswater Main Drain > Helena River	**< 0.01**
			Bayswater Main Drain > Maylands	**< 0.001**
Selenium	Not enough data to perform statistical analysis			
Zinc	$H_{(15, N = 105)} = 60.94$	**< 0.001**	Bayswater Main Drain > Central Belmont	**< 0.05**
			Bayswater Main Drain > Bennett Brook	**< 0.001**
			Bayswater Main Drain > Ellen Brook	**< 0.01**
			Bayswater Main Drain > Helena River	**< 0.01**
			Bayswater Main Drain > Maylands	**< 0.01**

Canning River – surface water metal concentrations

Table 14 A comparison of metal concentrations in surface waters of subcatchments draining into the Canning River

Metal	**Kruskal-Wallis test: H statistic**	**p**	**Multiple comparisons test (post-hoc)**	**p**
Aluminium	$H_{(9,\ N = 90) = 16.99}$	= 0.05		
Arsenic	$H_{(9,\ N = 90) = 24.76}$	**< 0.01**	No significant differences detected	> 0.05
Cadmium	Not enough data to perform statistical analysis			
Chromium	$H_{(9,\ N = 89) = 30.82}$	**< 0.001**	Bannister Creek > Lower Canning Bannister Creek > South Perth Mills Street Main Drain > South Perth	**< 0.05** **< 0.01** **< 0.05**
Cobalt	Not enough data to perform statistical analysis			
Copper	$H_{(9,\ N = 90) = 18.52}$	**< 0.05**	No significant differences detected	> 0.05
Iron	$H_{(9,\ N = 90) = 9.62}$	> 0.05		
Lead	$H_{(9,\ N = 89) = 18.17}$	**< 0.05**	No significant differences detected	> 0.05
Mercury	Was not detected in any surface water samples			
Manganese	$H_{(9,\ N = 90) = 20.70}$	**< 0.05**	No significant differences detected	> 0.05
Molybdenum	$H_{(9,\ N = 90) = 31.45}$	**< 0.05**	No significant differences detected	> 0.05
Nickel	$H_{(9,\ N = 90) = 27.82}$	**< 0.01**	Mills Street Main Drain > Bull Creek	**< 0.01**
Selenium	$H_{(9,\ N = 88) = 13.80}$	> 0.05		
Zinc	$H_{(9,\ N = 89) = 20.44}$	**< 0.05**	No significant differences detected	> 0.05

Tables 13 and 14 show comparisons in surface water concentrations between subcatchments draining into the Swan and Canning rivers respectively. Of those subcatchments draining into the Swan River, Bayswater Main Drain had consistently significantly higher metal concentrations in the surface water than other subcatchments for the majority of metals. Of those subcatchments draining into the Canning River, variability in metal concentrations in the surface water within subcatchments was generally greater than for the Swan. As such, there were fewer significant differences between subcatchments. Those subcatchments that were found to be significantly higher in surface water metal concentration were Bannister Creek and Mills Street Main Drain for chromium and nickel.

Aluminium levels exceeded the guideline for surface water at the majority of subcatchments with the exception of Jane Brook and Susannah Brook (Figure 61).

Arsenic, although detected in the surface water at the majority of subcatchments draining to both the Swan and Canning Rivers, did not exceed the guidelines for 95% Ecosystem Protection (Figure 62).

Cadmium was only detected within the surface water of four subcatchments draining to the Swan and one draining to the Canning and did not exceed the guidelines for 95% Ecosystem Protection (Figure 63).

Chromium concentrations in surface water exceeded the guidelines for 95% Ecosystem Protection in the Bayswater Main Drain, South Belmont, St Leonards Creek subcatchments draining to the Swan River and the Bannister Creek, Bickley Brook, Bull Creek, Mills Street Main Drain and the Southern River / Wungong subcatchments draining to the Canning River (Figure 64). Particularly high mean concentrations of chromium in surface waters were recorded in the Mills Street Main Drain and Bannister Creek subcatchments.

Mean concentrations of cobalt at Bayswater Main Drain and Upper Swan subcatchments (both draining into the Swan River) exceeded the 95% Ecosystem Protection guideline for surface waters (Figure 65). Although cobalt was detected at Bull Creek, Helm Street and Upper Canning subcatchments draining to the Canning River, guidelines were not exceeded.

The 95% Ecosystem Protection guideline for copper was exceeded in the surface water in the majority of the subcatchments (Bayswater Main Drain, Blackadder Creek, Central Business District, Perth Airport North, Perth Airport South, South Belmont, St Leonards, Upper Swan draining into the Swan River; and Bannister Creek, Bickley Brook, Bull Creek, Helm Street, Lower Canning, Mills Street Main Drain and Upper Canning draining into the Canning River) (Figure 66).

The iron concentrations at all subcatchments except Susannah Brook exceeded the guideline value for 95% Ecosystem Protection (Figure 67).

The mean lead concentrations at Bayswater Main Drain (draining into the Swan River) and Bickley Brook and Mills Street Main Drain subcatchments (draining into the Canning River) exceeded the guideline value for 95% Ecosystem Protection (Figure 68). Lead was not detected in seven subcatchments draining into the Swan River in surface waters but was detected in every subcatchment draining into the Canning River.

Manganese was detected at all subcatchments. However, concentrations were below the 95% Ecosystem Protection guidelines (Figure 69).

Molybdenum, nickel and selenium concentrations were also below the guidelines at all subcatchments (Figures 70; 71; 72 respectively); and concentrations of selenium in all subcatchments were also below the more conservative trigger value of 5 µg/L proposed for selenium in the United States (Lemly 1999).

The majority of subcatchments (except Bennett Brook, Ellen Brook, Henley Brook, Helena River and Jane Brook) exceeded the 95% Ecosystem Protection trigger value for zinc in surface waters (Figure 73).

Mercury was not detected in any of the surface water samples.

3.12 Chromium reducible sulphur suite

Sediments were analysed for the chromium reducible sulphur suite.

Summary

- The chromium reducible sulphur suite is a set of independent analytical methods that determine the acid/base account of a sample. This information is used to determine the potential for the occurrence of acid sulphate soils. Acid sulphate soils are classed as soils containing a naturally occurring horizon of sulphidic sediments which, when disturbed, oxidise and produce sulphuric acid and iron oxides.
- From the data available, acidification of sediments was not identified as a current issue at the sites sampled.
- In general, stored acidity with the potential to be of environmental concern was observed more frequently at sites draining into the Swan River than at sites draining into the Canning River.
- In general, potential acidity was observed in higher concentrations at sites that drain into the Swan River than at sites draining into the Canning River.

Chromium reducible sulphur suite data for the subcatchments are presented below.

Present acidification

A sediment pH of less then 4 is indicative that actual acid sulphate soil formation may have occurred (Dent 1986). The average pH of the sediments across the sites sampled did not fall below pH 4 in the current study. Therefore from the data available, onsite acidification is not currently an issue (Figure 74).

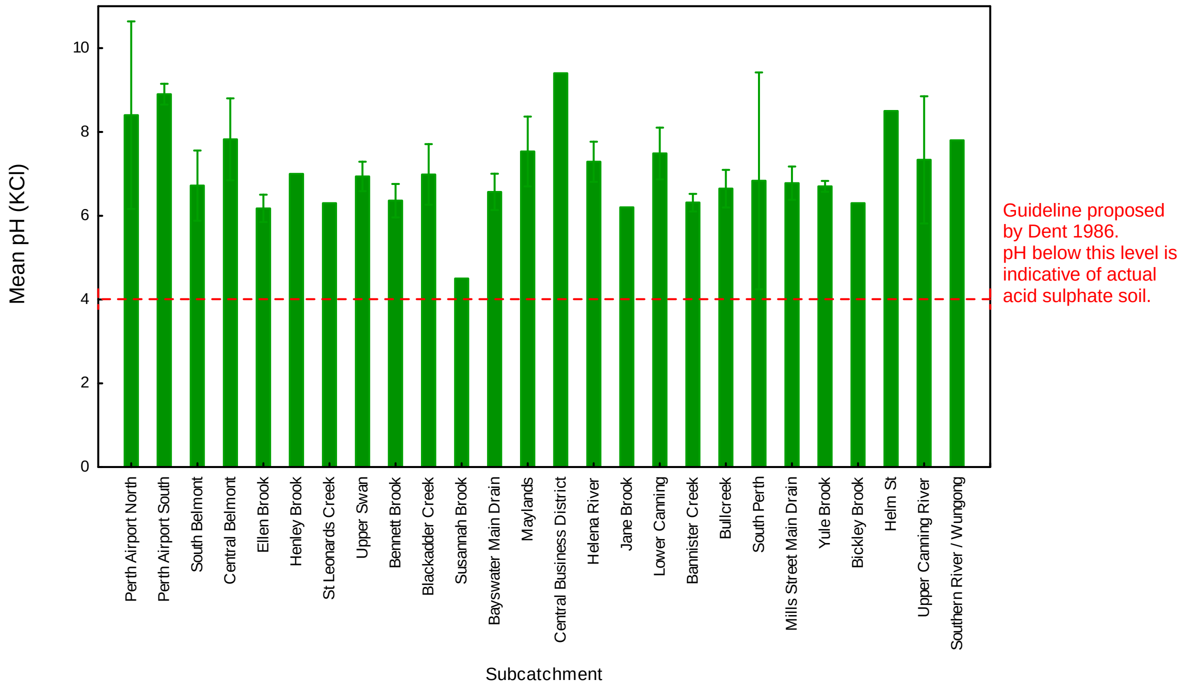

Figure 74 Mean sediment pH (KCl) across subcatchments. Error bars represent + 95% confidence interval.

Future acidification

The chromium reducible sulphur (SCr) analysis determines the reduced inorganic sulphide content of a sediment sample (Ahern 2004). This is indicative of the acid-producing potential of a site if the sediments were to undergo extreme oxidation. The acid neutralising capacity (ANC) is the natural ability of the sediment to maintain a neutral pH by buffering any acidification that occurs. The acid neutralising capacity is multiplied by 0.0327 (Degens, pers. comm. derived from guidelines proposed by DEC 2006) to convert the percentage of ANC to an equivalent percentage of sulphur. This is then multiplied by a safety factor (SF) because it is assumed that the capacity of the soil to adjust to the pH change is only two-thirds as effective as the original ANC value. This approximates an effective neutralising capacity for the sediment (Degens, pers. comm. 2007). The net potential acidity produced by the sediment is the chromium reducible sulphur available for further oxidation once the neutralising capacity of the sediment is exhausted.

Net potential acidity data are presented for individual drains. Mean net potential acidity data are presented in Figures 75 and 76 for drain sites draining to the Swan and Canning Rivers respectively.

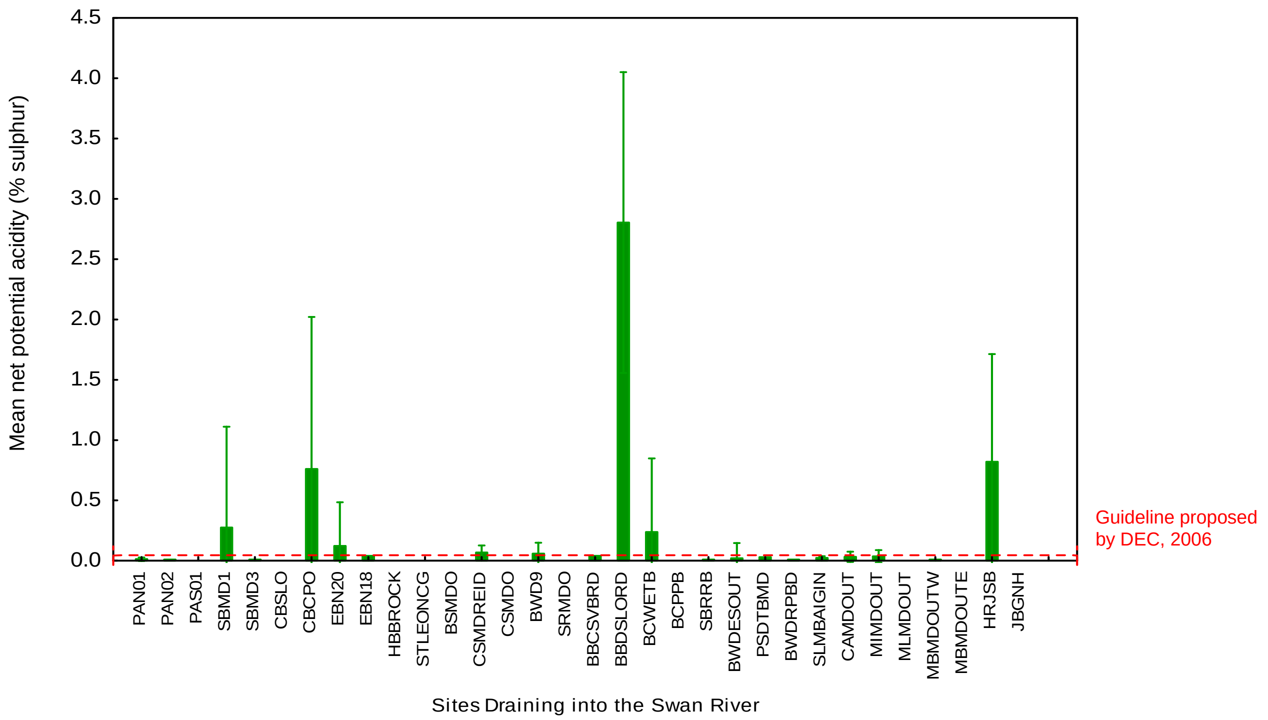

Figure 75 Mean net potential acidity at sites draining into the Swan River. Error bars represent + 95% confidence interval.

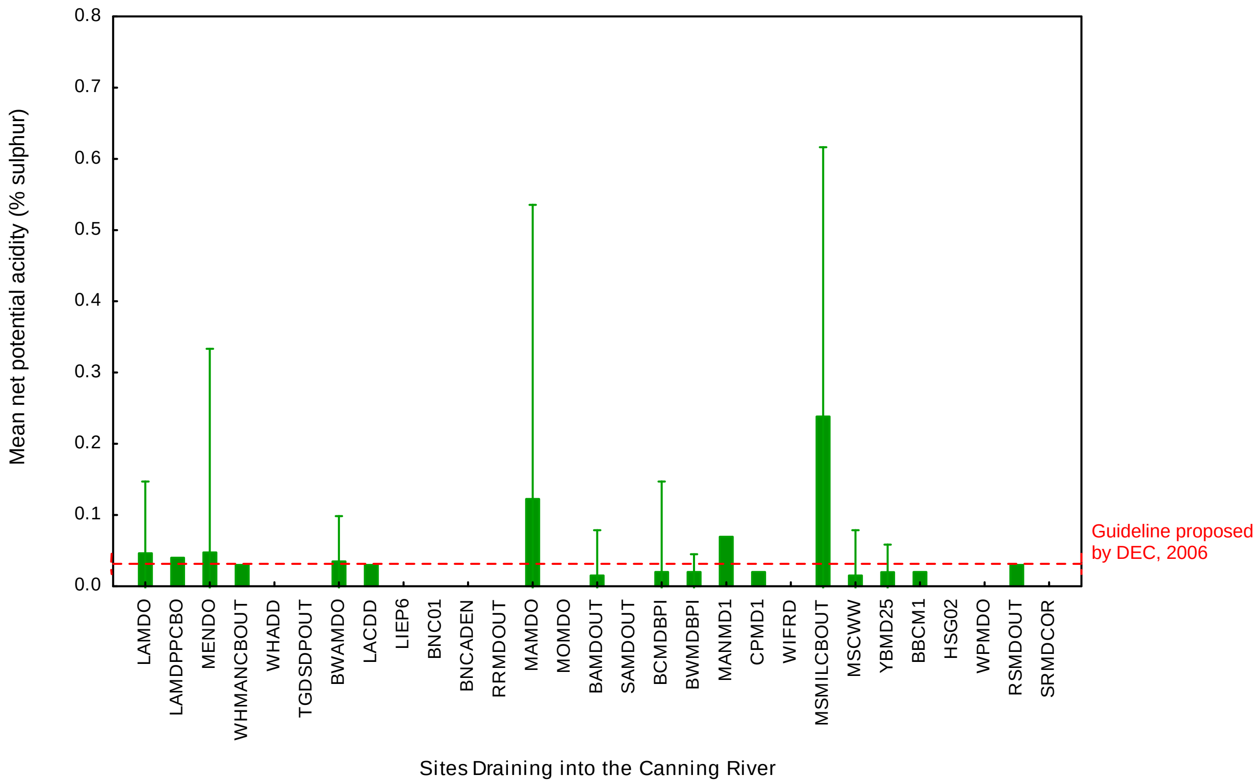

Figure 76 Mean net potential acidity at sites draining into the Canning River. Error bars represent + 95% confidence interval.

Mean net potential acidity = SCr x (ANC x 0.327 x SF)

Sites above the conservative trigger value of 0.03% sulphur (DEC 2006) are considered to pose an environmental risk if the sediment were to undergo complete oxidation. Generally there were more sites draining into the Swan River that had a mean net acidity exceeding this trigger value than sites draining into the Canning River. The exceedences for the Swan sites were also often more extreme then those on the Canning River – mean net potential acidity at site HRJSB (Helena River subcatchment) was approximately 20 times the trigger value and site BBDSLORD (Bennett Brook subcatchment) had a mean net potential acidity approximately 80 times the trigger value.

3.13 Major ions

Summary

- Calcium carbonate (as a measure of alkalinity), chloride, sulphate and fluoride were assessed.
- Alkalinity is a measure of the buffering capacity of water, or the capacity of bases to neutralise acids. There are currently no standards for alkalinity because alkalinity varies greatly with geology. However, Lower Canning and Upper Swan subcatchments had comparatively high alkalinities at specific drain sites.
- A chloride to sulphate ratio of less than 4 provides an indication of an extra source of sulphate being contributed to the system. Ratios below 4 were found in the Bayswater Main Drain, Central Belmont Main Drain, Perth Airport South, South Belmont, Bannister Creek, Bennett Brook, Bickley Brook, Mills St Main Drain, and South Perth subcatchments. The lowest ratio was found in the Bayswater Main Drain subcatchment.
- The highest fluoride levels were detected in the Helena River, Blackadder Creek and Bayswater Main Drain subcatchments.

Major ions data are presented for subcatchments.

Alkalinity as calcium carbonate

There are currently no guidelines for alkalinity because alkalinity varies greatly with geology. However, alkalinity levels of 20–200 mg/L are typical for freshwater. A total alkalinity level of 100–200 mg/L will stabilise the pH level in a stream. Levels below 10 mg/L indicate that the system is poorly buffered, and is very susceptible to changes in pH from natural and anthropogenic sources (Murphy 2005).

When averaged across sites and time, none of the subcatchments had alkalinity in excess of 200 mg/L. 35% of sites had alkalinity exceeding 100 mg/L (Figure 77). Susannah Brook was the only subcatchment with an alkalinity below 20 mg/L but was only sampled on one occasion.

A comparatively high alkalinity value of 1810 mg/L was recorded at LIEP6 (Lower Canning) in November. High values of between 140 mg/L and 250 mg/L were consistently recorded at the SRMDO (Upper Swan), and LACDD (Lower Canning) sites.

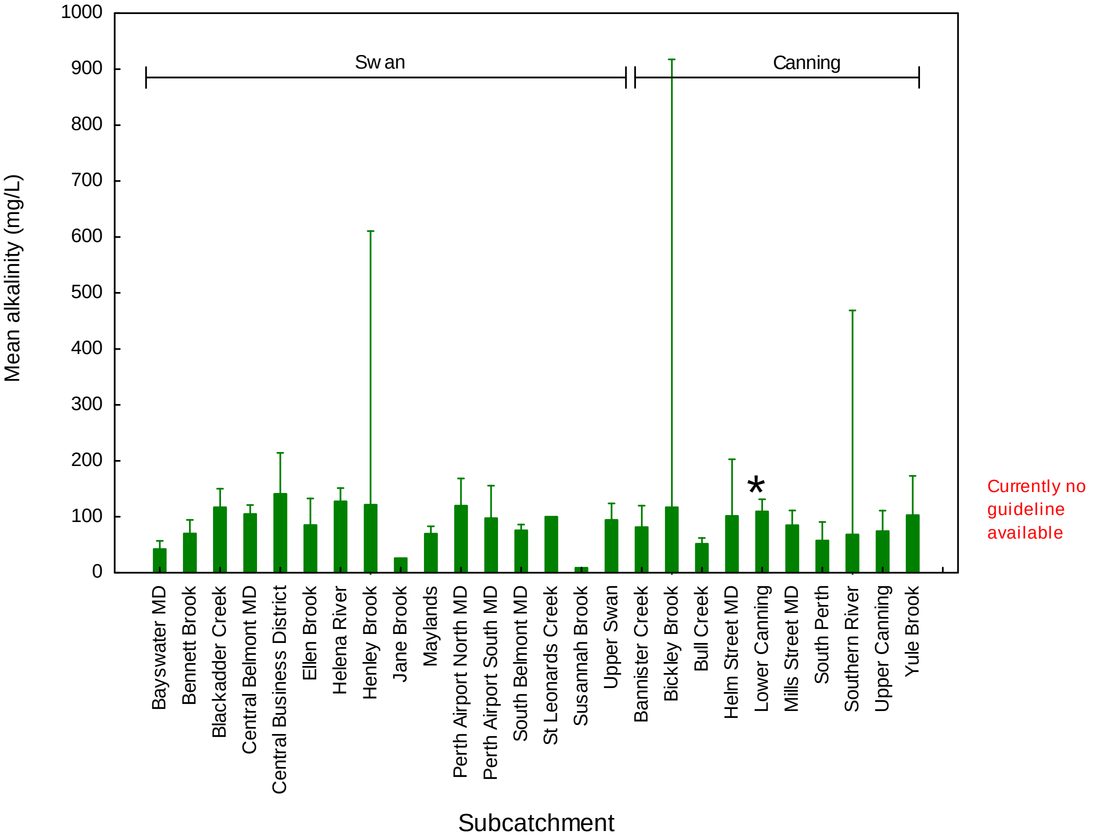

Figure 77 Mean surface water alkalinity (as calcium carbonate) across subcatchments draining into the Swan Canning system. Error bars represent + 95% confidence interval.

** Note: the high value of 1810 mg/L (for Lower Canning) was omitted for graphical representation of this data.*

Chloride and sulphate

The ratio of chloride to sulphate (by mass) in seawater is generally constant at approximately 7.2 (NRM 2006). In seawater the concentration of chloride is approximately 19400 mg/L and sulphate is approximately 2700 mg/L (NRM 2006). This ratio remains roughly constant when diluted with uncontaminated rain or freshwater. Estuaries can be expected to have a similar ratio. A chloride to sulphate ratio of less than 4, and certainly less than 2, is a strong indication of an extra source of sulphate from sulphide oxidation (that is, acid sulphate run-off) (Mulvey 1993).

There were 19% of sites with a chloride to sulphate ratio of less than 2 and 57% of sites with a ratio of less than 4. Average ratios below 4 were found in the Bayswater Main Drain, Central Belmont Main Drain, Perth Airport South Main Drain, South Belmont Main Drain, Bannister Creek, Bennett Brook, Bickley Brook, Mills Street Main Drain, and South Perth subcatchments. The lowest ratio of 1.5 was found in the Bayswater Main Drain subcatchment (Figure 78).

10% of sites had a ratio above 8. These sites were in the Ellen Brook, Jane Brook, Blackadder Creek, Susannah Brook and St Leonards Creek subcatchments.

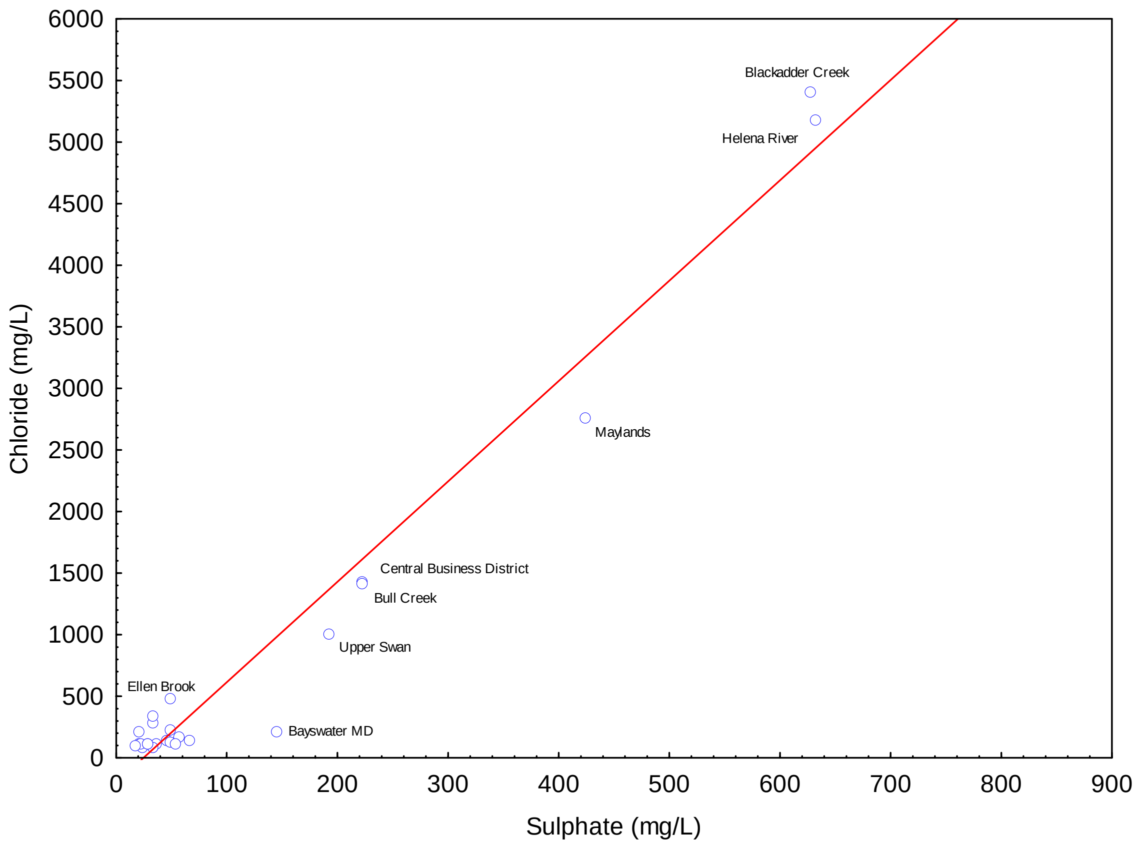

Figure 78 Chloride and sulphate concentrations in surface waters across subcatchments draining into the Swan Canning system.

The line represents the ratio of chloride to sulphate in seawater (NRM 2006).

Fluoride

There are currently no guidelines available for fluoride. Highest fluoride levels when averaged across sites and time were found in the Helena River, Blackadder Creek and Bayswater Main Drain subcatchments.

A notably high fluoride concentration of 94.0 mg/L was detected at BBDSLORD (Bennett Brook) in August. BWDESOUT (Bayswater Main Drain) had a concentration of 1.05 mg/L measured in May, and was the only other site to record a fluoride level above 1.0 mg/L (Figure 79).

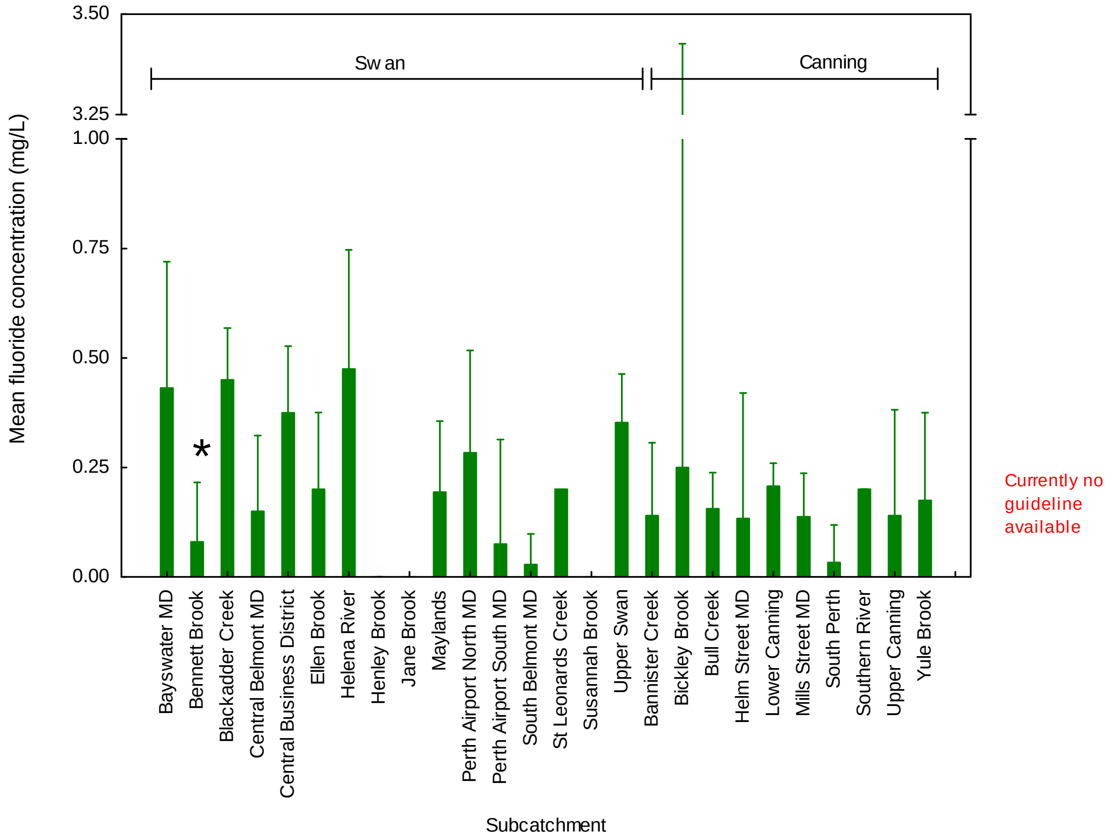

Figure 79 Mean fluoride concentration in surface waters across subcatchments draining into the Swan Canning system. Error bars represent + 95% confidence interval.

** The high fluoride concentration of 94 mg/L within Bennett Brook subcatchment (individual drain site, BBDSLORD) was omitted for graphical representation of the data.*

3.14 Nutrients

Summary

- High concentrations of nutrients, especially nitrogen and phosphorus usually determine the maximum biological productivity of an aquatic system. Natural sources of nutrients include weathering of rock, fixation of atmospheric nitrogen by plants, decomposition of biological material and leaching of soils. Anthropogenic nutrient sources include the application of fertilisers, use of domestic detergents and soaps and urban runoff.
- Total nitrogen and total phosphorus levels found in the subcatchments in this study generally reflect results found in previous studies in the Swan Canning system.
- The Upper Canning was the only subcatchment that exceeded the SCCP short-term total nitrogen guideline of 2.0 mg/L. However, 62% of subcatchments exceeded the long-term guideline of 1.0 mg/L.
- The BCMDBP1 (Bull Creek) site was identified as having high ammonium levels on all occasions sampled, averaging 4.2 mg/L.
- Ellen Brook, Mills St Main Drain and Lower Canning were the only subcatchments to exceed the SCCP short-term total phosphorus target of 0.2 mg/L, while 35% of the subcatchments exceeded the long-term target of 0.1 mg/L.
- 73% of subcatchments were above the guideline lower limit of 10 mg/L for dissolved organic carbon in surface water (UNESCC 1996) and 54% of subcatchments were above the guideline limit of 1% for percentage total organic carbon (ANZECC and ARMACANZ 2000).

Nutrient data are presented for subcatchments.

Nitrogen

Mean total nitrogen concentrations in surface water exceeded the SCCP short-term target of 2.0 mg/L (SRT 2004) in the Upper Canning subcatchment only. However, nitrogen concentrations in 50% of subcatchments exceeded the South West Lowland Rivers Freshwater Guideline of 1.2 mg/L and in approximately 62% of subcatchments exceeded the SCCP long-term target of 1.0 mg/L (Figure 80).

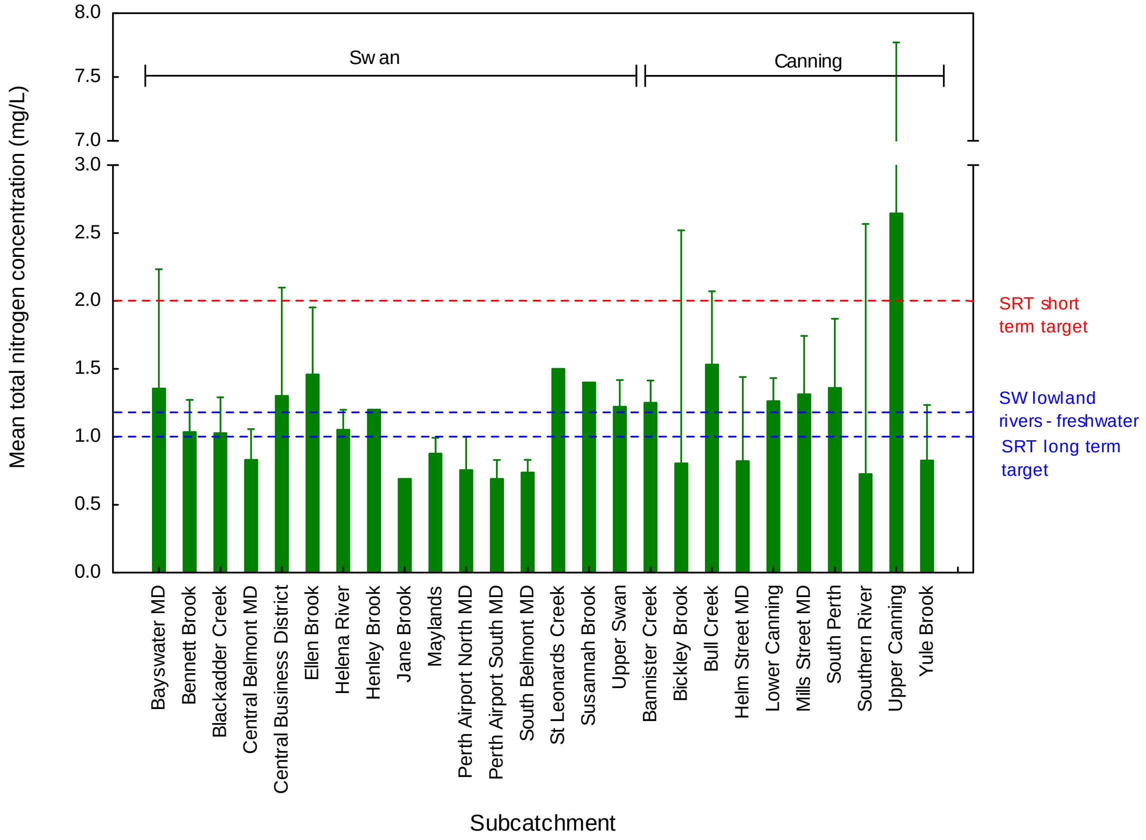

Figure 80 Mean total nitrogen concentration in surface waters across subcatchments draining into the Swan Canning system. Error bars represent + 95% confidence interval.

The major forms of nitrogen – dissolved organic nitrogen, total oxidised nitrogen (nitrate and nitrite), and ammonia/ammonium are also presented (Figure 81).

The South West Australia Lowland River Ecosystem Protection Freshwater Guideline for ammonium is 0.08 mg/L (ANZECC and ARMCANZ 2000). 42% of subcatchments exceeded this concentration. The highest ammonium levels were in the Bull Creek, Central Business District, South Perth and Bayswater Main Drain subcatchments. The BCMDBP1 (Bull Creek) site was identified as having exceptionally high ammonium levels on all occasions sampled, averaging 4.2 mg/L. The MBMDOUTW (Central Business District) site was another site that consistently recorded values significantly in excess of the guidelines, averaging 0.8 mg/L.

The South West Australia Lowland River Ecosystem Protection Freshwater Guideline for total oxidised nitrogen is 0.15 mg/L. 69% of subcatchments exceeded this level. The highest levels were reported for the Upper Canning and Susannah Brook subcatchments. The highest total oxidised nitrogen level recorded was 5.1 mg/L at WPMDO (Upper Canning) in August. LACDD

(Lower Canning) and MLMDOUT (Maylands) had the next highest total oxidised nitrogen levels of any drains with values above 0.8 mg/L on one or more occasion.

There are currently no guideline levels available for dissolved organic nitrogen. Highest levels were recorded in the Upper Canning and Ellen Brook subcatchments. The highest dissolved organic nitrogen level recorded was 3.9 mg/L at WPMDO (Upper Canning) in August. BWDESOUT (Bayswater Main Drain), EBN18 and EBN20 (Ellen Brook), and MENEDGCBOUT (Lower Canning) all had dissolved organic nitrogen levels above 1.5 mg/L on one or more occasion.

The proportions of the different forms of nitrogen varied across the subcatchments. Dissolved organic nitrogen (for example, urea) was the dominant form of nitrogen in most subcatchments. However, the Central Business District, and Bull Creek subcatchments had higher proportions of ammonium. Jane Brook, Susannah Brook and Upper Canning had higher proportions of total oxidised nitrogen. Particulate organic nitrogen was not measured but can be estimated by subtracting the sum of the three measured forms of dissolved nitrogen from the total nitrogen concentration. Particulate organic nitrogen (for example, phytoplankton) appeared to be a minor component of the total nitrogen level making up 17% of the total nitrogen level across all subcatchments.

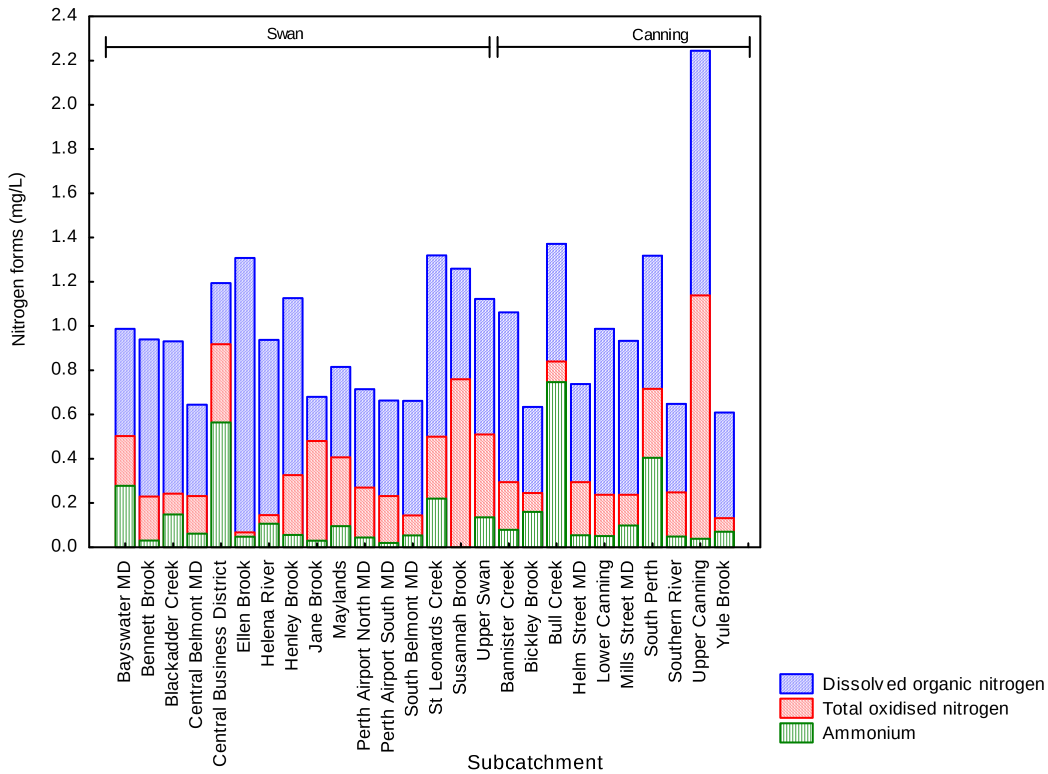

Figure 81 Proportion of the different forms of nitrogen in surface waters across subcatchments draining into the Swan Canning system

Total nitrogen was also measured in the sediment in February, May and November. There are currently no guidelines available for total nitrogen in sediment but as a general guide levels above 500 mg/kg should be further investigated (UNESCC 1996). Bennett Brook, Central Belmont Main Drain and Yule Brook had levels above this concentration. Highest values recorded were 19 000 mg/kg at YBMD25 (Yule Brook) and 13 000 mg/kg at BBDSLORD (Bennett Brook).

There appeared to be no relationships between total nitrogen concentrations in the sediment and surface water on a subcatchment scale.

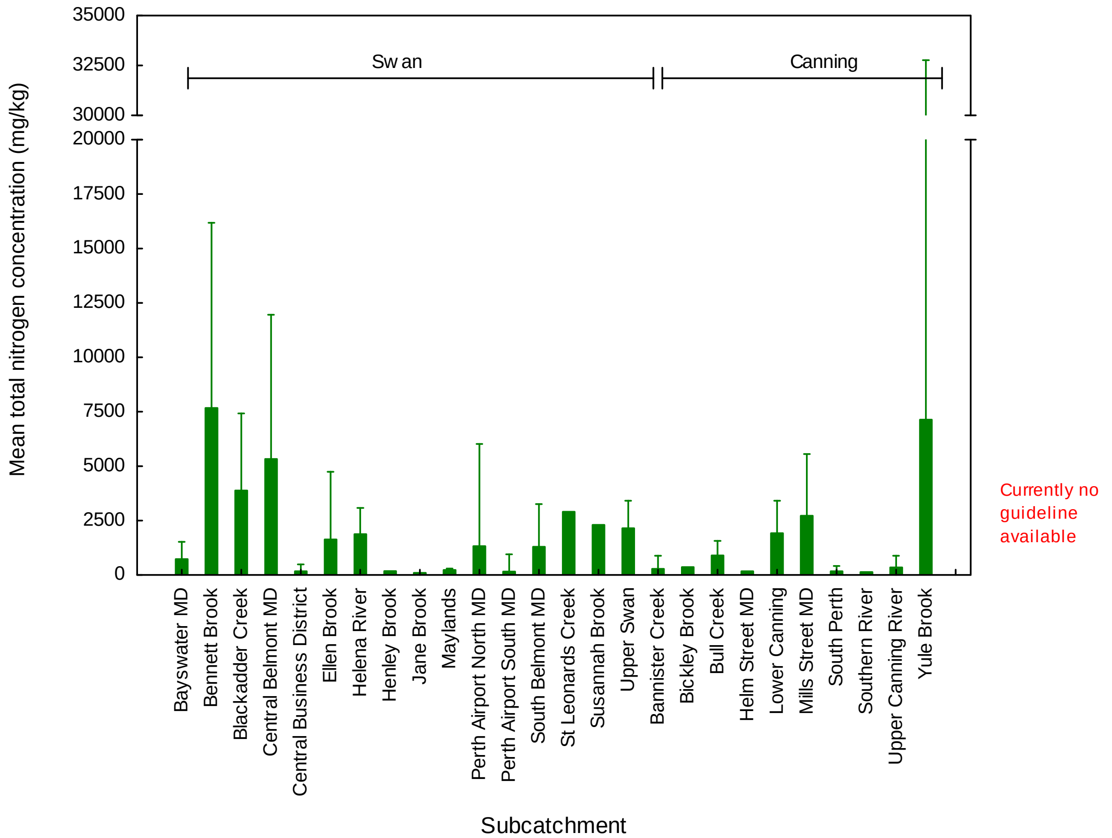

Figure 82 Mean total nitrogen concentration in sediments across subcatchments draining into the Swan Canning system. Error bars represent + 95% confidence interval.

Phosphorus

Mean total phosphorus concentrations in surface waters are presented in Figure 83. Mean total phosphorus concentrations exceeded the SCCP short-term target of 0.2 mg/L (SRT 2004) in Ellen Brook, Mills Street Main Drain, and Lower Canning subcatchments Figure 83). 35% of the subcatchments exceeded the SCCP long-term target of 0.1 mg/L and half the subcatchments exceeded the South West Australia Lowland Rivers Freshwater Guideline of 0.065 mg/L.

Higher than average total phosphorus concentrations were found at several sites in February including concentrations of 0.75 mg/L at LAMDPPCBO (Lower Canning subcatchment), 0.56 mg/L at MSMILCBOUT (Mills Street Main Drain subcatchment), 0.55 mg/L at EBN13 (Ellen Brook subcatchment), 0.53mg/L at EBN18 (Ellen Brook), and 0.52 mg/L at CSMDREID (Upper Swan subcatchment). The highest total phosphorus concentration recorded was 1.2 mg/L at TGDSDPOUT (Lower Canning subcatchment) in May.

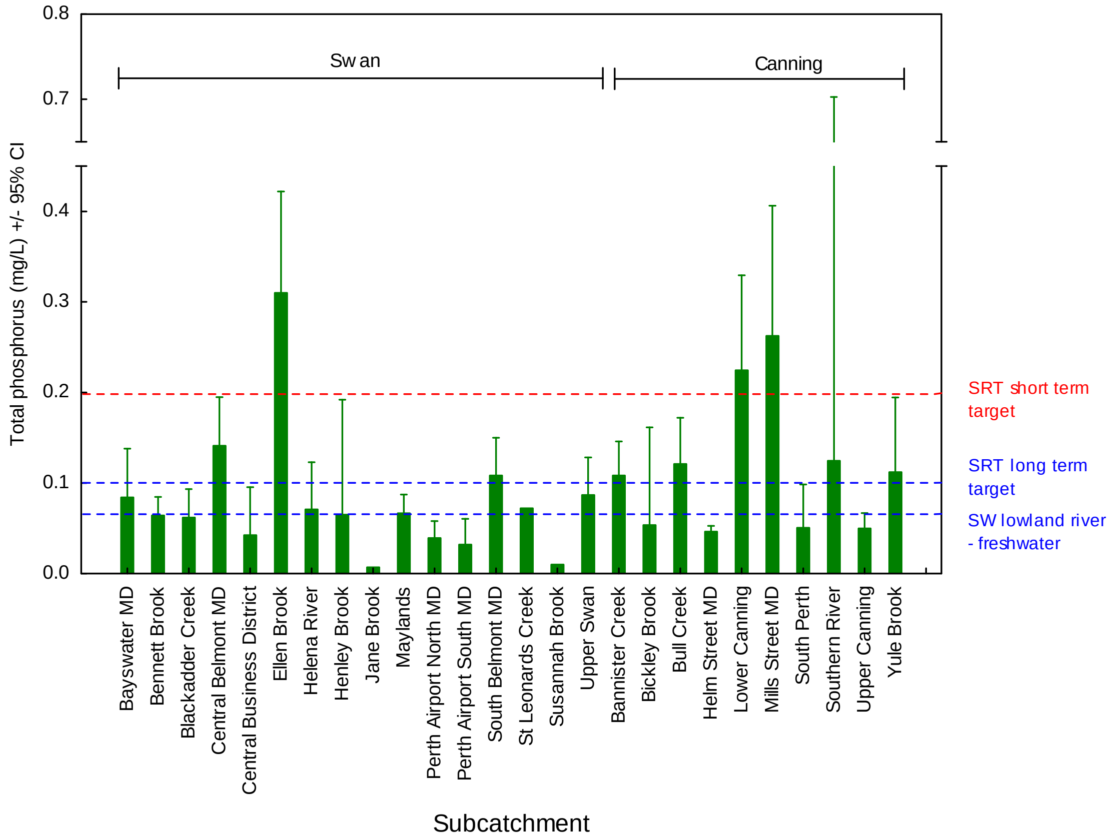

Figure 83 Mean total phosphorus concentration in surface waters across subcatchments draining into the Swan Canning system. Error bars represent + 95% confidence interval.

Mean filterable reactive phosphorus (soluble phosphorus) concentrations across subcatchments are presented in Figure 84. Particulate phosphorus was not measured but can be estimated by subtracting the filterable reactive phosphorus concentration from the total phosphorus concentration. The particulate phosphorus component made up 61% of the total phosphorus concentration across all subcatchments.

The South West Lowland River Ecosystem Protection Freshwater Guideline for filterable reactive phosphorus is 0.04 mg/L (ANZECC and ARMCANZ 2000). Filterable reactive phosphorus concentrations in 27% of subcatchments exceeded this level. Ellen Brook and Mills Street Main Drain subcatchments exhibited the highest concentrations.

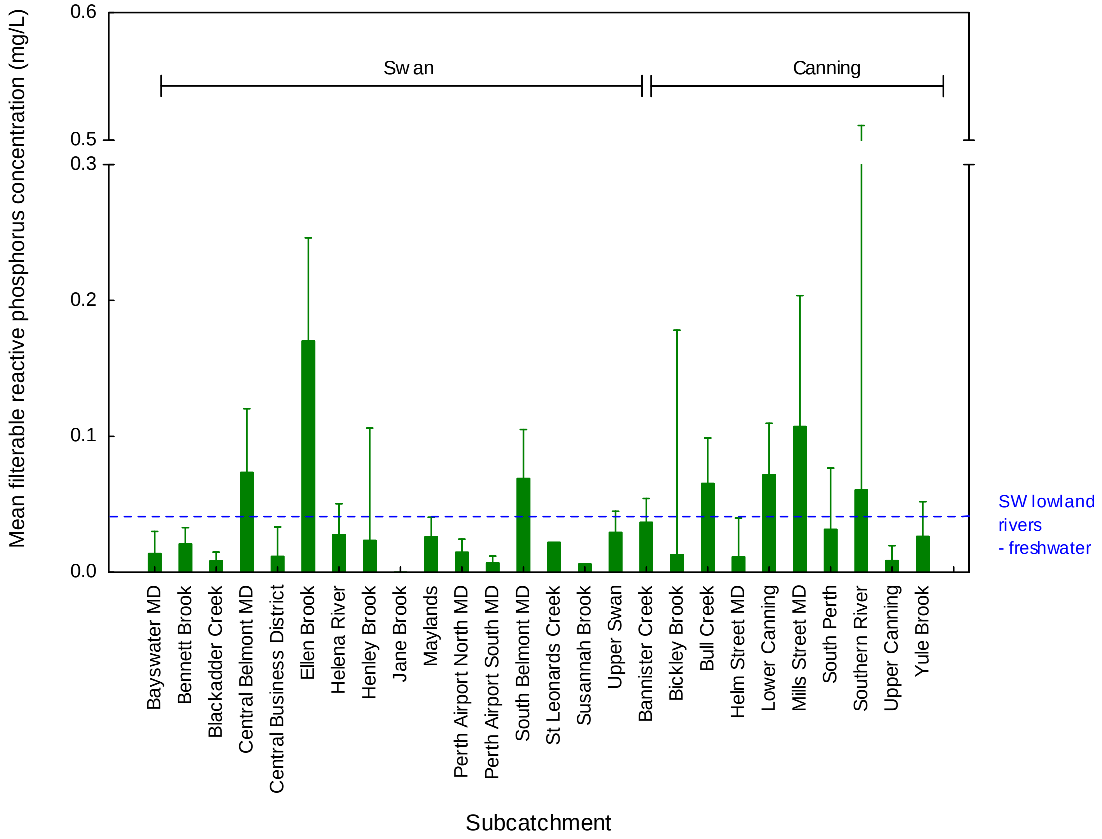

Figure 84 Mean filterable reactive phosphorus concentration in surface waters across subcatchments draining into the Swan Canning system. Error bars represent + 95% confidence interval.

Mean total phosphorus concentrations in sediments are presented in Figure 85 (data from February, May and November only). There are currently no guidelines available for total phosphorus in sediment but as a general guide, concentrations above 100 to 150 mg/kg should be further investigated (UNESCC 1996). Mean total phosphorus in sediments at approximately 54% of subcatchments exceeded this value.

Central Belmont Main Drain, Bennett Brook and Yule Brook subcatchments had the highest mean concentrations of total phosphorus in the sediment. These are the same three subcatchments that had the highest total nitrogen concentrations in the sediment.

There were no relationships apparent between total phosphorus concentrations in the sediment and surface water on a subcatchment scale.

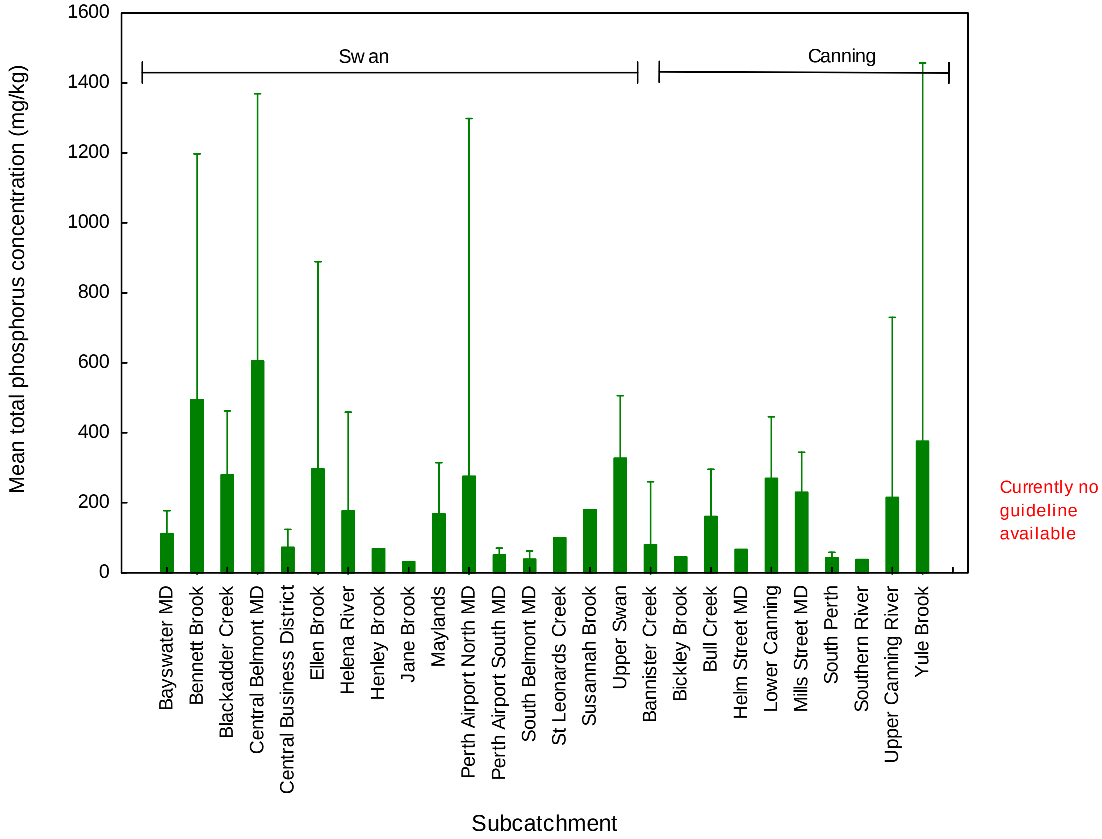

Figure 85 Mean total phosphorus concentration in sediments across subcatchments draining into the Swan Canning system. Error bars represent + 95% confidence interval.

Carbon

Mean dissolved organic carbon concentrations in surface waters are presented in Figure 86. There is currently no guideline available for dissolved organic carbon in surface water but as a general guide, concentrations from 10 to 100 mg/L should be further investigated (UNESCC 1996). Dissolved organic carbon in 73% of subcatchments exceeded 10 mg/L.

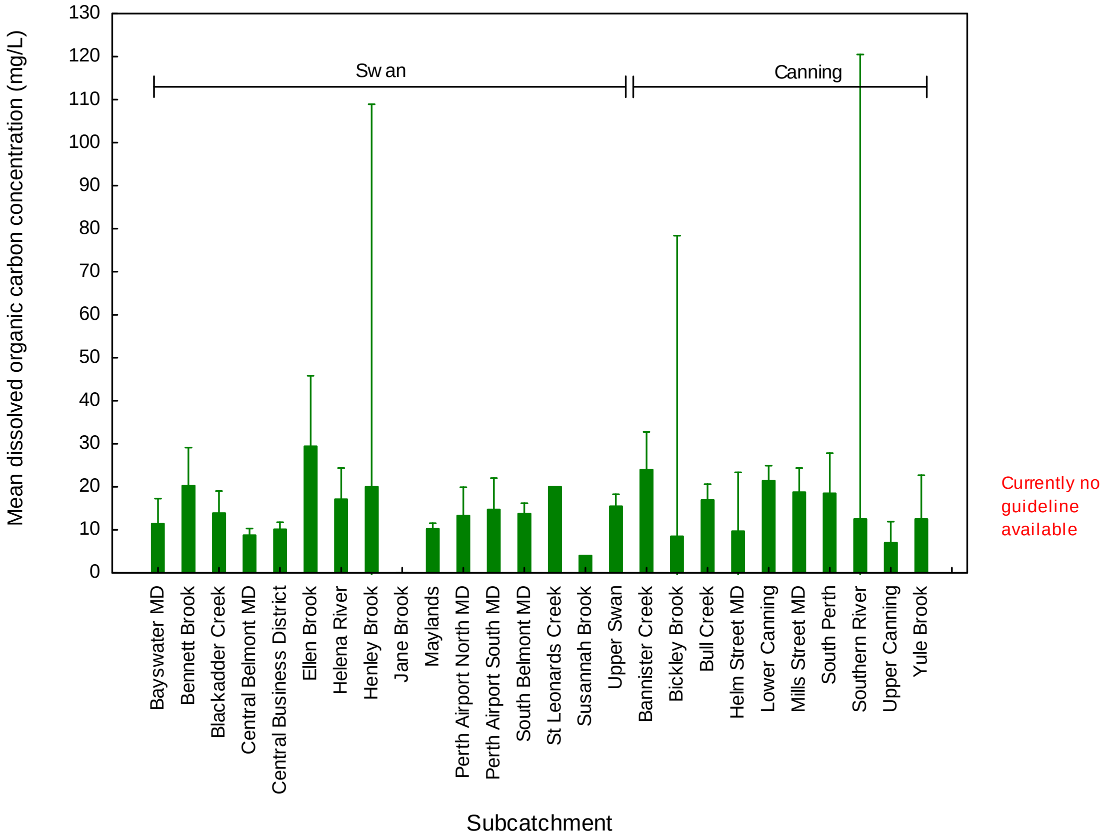

Figure 86 Mean dissolved organic carbon concentration in surface waters across subcatchments draining into the Swan Canning system. Error bars represent + 95% confidence interval.

Mean total organic carbon in sediments are presented in Figure 87. There are currently no guidelines available for total organic carbon concentration in sediment. However, when total organic carbon as a percentage is considered, values above 1% may be indicative of a potentially affected system (ISQG Low: ANZECC and ARMCANZ 2000). 54% of sites had greater than 1% total organic carbon. Bennett Brook, Central Belmont Main Drain and Susannah Brook subcatchments had the highest average total organic carbon concentrations.

Total organic carbon greater than 10% was recorded at three individual drain sites on one or more occasion. These drains were BBDSLORD (Bennett Brook) in August and November, CBCPO (Central Belmont Main Drain) in November, and SRMDO (Upper Swan) in February.

There was no relationship apparent between dissolved organic carbon in the surface water and total organic carbon in the sediment.

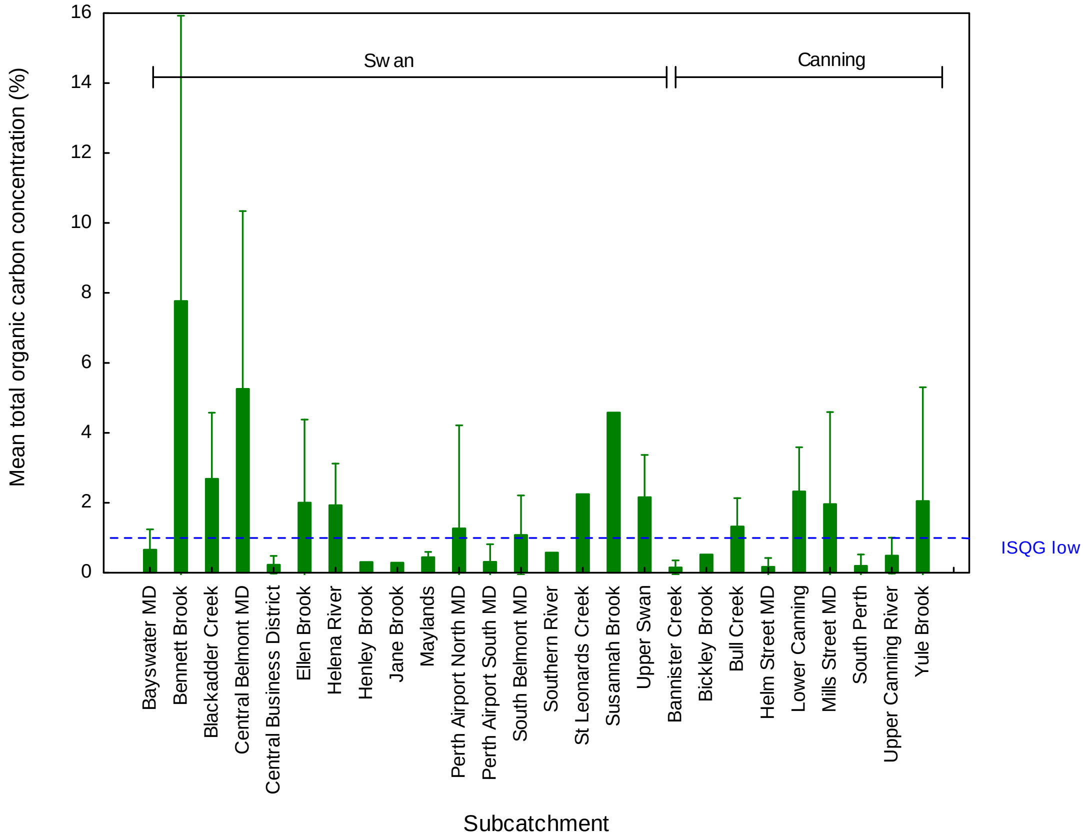

Figure 87 Mean total organic carbon (as %) in sediments across subcatchments draining into the Swan Canning system. Error bars represent + 95% confidence interval.

4 Discussion

In many cases the data presented were highly variable as demonstrated by the broad 95% confidence intervals. This is not uncommon in environmental investigations of this nature and was reported in an earlier study assessing the water quality in Bayswater Main Drain (DOE 2003b). Such high variability is particularly common in studies where grab samples have been taken as they represent merely a snapshot in time. Additionally, this study was a surveillance or baseline investigation to obtain information from as wide an area and as many drains as possible within the Swan Canning system. As such, individual drain sites generally only had a maximum of four sampling events.

Where there was not an obvious seasonal pattern (or differences in concentrations of contaminants detected between sampling periods), individual drain sites were pooled into subcatchments. In this way, subcatchments were prioritised for potential future remediation efforts or further investigation.

With regard to the use of guidelines and trigger values in the current study, it should be acknowledged that guidelines do not currently exist for stormwater and associated sediments. Generally, the guidelines applied here were conservative guidelines relating to ecosystem health or recreational use, because it is recognised that although samples were taken from a series of drains and associated waterways, these all drain into the ecologically sensitive Swan Canning system. In addition, some of the sites are known recreational areas. Hence the use of guidelines in the current study was to provide a general frame of reference as to the state of water and sediment quality at specific areas within the drainage system. It is intended that in cases where measured values exceed the referenced guidelines, this should be interpreted as an indication that further consideration should be given to the situation. For example, by way of targeted impact studies in the downstream receiving environment.

Loads were not measured as part of this study but are a key component for management of the subcatchments. While contaminant concentrations are high in some drains, the environmental impact may be relatively small if the volume of water discharged from the drain to the receiving environment is small. The Avon River provides approximately 80% of the flow into the Swan River (SRT 2000a) but was not investigated in the current study. Flows from Ellen Brook provide approximately 8% of the average annual discharge, Bayswater Main Drain provides approximately 3%, Helena River and Bennett Brook each provide approximately 2%; and the other drains each provide less than 2% of the flow (SRT 2000a). In the Canning River, approximately 30% of the discharge flows from the Southern River subcatchment, 19% from Yule Brook, 13% from Bannister Creek and 7% is provided by Bickley Brook and Mills Street Main Drain (SRT 2000a). Therefore, waterways such as Ellen Brook and Southern River should not necessarily be disregarded as priority subcatchments if concentrations of contaminants are low because as a consequence of the volume of water they transport, the net load of contaminants arriving in the Swan Canning system may ultimately be of concern.

A discussion follows for each group of parameters investigated.

4.1 Physical data

The Perth Metropolitan area experienced its driest year on record in 2006 (BOM 2006). As is typically the case, the majority of rain and subsequent flow into the river during 2006 occurred in the winter months, in this case between June and October. Rainfall events during summer and early autumn were limited and sporadic.

Significant rainfall events occurred late in the February sampling period and throughout the August sampling period. The May and November sampling periods were less influenced by rainfall.

First rains typically carry a flush of contaminants and suspended solids that have built up on roads and other hard surfaces over time (Ellen Brockman Integrated Catchment Group 2005). As the drains are very responsive to rainfall events, periods of heavy rainfall generally increase the loads of contaminants entering the receiving waterbody. However, once the first flush has passed through, rainfall may then have a diluting effect on contaminants within the system. Many of the drains also intercept the watertable and hence their base flows are influenced by groundwater inputs. Those waterways that do not intercept the watertable tend to dry out in summer and include subcatchments such as Ellen Brook and Helena River.

The measurement of total suspended solids includes silt, phytoplankton, and organic matter (Ellen Brockman Integrated Catchment Group 2005). A high total suspended solids measurement is typically associated with seasonal rainfall runoff (ANZECC and ARMCANZ 2000). This was found to be true in the case of the three highest individual total suspended solids readings that were taken in the Ellen Brook, Henley Brook and Mills Street Main Drain subcatchments during rainfall events. No sites were consistently high for total suspended solids in all sampling periods suggesting that total suspended solids is dependent on the prevailing environmental conditions and recent disturbance of soils.

Total suspended solids may be an indication of erosion and can result in increased deposition of material to the substrate that can smother faunal communities (Wood 2004). The subcatchments with the highest total suspended solids concentrations were typically the northern subcatchments on the Swan River where there is significant agricultural land use.

Contaminants such as metals, organic compounds and phosphates commonly bind to sediment and can be transported along with the suspended sediment. Once in waterways, contaminants bound to suspended sediment may be transported directly to the river, drop out into the drain sediment, decompose, volatilise, or in the case of nutrients be taken up by aquatic plants and algae (SRT 2003c).

Temperature plays an important role in the speed at which chemical reactions occur in waterways and also influences the solubility of chemicals in water. It can also affect the physiological rates of biological activity in the environment (ANZECC and ARMCANZ 2000). For example, algal blooms in the Swan Canning system are often associated with higher summer temperatures (SRT 2003c). Results showed that higher drain temperatures were associated with the hotter summer and early autumn months in the Swan Canning system. High or low water temperatures in the waterways may also be linked to human activity such as industrial wastewater discharges. However, there was no clear evidence of this from the data available in the current study.

The electrical conductivity of aqueous solutions is dependent upon the ion concentration of the solution, and hence the salt content of the water. Sodium chloride is the main contributor to water salinity but other ions present may include calcium and magnesium salts (Degens 2000). The electrical conductivity is strongly influenced by geology and can fluctuate naturally (Degens 2000). It may also be abnormally raised by human activity such as vegetation clearing and overuse of fertilisers. Rainfall will tend to reduce conductivity levels.

Electrical conductivity was greater than the aquatic ecosystem upper limit of 0.3 mS/cm (ANZECC and ARMCANZ 2000) at all except two individual drain sites on all sampling occasions. Electrical conductivity also exceeded 55 mS/cm (an indicator of saline waters) at 12 individual drain sites on one or more occasion and suggests that the sites are influenced by estuarine water mixing. All 12 sites are characteristically located where the drain outlet meets the river. Electrical conductivity data at these particular sites should be treated with caution because they will not necessarily provide a true reflection of the subcatchment condition, but may instead reflect local estuarine interference.

Dissolved oxygen levels in waterways are critical to the health of aquatic ecosystems. Oxygen is consumed by organisms during respiration and is important in the decomposition of plant and animal waste (oxidation of organic matter) by micro-organisms such as bacteria (Degens 2000). The primary sources of dissolved oxygen in water are dissolution from the surrounding air and photosynthesis by aquatic plants and algae (Degens 2000).

Dissolved oxygen levels may be lowered or elevated as a consequence of pollution events. For instance fertiliser leaching may result in algal blooms that can initially raise dissolved oxygen levels as the algae grow and later reduce the levels as they die off and decompose (SRT 2003c). Temperature, atmospheric pressure and salt concentration all affect the solubility of oxygen in water (Degens 2000).

The dissolved oxygen levels at individual drain sites were highly variable, ranging from approximately 3% in Bannister Creek in February to approximately 180% in Bull Creek in November. When data were averaged across subcatchments, less than 20% of the subcatchments had dissolved oxygen levels within the recommended range of 80% to 120% (South West Lowland Rivers Freshwater Guidelines – ANZECC and ARMCANZ 2000). Dissolved oxygen was below the recommended range in all other subcatchments.

Biological oxygen demand, a measure of the rate of uptake of oxygen by micro-organisms in a sample of water at a fixed temperature over a given period of time, was measured in this study (ANZECC and ARMCANZ 2000). Biological oxygen demand is a measure of the concentration of biodegradable organic matter present in the water. It can be used to infer the general quality of the water and its degree of pollution by biodegradable organic matter.

Only fifteen sites had biological oxygen demand levels above the detection limit of 5 mg/L on one or more occasion (ANZECC and ARMCANZ 2000). The generally low biological oxygen demand levels encountered in the drains suggest that the overall low dissolved oxygen levels in the drains are probably a consequence of poor dissolution from the atmosphere and limited plant and algal photosynthetic activity in the drains. It may indicate that eutrophication and decomposition of organic matter is not a major factor affecting dissolved oxygen levels in most of the drains. However, further investigation is necessary to determine this.

4.2 Microbial water quality

Faecal coliforms and enterococci are bacterial organisms that provide an indication of faecal contamination. Numbers of these organisms are used to determine the suitability of a waterbody for recreational purposes (ANZECC and ARMCANZ 2000). They were included in the current study because it has been acknowledged that areas of the drainage system are used for recreational activity (such as the Helena River drain site, HRJSB). In addition, all the sites drain into the Swan Canning system, which is used extensively for activities such as boating, fishing, wading and swimming.

High levels of these bacteria indicate an increased risk of human illness when in contact with the water containing them. Some potential illnesses due to pathogen contaminated recreational waters include ear, eye, nose, throat and skin diseases as well as gastrointestinal disorders (ANZECC and ARMCANZ 2000).

In the current study, the numbers of these organisms in all subcatchments were higher than the Primary Recreational Guideline value. This indicates that people coming into direct contact with these waters (such as through swimming and wading) may suffer the symptoms described. In addition, Secondary Recreational Guidelines were exceeded in the Blackadder Creek, Central Business District, Helena River, Henley Brook, Maylands, Perth Airport North, Perth Airport South, Bannister Creek, Bickley Brook, Lower Canning River, Mills Street Main Drain and Upper Canning River subcatchments. This indicates that even secondary contact in these areas (such as through kayaking) may pose a risk to human health.

Both faecal coliforms and enterococci can originate from human and other animal faeces. Therefore, the high levels of bacteria detected at these sites may be attributable to a variety of sources including septic tanks (for example, Bayswater Main Drain, DOE 2003a), dog faeces washed in from adjacent recreational areas, faecal matter from piggeries, poultry farms, dairies and stock holding yards in addition to faecal pollution from other animals living in the vicinity.

High faecal matter is often reported in conjunction with high levels of ammonia/ammonium in the case of sewage leaks into a system (UPRCT 2001). Although Bull Creek had elevated ammonium levels at site BCMDBPI on all sampling occasions, it is unlikely to be linked to a sewer leak because, at this particular drain site (BCMDBPI) within the Bull Creek subcatchment, enterococci numbers were relatively low throughout the period and faecal coliform levels were also reasonably low with a peak only in November.

This study provides baseline information that indicates faecal contamination is present at levels that warrant further investigation across all subcatchments examined (based on the guidelines applied). However other factors such as flushing rates and retention times should also be taken into account for these drainage systems in assessing potential impact to human health. Comparisons with reference locations would also be beneficial in order to determine background levels of these bacteria in the system.

In order to pinpoint sources of this faecal contamination, a targeted approach is recommended. It would be advisable to focus sampling efforts on those sites that are known to be used for recreational purposes and those drains that are located where the drain outlet meets the river such as HRJSB (Helena River subcatchment) and MBMDOUTE (Central Business District subcatchment). These are areas where there is an increased likelihood for human contact. Based on the data available at this time it is recommended that recreational contact with drainage waters be avoided.

4.3 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) in the current study were typically only detected in the sediments. This was most likely because PAHs have low solubility in water and are rapidly bound to suspended organic and inorganic particulate matter, which is deposited in the bottom sediments (Edwards 2002). Drain systems typically have high particulate matter which is often present as a result of road and vehicle wear, atmospheric deposition, erosion, and construction operations (Davies et al. 2000).

PAHs comprise a group of over one hundred different chemicals. The fifteen PAHs analysed for in the current investigation are among the 17 PAHs that were identified as being of greatest concern with regard to potential exposure and adverse human health (DOH 2004). They are described as carcinogens to humans (Grimmer 1983) and are toxic to aquatic life (Connel 2000). These individual PAHs consistently exceeded the Low Trigger Value for ecosystem health at sites sampled within the Helena River and Central Business District subcatchments and on the one occasion that Perth Airport South was sampled (all drain into the Swan River). This indicates that adverse effects to ecosystem health may occur at these sites as a result of PAH contamination.

High concentrations of PAHs at these sites may be due to road runoff containing fuel and oil (Davies et al. 2000), or in the case of the sampling sites in the Central Business District subcatchment, the incomplete burning of fuel used by boats in the vicinity of the Barrack Street Jetty may be a contributing factor. PAHs have been shown to be emitted from the combustion engines of vessels (Dane et al. 2006) and an incomplete combustion process can lead to PAH contamination of water via the exhaust system (Mosisch and Arthington 2001).

The PAHs in the current study are divided into two groups: low molecular weight PAHs and high molecular weight PAHs. In aquatic systems, toxicity of these compounds has been shown to increase with increased molecular weight (Eisler 1987) and degradation time of PAHs in the environment is known to decrease with increasing molecular weight (DEWR 2004).

Of the low molecular weight PAHs, phenanthrene was consistently present in the highest concentrations, reaching concentrations of 1.1 mg/kg (normalised to 1% organic carbon), which is almost five times the Low Trigger Value for Ecosystem Protection. Phenanthrene has been described as being endocrine disrupting, mutagenic, carcinogenic and teratogenic (Fetzer 2000). It has been shown to interfere with the hormonal system, increase the frequency of mutation, induce cancer and cause defects to developing embryos of exposed organisms. As in the case for phenanthrene, where other PAHs were detected (both low and high molecular weight) the Low Trigger Value for ecosystem health was exceeded (where available) for almost every PAH investigated.

Of the high molecular weight PAHs, fluoranthene, pyrene and benzo(b)&(k)flouranthene were consistently present in the highest concentrations across the Helena River, Perth Airport South and Central Business District subcatchments). It should be noted that dibenzo(a,h)anthracene also exceeded the High Trigger Value for ecosystem health on one occasion for the Perth Airport South subcatchment. The High Trigger Value is intended to represent a concentration above which, adverse biological effects are expected to occur more frequently (Simpson et al. 2005; ANZECC and ARMCANZ 2000).

Sediments of waterbodies such as the Swan Canning system provide a substrate for a wide range of both microscopic and macroscopic organisms, many of which have been shown to ingest organic material from the sediments, thereby mobilising PAH compounds into the food chain (Mosisch and Arthington 2001). Additionally, PAHs have the potential for bioaccumulation and have been recorded in the tissues of plankton, vascular plants, molluscs and fish (Neff 1979). The ensuing toxicity to higher level organisms as a result of bioaccumulation is thought to constitute a significant ecological risk (Mosisch and Arthington 2001).

A review of the occurrence and effects of PAHs on Australia's marine environment (Connel 2000) describes a range of detrimental physiological responses resulting in histopathological effects such as abnormal growth, occurrence of tumours and the potential for deleterious effects on larval stages of marine species. It is further noted that such responses have not had extensive evaluation in Australian waters (Connel 2000). However, studies conducted in Canada and the United States have demonstrated inhibited reproduction, delayed emergence, sediment avoidance and mortality in benthic invertebrates (Fabacher et al. 1991). In addition, fish have exhibited fin erosion, liver abnormalities, cataracts, and immune system impairments leading to increased susceptibility to disease (O'Conner and Huggett 1988; Weeks and Warinner 1986; 1984).

The evidence provided here indicates that PAH contamination at the sites assessed within the Helena River, Perth Airport South and Central Business District subcatchments warrants further investigation. It is recommended that this includes an assessment of the ecosystem impact of such chemicals at these sites using bioaccumulation and ecotoxicological approaches.

4.4 Petroleum hydrocarbons

The total petroleum hydrocarbon (TPH) group comprises a broad family of several hundred chemical compounds that originate from crude oil. None of the TPHs tested for in the current study (including the BTEX group: benzene, toluene, ethylbenzene and xylenes) were detected in surface water samples. Similarly, TPHs were only detected in very few surface water samples in earlier drain studies in the Swan Canning system (SRT 2003a and 2003b). This may indicate that chronic hydrocarbon contamination does not occur at these sites. However there may be frequent acute contamination incidences associated with first flush and storm runoff events, which may not have necessarily been detected in the current study.

The BTEX petroleum hydrocarbons are relatively volatile and are a subset of the C6 – C9 TPHs. These were also not detected in any of the sediment samples in the current study, perhaps because of their volatility. However, when sediments were analysed for TPHs of chain length C6 – C9 they were detected in a very small proportion of samples. Similarly, only a few sediment samples showed a presence of the longer chain TPHs: C10 – C14, C15 – C28 and C29 – C36 (approximately 13% of all sediment samples contained any form of detectable petroleum hydrocarbons). As such, there was insufficient data to determine patterns among sites or seasons. Again, a possible reason for this is that this study was not targeting first flush and storm runoff events.

As far as potential risk to ecosystem health is concerned, in general petroluem hydrocarbons are not expected to significantly bioaccumulate under most conditions (Lansdell and McConnell 2003). However, the mechanisms of toxicity of petroleum hydrocarbons are not well documented (Lansdell and McConnell 2003). The data presented here suggest that contamination from oils and grease is low, which is contrary to expectation, especially in subcatchments that are dominated by industries with high fuel use (such as Perth Airport South and Perth Airport North). If further work were conducted to assess TPHs, an experimental design that targets first flush and storm runoff events would be recommended to increase the chance of detection before these compounds volatilise.

4.5 Polychlorinated biphenyls

Polychlorinated biphenyls (PCBs) were not detected in any of the surface water or sediment samples collected. However, the limit of reporting provided by the analytical laboratory was 0.1 µg/L and 0.1 mg/L respectively. The majority of the 95% Ecosystem Protection guidelines (ANZECC and ARMCANZ 2000) that exist for these compounds are lower (in some cases orders of magnitude lower) than the limit of reporting. Therefore non-detect data should be treated with caution and it should not be assumed that a non-detect value means that PCBs are not present in the environment at concentrations of environmental significance. PCBs are persistent organic pollutants and are considered to be ubiquitous in the environment, being reported in as remote locations as Svalbard in the Arctic (Norheim et al. 1992). They are reported to have caused a range of serious deleterious effects in aquatic organisms (USEPA 1983) so should not be dismissed from all further studies. However, should lower limits of reporting become available it is recommended that future studies incorporate these.

4.6 Organochlorine and organophosphorus pesticides

Like PAHs, organochlorine (OC) pesticides were typically only found in the sediments in the current study, with very few detections in water. This is because they are hydrophobic. That is they have a low solubility in water and are rapidly bound to suspended organic and inorganic particulate matter. These compounds generally resist degradation by chemical, physical or biological means. Like PCBs, they are extremely persistent and have half lives ranging from months to years and in some cases, even decades. Despite the fact that the importation, manufacture and use of OC pesticides has been phased out in Australia in recent years and completely banned in 2004 (Stockholm Convention), they are often still detected in soil because of their persistent nature (DEH 2004).

Furthermore, most OC pesticides are lipophillic, i.e. they are attracted to the fatty tissues of aquatic organisms and are bioaccumulated significantly in animals such as fish (DEWR 2004). Consequently, animals high up the food chain such as birds of prey and humans can accumulate higher levels of the pesticides than those lower down the food chain. OC pesticides are used to control pests. Therefore it is of no surprise that they are highly toxic to other, non-target organisms that are exposed to them. They can have serious short-term and long-term effects at low concentrations. In addition, non-lethal effects such as immune system and reproductive damage can also occur. They are known endocrine disruptors, having oestrogenic properties that are able to interfere with reproductive system function, inducing reproductive organ abnormalities and fertility problems (Ulrich et al. 2000; ATSDR 1994). Like PAHs, they are also carcinogenic, mutagenic and teratogenic (Fox 1995; MAFF 1981).

Given the wealth of toxicity information available, it is perhaps surprising that few guidelines exist for these compounds in sediments. Just six out of the 16 OC pesticides investigated in the current study have guidelines, and for each of these, the guideline levels were consistently exceeded. In fact, on most occasions that OC pesticides were detected, not only the low interim sediment quality guideline was exceeded but also the high guideline. It is important to note that for the current study, laboratory limits of reporting were higher than all Low Trigger Values available for sediments, suggesting that non-detect data should be treated with caution. It should not be assumed that where these compounds were not detected, they are not present. Like PAHs, OC pesticides are reported as being ubiquitous in the environment (Kanatharana et al. 1994).

Subcatchments of interest draining into the Swan River were Helena River, South Belmont Main Drain, Central Belmont Main Drain, Upper Swan, Blackadder Creek, Maylands and Bayswater Main Drain. Helena River had the highest number of individual OC pesticides detected and typically in the highest concentrations, exceeding both low and high guidelines on most occasions that they were detected. Subcatchments of interest draining into the Canning River were Mills Street Main Drain and Lower Canning.

The apparently higher occurrence of OC pesticides in those subcatchments draining into the Swan than the Canning may be at least partly attributable to the higher proportion of rural and agricultural areas in the Swan subcatchments. For example, it is known that the Upper Swan and the Helena River subcatchments support agricultural practices such as viticulture and citrus farming. Although the use of OC pesticides by the agriculture industry has been de-registered in Australia, recent studies have shown that orchards and old orchard sites and vineyards are often still contaminated with OC pesticides such as dieldrin, heptachlor and DDT, which break down comparatively slowly in the soil (DOAg 2005).

In addition to the agricultural industry, a major application of OC pesticides was in the protection of livestock, buildings and households from the damaging effects of insects (DEWR 2004) and these uses are also expected to have contributed to the environmental burdens that remain in the Swan Canning system.

Although, this study was not designed to assess temporal trends, it is noted that the exceptionally high levels of OC pesticides detected in the sediment at Helena River during the August sampling event may be related to rainfall. It had been raining fairly consistently over a few days in the Helena River subcatchment when this site was sampled. It is possible that the run-off from this fairly rural subcatchment carried high levels of OC pesticides with it. Further support for this theory is the fact that OC pesticides were detected in the surface water at this site during this sampling event. This was an unusual occurrence – OC pesticides only being detected in two surface water samples throughout the entire study.

Finally, it is important to note that the laboratory reporting limits were relatively high (0.01 µg/L for surface water and 0.01 mg/kg for sediments), suggesting that non-detect data should be treated with caution, as OC pesticides are likely to be present at lower levels than were detected here. A study of Mills Street Main Drain as part of the SCCP (SRT 2003b) reported the OC pesticides, p,p-DDT and dieldrin at concentrations as low as 3 and 4 ng/L respectively in surface waters of the drain.

It is recommended that any further investigation of OC pesticides in the Swan Canning system include an assessment of the ecosystem impact of such chemicals at these sites using bioaccumulation and ecotoxicological approaches and incorporating lower limits of reporting for chemical analyses as these become available. In addition, an evaluation of catchment sources of OC pesticides may be beneficial.

Unlike OC pesticides, OP pesticides were not detected in any of the surface water or sediment samples collected. However, the limit of reporting was 0.1 µg/L and 0.1 mg/kg respectively and these compounds are known to cause significant environmental harm at concentrations orders of magnitudes lower, as reflected in the guidelines (ANZECC and ARMCANZ 2000). There are currently no sediment quality guidelines for OP pesticides. Therefore, as for OC pesticides it is recommended that non-detect data should be treated with caution and that any subsequent studies incorporate lower limits of reporting as these become available.

4.7 Herbicides

Herbicides are a group of compounds used to control or inhibit the growth of plant pests. Like the pesticides previously discussed, they can be harmful to both environmental and human health in trace concentrations.

Herbicides in the current study were only detected sporadically, which again, may be an artefact of the relatively high limits of reporting of the laboratory (0.1 µg/L in surface water and 0.1 mg/kg in sediments). Due to the sporadic nature of detections, herbicide data are presented at the level of individual drain, rather than being pooled to the level of subcatchment so as not to underestimate the concentrations of these compounds on occasions where they were detected.

Unlike the pesticides previously discussed, herbicides were more commonly detected in surface water than in sediments (although again the comparatively high limits of reporting, especially for sediments, should be taken into account when considering the validity of the non-detect data).

The herbicides that were detected were simazine (both in sediments and surface water), and atrazine, trifluralin and metolachlor (only present in surface water). Atrazine and simazine were the most frequently detected although concentrations were typically below the guidelines for 95% Ecosystem Protection (ANZECC and ARMCANZ 2000), except for simazine, which exceeded the guidelines on one occasion at site SRMDO in the Upper Swan subcatchment. This drain is adjacent to recreational parkland with maintained lawns and also the subcatchment is a rural area. The presence of simazine may be at least partly attributable to either land use. Additionally, metolachlor, although only detected on one occasion in the current study, exceeded the guideline for 95% ecosystem health in the surface water of drain, YBMD25 in the Yule Brook subcatchment, another site adjacent to a lawned recreational area.

Atrazine and simazine are common herbicide applications. Atrazine is the most commonly used herbicide in the world (Hayes et al. 2002). In many cases the two compounds are applied in combination (MAFF 1981). These compounds are used to control weeds in crops and orchards (Hayes et al. 2002; Cornell University 1998) and in viticulture (DOAg 2005). Non-agricultural uses of atrazine and simazine have included weed control on vacant lots, roadside verges, recreational parkland areas, golf fairways and turf. Atrazine, simazine and metolachlor are often used as a pre-emergent herbicide to control weeds before new seedlings emerge from the soil (Hines et al. 2001; Grimmett and Weiss 1967).

For atrazine and simazine, the guidelines are currently 13.0 and 3.2 µg/L respectively in water. There are no guidelines for these compounds in sediments. However, it should be noted that there is evidence in the scientific literature that these compounds can cause serious chronic effects at substantially lower levels than the current guidelines. For example, atrazine is a known endocrine disruptor (it interferes with the hormone function of organisms) and has been shown to induce hermaphroditism (a condition where characteristics of both sexes are displayed) in genetically male frogs at levels as low as 0.1 µg/L. It is thought that atrazine promoted the conversion of testosterone to oestrogen to bring about this effect (Hayes et al. 2002). The authors concluded that other amphibian species exposed to atrazine in the wild could also be at risk of impaired sexual development.

In addition to direct toxic effects such as the hermaphroditism described, the phytotoxicity of these compounds may also cause deleterious effects to aquatic life by killing aquatic plants and also by indirectly altering the water quality through removal of aquatic plants resulting in reductions in dissolved oxygen levels, as has been shown for atrazine (MAFF 1981).

Aside from its risk to aquatic health, atrazine is also considered to be mutagenic (can induce significant chromosomal damage) and cause reproductive defects in humans (Cox 2002). It is a known carcinogen (Cox 2001) as is simazine (Cornell University 1998).

Atrazine is persistent (half-life of 125 days in sandy soils – WHO 1990). It is not easily adsorbed to soil particles (which perhaps explains why it was not found in the sediment in the current study), rendering it highly mobile in some soils (US and Canadian International Joint Commission 1992). As a result it often causes contamination of surface and groundwaters (WHO 1990). In the United States for example, it has been found in the groundwater of all 36 river basins studied by the United States Geological Survey (Cox 2001), which estimated that persistence in deep lakes may exceed ten years.

Simazine is also moderately persistent with a half-life of up to 140 days. It binds to clay and organic matter, especially in drying conditions like those experienced during the warmer seasons in Perth. There is little lateral movement in soil, but it can be washed along with soil particles in run-off water. Its low water solubility makes it less mobile than atrazine (DOAg 2001) and thus would more usually be found in sediments than surface water. Again, this indicates that the non-detects for this compound (with one exception) in sediments in the current study should be treated with caution due to the comparatively high laboratory limit of reporting.

There is an apparent peak in pesticide concentration (atrazine, simazine and metolachlor) during August. This is likely to be related to an intense application during the spring pre-emergence season as was observed in a United States study for metolachlor and atrazine (Hines et al. 2001).

It is less easy to prioritise specific subcatchments for herbicides than for some of the other contaminants already discussed because their occurrence was fairly sporadic across many subcatchments. However, guidelines were exceeded in the surface water of the Upper Swan and Yule Brook subcatchments (only one occasion in each), and Maylands was the only subcatchment where herbicides were detected in the sediments.

The results of the current study indicate that simazine, atrazine, trifluralin and metolachlor should be highlighted as herbicides of concern.

It is recommended that any further investigation of herbicides in the Swan Canning system includes an assessment of ecological impact using ecotoxicological approaches that incorporate chronic (long-term exposure at non-lethal levels) endpoints for the chemicals of concern. Bioaccumulation studies would not be necessary since these herbicides generally do not have a high potential to bioaccumulate.

It is also recommended that as lower limits of reporting become available, these be incorporated into further assessments of herbicides.

4.8 Anionic surfactants

Anionic surfactants enter the environment mainly through the discharge of aqueous wastes from household and industrial laundering and other cleansing operations. Industrial facilities that use detergents to clean machinery often discharge anionic surfactants directly into the water supply (USEPA 1983). These compounds are also commonly used in conjunction with other industrial, agricultural and household chemicals to improve the emulsifying, spreading, sticking or absorbing properties of liquids. For example, herbicides are commonly formulated or applied with surfactants to reduce the surface tension of water and allow for more effective movement of the herbicide through the cuticle of target weeds.

Anionic surfactants are measured in a water sample by means of the methylene blue active substances (MBAS) colorimetric method. This is a rapid procedure that allows any anionic surfactants within a sample to react with methylene blue to form a blue coloured complex that is extracted and measured (APHA 1998). Anionic refers to the negative charge that these surfactants have. Surfactants also come in nonionic and cationic form. Only anionic surfactants were measured in the current study.

All three types of surfactants have been shown to be toxic to aquatic life (Liwarska-Bizukojc et al. 2005, Ghirardini et al. 2000, Warne and Schifko 1999), although nonionic surfactants are typically more toxic (by orders of magnitude) than anionic surfactants (Liwarska-Bizukojc et al. 2005). For example, studies on an estuarine mollusc showed a breakdown product of a common nonionic surfactant to be both toxic and potentially endocrine disrupting (Nice 2005; Nice et al. 2003; 2001).

In the current study, MBAS were only detected at six drain sites within four subcatchments (Lower Canning, Upper Swan, Bull Creek and Blackadder Creek), with no single site having more than one detection over the four sampling periods. This would suggest that there is generally not a problem with anionic surfactants in the Swan Canning system. There is no guideline for Ecosystem Protection for these compounds. However, a guideline does currently exist for recreational use. This guideline value of 0.2 mg/L was met and exceeded at one site within each of the Blackadder Creek and Lower Canning subcatchments where the concentrations of MBAS were 0.3 and 0.2 mg/L respectively.

Since surfactants are commonly applied in conjunction with herbicides, potential links between herbicide detections and MBAS were examined. Four sites in the current study had detections of both herbicides and MBAS, but the sampling occasions corresponded only once (drain site LACDD in the Lower Canning subcatchment). Nonionic surfactants are more commonly applied with herbicides and these were not tested for in the current study.

It has been acknowledged that the standard MBAS assay suffers from salt interference in estuarine and marine waters due to the high concentration of chloride ions (George and White 1990). Although the water in the drains in the current study was generally fresh, it was shown that at particular drains there appeared to be saltwater mixing for at least some of the sampling period. This may have resulted in some interference with the results, yielding unreliable data from these sites.

It is recommended that should future MBAS analyses be conducted on samples from these sites that the modified method for MBAS for estuarine and marine waters be applied (George and White 1990). It is also recommended that future assessments of surfactants include the more harmful nonionic surfactants (Liwarska-Bizukojc et al. 2005) and cationic surfactants.

4.9 Metals

Metals occur naturally and can be either essential or non-essential. Essential metals are necessary components in metabolic function of organisms. Although some non-essential metals may have benefits, they are not necessary for an organism's survival (Kapustka et al. 2004). Essential metals and non-essential metals vary between flora and fauna. For plants, essential metals (that were included in this study) are copper, manganese, molybdenum, nickel and zinc, whilst non-essential metals include cobalt. For animals, chromium, copper, cobalt, iron, manganese, molybdenum, nickel, selenium and zinc are essential metals. For both plants and animals, arsenic, cadmium, lead and mercury are considered to be both non-essential and non-beneficial. Excess concentrations of any metal, whether essential or non-essential, can result in metal toxicity (Kapustka et al. 2004), which can manifest itself in a variety of endpoints from deformed larval development to mortality (as seen in oysters exposed to cadmium) (Robert and His 1985).

Of the suite of 14 metals measured in the current study, all were detected in both sediment and surface water samples with the exception of mercury, which was only detected in sediments. For many metals, guidelines for 95% ecosystem health (ANZECC and ARMCANZ 2000) were exceeded. The surface water concentrations presented here are for total metals. That is, the water samples were not filtered to remove metals bound to suspended sediments. This means that the metal concentration in surface waters at each site is considered to be the maximum potential metal concentration available. This type of metal analysis is appropriate for a baseline or surveillance type of study such as this. However, for subsequent targeted studies (based on locations with high total metal concentrations), it is recommended that only bioavailable metals be assessed. From this information it is easier to assess risk to aquatic health.

There was a high variability in metal concentration in sediments between sites (within subcatchments). In contrast to this, in surface waters the metal concentrations were more consistent between sites within a subcatchment, possibly as a consequence of transport occurring between sites. The high degree of spatial variability in metal concentrations within sediments may be due to variations in factors that affect metal binding such as sediment texture, organic coatings, sulphide content, oxidation/reduction reactions, and physical conditions such as acidity and salinity (Luoma et al. 1997).

Metals can be contributed to stormwater from anthropogenic sources such as vehicles, housing materials and atmospheric pollutants. Road runoff can contain metals in fuel, gas and lubricating oil products (cadmium, copper, lead and zinc), tyre and brake wear (cadmium, chromium, copper, lead and zinc) and engine wear (chromium, iron and copper) (Davies et al. 2000). The concentration of metal pollutants in road runoff has been shown in the past not to be correlated with traffic volume, but instead with areas of rapid deceleration (traffic lights, corners and exit lanes) where there is an increased incidence of tyre and brake wear. In addition, slow moving and idling vehicles emit combustion products at a higher rate than faster travelling vehicles as a result of decreased combustion efficiency (Davies et al. 2000). Other factors that have been found to influence road runoff contaminants are road type, vehicle type and verge conditions (Davies et al. 2000).

Roof runoff has also been identified as a primary contributor of metals in stormwater. Past studies have identified primarily zinc (Pitt and Lalor 2000) but also contaminants such as copper (Chang et al 2004), lead (Gromaire-Mertz et al. 1999), cadmium and chromium (Pitt and Lalor 2000) as key contaminants in runoff from roofing materials. The concentration and type of metals in the runoff has been found to vary greatly between roof types (Chang et al. 2004, Gromaire-Mertz et al. 1999). In particular, galvanised roofs are considered to be major contributors of zinc to stormwater runoff (Pitt and Lalor 2000). Likewise, arsenic may be present in runoff as a result of being used as a timber treatment, and lead through its use in building paints (DOE 2005). Additionally, mercury may be present in sediments as a result of the burning of biomatter during bushfires (Packham et al. 2007) and aluminium and iron may be at least partly attributable to the underlying geology of the region. Further pathways of metal pollutants to stormwater drains are from atmospheric emissions from oil and coal combustion, mining and smelting activities, waste incineration, phosphate fertilisers, combustion of wood products and cement production (for example, Sorme et al. 2001).

On a local scale, there are many small industries in the subcatchments such as metal plating and auto-repair shops that may be contributing metals to the drains. However, targeted studies are required to confirm this.

The physiochemical form of metals must be known to understand mobility and bioavailability in the natural environment (Du Laing et al. 2007). Some metals can occur at naturally high concentrations in the environment, unrelated to contamination (Langmuir et al. 2004). As a consequence of the current study using the complete sediment digest for metal content analysis, there is no distinction between metals adsorbed to the surface of sediments and metals that are incorporated in the ped structure. While the data provides an indication of the sediment metal content of each site, it is not necessarily indicative of contaminant concentrations. However, changes in site environmental condition could result in alterations to the physiochemical form of the metal. That is, extreme acidity can result in the release of metals from the sediment (Du Laing et al. 2007). Thus the critical sediment metal content at each site is the proportion available for release, provided appropriate conditions are present (such as extreme acidity or salinity). Again, this type of analysis is appropriate for a baseline or surveillance type of study. However, for subsequent targeted studies, with the intention of determining risk to aquatic health, it is recommended that only bioavailable metals be assessed.

The snapshot sampling regime for surface water and sediments in the current study does not take into account the possibility of metal bioaccumulation in organisms. Although certain metals may be below detection limits they could still be causing detriment to aquatic organisms as a consequence of bioaccumulation (Shi and Wang 2004; De Mora et al. 2004). Organisms can accumulate metals in their systems through absorption, respiration, inhalation and ingestion. Many factors affect the bioaccumulation of metals in an organism, including physiology, metal speciation and bioavailability, as well as physiochemical factors that increase bioavailability such as changes in salinity, acidity and water hardness. Generally, organisms have the ability to regulate essential metals such as zinc, manganese and copper. However, toxicity can manifest if the rate of metabolic breakdown and excretion of the metal is exceeded by uptake concentrations. Generally the bioaccumulation of non-essential metals (for example, cadmium, lead and mercury) is of greater concern to organisms as they are not typically regulated. Thus excretion is insignificant and accumulation is often synonymous with uptake (Phillip and Rainbow 1994). These effects have the potential to magnify across trophic levels (Kapustka et al. 2004).

To assess the impact of such metals on organisms within the receiving environment downstream from the drains in the current study, it is recommended that biological techniques including bioaccumulation and ecotoxicological approaches be incorporated into future investigations. Now that this baseline dataset of total metals has been established, it is recommended that for subsequent water quality and sediment quality analyses bioavailable metals be assessed because the bioavailable fraction is that which aquatic organisms are expected to be exposed to.

4.10 Chromium reducible sulphur suite

Acid sulphate soils are categorised as either potential acid sulphate soils (PASS) or actual acid sulphate soils (AASS). PASS have a pH close to neutral and contain a highly reduced horizon of sulphide minerals (commonly pyrite). When unoxidised, the soils remain innocuous to the environment, human health and manmade structures. However the formation of AASS through disturbance of PASS produces sulphuric acid and large quantities of soluble iron (see the equation below). This can result in subsequent leaching of potentially toxic elements (such as lead, arsenic, aluminium) if they are present in the soils, which may lead to contamination of surface waters and groundwaters, and harm to associated biota through direct exposure to these contaminants and through loss of habitat.

$$\mathbf{FeS_{2(s)} + 7/2\ O_{2(g)} + H_2 0_{(l)} \rightarrow Fe^{2+}_{(aq)} + 2SO_4^{2-}{}_{(aq)} + 2H^+_{(aq)}}$$

Sulphide formation is a natural part of the global sulphur cycle that occurs when iron rich sediments are inundated with sulphate rich water (such as sea water) in the presence of sulphate reducing bacteria and significant quantities of organic matter (Dent 1986). Oxidation of sulphides can be triggered by soil excavation for land development and agriculture and disturbance of soils through lowering of water tables by drainage or groundwater use.

Sulphide content (indicated by chromium reducible sulphur percentage) at a site is not an indication of decreased drain sediment quality. Sulphide accumulation may simply reflect high organic loading to sediments coupled with sulphate and iron inputs from either sediments or groundwater and a continued state of water logging (Degens, pers. comm. 2007). Sulphide content indicates the possibility of acidification occurring in the future if inappropriate sediment disturbance occurs and triggers sulphuric acid production that exceeds the acid buffering capacity of the sediments.

Acidification was not identified as a current issue at any of the drain sites. On a regional scale, sites draining into the Swan River generally have sediments with higher net sulphide acidity than sites draining into the Canning River. This may be due to longer periods of drainage in the Swan River sites or more suitable conditions for formation of sulphides in the drain sediments (for example, increased sulphate, iron and organic matter inputs). On a local scale there is high spatial variability within sites. This variability probably reflects spatial variation between sampling times more than seasonal variations in sediment sulphide content. Such variability generally changes over periods of years unless a dramatic disturbance has occurred (Degens, pers. comm. 2007).

pH is a key factor influencing the solubility of metal ions (Langmuir et al. 2004) and the disturbance of acid sulphate soils can be accompanied by the release of soluble iron, aluminium and other metals such as lead and arsenic if these are present in the soils (LWQB 2006). Therefore any acid production by sulphide oxidation is considered to be an additional risk factor that can contribute to surface and groundwater contamination and the disturbance of sulphides should be avoided regardless of the metal concentrations within the sediment. Although the possibility of metal dissolution can be of environmental concern, it is a component of the more comprehensive issue of acid sulphate soil oxidation that can be avoided through applying best management practices. When assessing whether acid sulphate soil poses a risk to the environment it is necessary to consider the potential for acidification (that is, net sulphide acidity content) and whether this soil is likely to be disturbed (thus causing oxidation).

In the current study, it should be noted that chromium reducible sulphur may be underestimated due to the monosulphide component being unstable and often oxidising during the drying and grinding process in the laboratory method (Ahern 2004). Additionally, the sampling periods were quarterly, capturing each of the seasons within a year. The summer sampling period was in November to ensure that the majority of the drains had enough volume for water samples to be collected. Consequently no data is available to indicate whether oxidation of sediments occurs in the driest period of the year (December to March) when some drains are known to completely dry out and where oxidation of sediments may contribute acidity to the Swan Canning system with the first flush or summer thunderstorm events.

When using this data as baseline information it should also be taken into consideration that 2006 was the driest winter on record and thus may not necessarily be representative of the occurrences during an average seasonal cycle. It must also be noted that whilst the information presented is a useful starting reference, follow-up targeted investigations are required to fully establish the spatial extent of sulphides in the sediments at the sites and risk status of these materials.

The sampling procedure indicates the occurrence of sulphides within a depth of 3 cm from the surface. However, there can be the high risk of actual acid sulphate soil and potential acid sulphate soil formation within 3 m from the surface (Degens and Wallace-Bell 2007; Degens and Wallace-Bell 2006). Thus the information presented can be used as an indication of where disturbance of sediments should be avoided, but is not detailed enough to suggest the sediments are adversely influencing water quality in the drains.

4.11 Major ions

Alkalinity as calcium carbonate is a measure of the buffering capacity of water, or the capacity of bases to neutralise acids. A measure of alkalinity refers to the ability of water to resist change in pH. The presence of buffering materials helps neutralise acids as they are added to the water (Murphy 2005).

The buffering materials are primarily the bases bicarbonate and carbonate (above pH 8.3 carbonate predominates and below pH 8.3 bicarbonate predominates), and occasionally hydroxide, borates, silicates, phosphates, ammonium, sulphides and organic ligands (Murphy 2005). As most of the drains which were sampled in this study had pHs below 8.3 it is presumed that bicarbonates predominate in these systems.

Waters with low alkalinity are very susceptible to changes in pH. Waters with high alkalinity are able to resist major shifts in pH. As increasing amounts of acid are added to a waterbody, the pH of the water decreases and the buffering capacity of the water is consumed. If natural buffering materials are present, pH will drop slowly to around 6, then a rapid pH drop occurs as the bicarbonate buffering capacity is used up. At pH 5.5, only very weak buffering ability remains, and the pH drops further with additional acid (Murphy 2005). A solution having a pH below 4.5 contains no alkalinity, because there are no bicarbonate ions left (Murphy 2005).

Hard water has a high mineral content. Calcium and magnesium in the form of carbonates are normally the main constituents. Hard water can help regulate the metal content in water.

Bicarbonate and carbonate ions in water can remove toxic metals (such as lead, arsenic, and cadmium) by precipitating the metals out of solution (Murphy 2005).

Most subcatchments had sufficient alkalinity to buffer pH in the waterbody. There were 35% of subcatchments with a mean alkalinity between 100 and 200 mg/L, which is high enough to stabilise the pH level in a stream (Murphy 2005). Susannah Brook was the only subcatchment with an alkalinity below 10 mg/L. However, this subcatchment was only sampled on one occasion. Most of the subcatchments have sufficiently high alkalinity to be able to resist falls in pH from the addition of natural or human induced acidic waters over the short term. An extremely high alkalinity value of 1810 mg/L was detected at LIEP6 (Lower Canning) in November. This value is unexplained and may be due to sampling or analytical error.

The ratio of chloride to sulphate (by mass) in seawater is generally constant at approximately 7.2 (NRM 2006). In seawater the concentration of chloride is approximately 19400 mg/L and sulphate is approximately 2700 mg/L (NRM 2006). This ratio remains roughly constant when diluted with uncontaminated rainwater or freshwater. Estuaries can be expected to have a similar ratio. Increased levels of sulphate relative to chloride combined with low pH indicate the presence of acid sulphate runoff (Mulvey 1993). Sulphate input into waterways can occur from acid sulphate run-off, acid rain (sulphur dioxide air pollution), organic acids from wetlands, fertiliser use and mine site acid runoff (NRW 2006).

Average chloride to sulphate ratios below 4 were found in 57% of subcatchments including the Bayswater Main Drain, Central Belmont Main Drain, Perth Airport South Main Drain, South Belmont Main Drain, Bannister Creek, Bennett Brook, Bickley Brook, Mills Street Main Drain, and South Perth subcatchments. A chloride to sulphate ratio of less than four may be an indication of an extra source of sulphate from sulphide oxidation. The lowest ratio of 1.5 was found in the Bayswater Main Drain and suggests that this subcatchment may be experiencing inputs of sulphates.

Fluoride compounds, usually calcium fluoride, are naturally found in low concentrations in waterways (Windom 1971). The ocean has an average concentration of 1.3 ppm (Windom 1971). In high concentrations, fluoride compounds are toxic and can cause human fatalities (NHMRC and ARMCANZ 2000). There are currently no guidelines available on suitable fluoride concentrations for ecosystem health. The Australian Drinking Water Guideline value is 1.5 mg/L for human health (NHMRC and ARMCANZ 2000). An extremely high fluoride value of 94.0 mg/L was detected at BBDSLORD (Bennett Brook) in August. This value is unexplained and may be due to sampling or analytical error. Mean fluoride concentrations in all other subcatchments were below 0.5 mg/L suggesting that they are natural background levels.

4.12 Nutrients

Although nutrients were not the focus of this study, they were assessed at the request of the SRT to provide background information.

High concentrations of nutrients, especially nitrogen and phosphorus, usually determine the maximum biological productivity of an aquatic system (SRT 2000b). Excess levels of nutrients can stimulate the growth of plants to the extent that they begin to dominate an aquatic system, often to the exclusion of other species. Such systems experience a loss of biodiversity. The increased occurrence of phytoplankton bloom activity in the Swan Canning system is indicative of high nutrient concentrations (SRT 2000b).

Natural sources of nutrients include the weathering of rock, fixation of atmospheric nitrogen by some plants, decomposition of biological material, and leaching of soils (EPA SA 2004). Diffuse sources are believed to provide the majority of nutrients to the Swan coastal plain (SRT 2000a) such as domestic detergents and soaps, urban runoff and application of fertilisers to urban gardens and parks, arable lands, pasture, orchards and intensive horticulture practices (EPA SA 2004). Point sources include septic tanks, sewer overflows, landfill sites, industrial contaminated sites, agricultural properties with intensive livestock practices (such as piggeries, poultry farms, dairies, and stock holding yards) and industrial effluent (Kinhill Engineers 1995). Sharma et al. (1994) found that in medium density unsewered residential areas, about 80% of the inputs of nitrogen and phosphorus are from septic tanks.

The SCCP Action Plan has set targets for total nitrogen and total phosphorus in order to monitor river health and reduce the incidence and severity of algal blooms (SRT 2004). If a tributary is already passing the short-term target of 2.0 mg/L for total nitrogen and 0.2 mg/L for total phosphorus, it is then assessed against the long-term target of 1.0 mg/L for total nitrogen and 0.1 mg/L for total phosphorus (SRT 2003c). If the tributary is passing both its short and long-term targets, it is further assessed to ensure its water quality is not degrading (SRT 2003c). The SRT's nutrient targets have a specific compliance system associated with them. Results from this study provide only a snapshot over one year and so are not directly comparable to the SRT's nutrient targets. They are applied to the current dataset at the request of the SRT and provide a general guide only.

The Swan Canning Catchment Compliance Summary shows that since 2004 all 15 monitored subcatchments have achieved the short-term target for total nitrogen. However, Ellen Brook, Mills Street, Bannister Creek, Bayswater Main Drain, Southern River, Bickley Brook, and Bennett Brook exceeded the long-term target in 2007 (DOW 2007).

In comparison, in the current study, the Upper Canning subcatchment was higher than the SCCP short-term target for total nitrogen. However, the subcatchment was only sampled on five occasions at two sites, as the tributaries tended to dry out in summer. The highest total nitrogen value recorded was 10.0 mg/L at WPMDO (Upper Canning) in August which raised the overall average for the Upper Canning subcatchment. This sample was collected after recent rains and may be a consequence of fertiliser runoff.

Sixteen subcatchments (62% of total) were higher than the SCCP long-term target for total nitrogen in this study. The highest mean concentrations (aside from Upper Canning) were recorded in Bull Creek, Susannah Brook, St Leonards Creek, and Ellen Brook subcatchments. Bull Creek had elevated ammonium levels at site BCMDBPI which accounts for its high total nitrogen levels. The other three subcatchments are all upstream on the Swan River. Land uses in these subcatchments are primarily agricultural so fertiliser and livestock faecal waste are likely to be major contributors of nitrogen (SRT 2000a).

Nitrogen exists in several forms, most of which are soluble and rapidly transported through the catchment (Kinhill Engineers 1995). Travel and residence times of nitrogen in the catchment will largely depend on flow rates of surface, subsurface and groundwater flows. Oxidised forms of nitrogen (nitrates and nitrites) are common in arable soils and flowing waters, while reduced forms of nitrogen (ammonia and ammonium) are common in surface runoff and stagnant waters (SRT 2000a). Organic nitrogen associated with biological particulate material, is not soluble and is less mobile. Mineralisation, assimilation and microbial denitrification can be an important removal process of nitrogen from saturated sandy soils and some studies have shown that as little as 20% of nitrogen added to a sandy catchment may reach the estuary (Kinhill Engineers 1995). For instance, Appleyard (1995) found that nitrate concentrations are significantly higher in sewered urban areas (average concentration >1 mg/L as N) than sewered non-urban areas (average concentration >0.5 mg/L as N). However, the measured concentrations were all lower than expected from the fertiliser inputs indicating that denitrification was taking place.

In the current study, particulate organic nitrogen concentrations were fairly consistent throughout the subcatchments and averaged just under 20% of the nitrogen concentration. Dissolved organic nitrogen was the more dominant form of organic nitrogen in the majority of drains. The total nitrogen concentration in subcatchments such as Ellen Brook and Helena River was almost entirely made up of dissolved organic nitrogen. This form of nitrogen may be derived from natural sources or come into the system as, for example, fertiliser (such as urea). The prevalence of dissolved organic nitrogen suggests that conditions (for example, pH, dissolved oxygen, carbon levels) are not amenable for mineralisation of the dissolved organic nitrogen or there has been insufficient time for conversion to ammonia/ammonium and nitrite/nitrate to occur.

Bull Creek and Central Business District subcatchments have a predominance of ammonium in their systems. This suggests the drains in these subcatchments are slow flowing, reducing environments, or they are capturing low dissolved oxygen level stormwater or groundwater. The Central Business District has a high proportion of piped drains which may also limit oxidation of ammonium. Ammonium can be naturally occurring or may be introduced through fertilisers, animal wastes, and other anthropogenic sources (SRT 2000b). Upper Canning, Susannah Brook, and Jane Brook were three subcatchments in which total oxidised nitrogen forms were prevalent. These systems tend to be faster flowing streams that are well oxygenated. Nitrates tend to be the most bioavailable form of nitrogen so they will be readily taken up by plants and algae (Kinhill Engineers 1995).

The Swan Canning Catchment Compliance Summary shows that since 2002 all 15 monitored subcatchments have been meeting the short-term target for total phosphorus, with the exception of Ellen Brook (DOW 2007). In Ellen Brook, Mills Street, Southern River, and Belmont South, the long-term target has been exceeded since 2004 (DOW 2007).

Ellen Brook, Mills Street Main Drain and Lower Canning subcatchments had higher average total phosphorus levels than the SCCP short-term target for total phosphorus in this study. Nine subcatchments (35% of total) were higher than the SCCP long-term target for total phosphorus. As discussed for nitrogen, these targets are applied to the current dataset at the request of the SRT as a general guide only because the SCCP targets have a specific compliance system associated with them which was not followed for this study.

Ellen Brook drains a predominantly semi-rural district with the main sources of nutrients being fertiliser and livestock faecal waste. The catchment consists of nutrient deficient sands and soils which have little or no surface nutrient retention capacity (SRT 2000b). A strong groundwater gradient in Ellen Brook is generated from the Gnangara Mound and assists the rapid hydrologic transport of nutrients through the subcatchment (SRT 2000b).

Mills Street Main Drain subcatchment has urban, commercial and light industrial land uses. Phosphorus inputs may be from application of fertilisers to urban gardens and parks or from other sources. In 1986, many Perth businesses were found to discharge wastewater inappropriately, either directly to drains or indirectly via soil soaks (Thurlow et al. 1986).

The Lower Canning subcatchment has similar land uses to the Mills Street Main Drain subcatchment, but also includes some small scale agricultural activity. High levels of total phosphorus in this subcatchment were particularly prevalent in two compensating basins (WHMANCBOUT and MENDEDGCBOUT) which collect stormwater from commercial and industrial sites, and the TGDSDPOUT site which receives stormwater runoff from the car parking bays surrounding a number of fast food outlets.

Subcatchments including Jane Brook, Helena River, and Susannah Brook had comparatively low levels of nutrients. Factors which could contribute to this include the high proportion of clays and lateric soils, and remnant vegetation on the Darling Scarp which these subcatchment drain (SRT 2000b). Nutrient uptake in these areas is efficient and limits nutrient export to the waterways. Additionally large tracts of these subcatchments are protected for public water supply.

Phosphorus, mainly present as inorganic phosphate, is not as mobile as nitrogen and tends to strongly adsorb to soils (particularly iron and aluminium oxide rich soils), and particulate material (SRT 2000b). Particulate forms of phosphorus, including organic material or inorganic minerals also have limited mobility unless disturbed (SRT 2000b). Mobilisation of phosphorus depends on both the physiochemical process occurring at the soil-water interface, erosion processes occurring at exposed soil surfaces, and sediment resuspension in waterways (SRT 2000b).

On average, 39% of the total phosphorus concentration throughout the drains appeared as filterable reactive phosphorus. However, the ratio of particulate phosphorus to filterable reactive phosphorus varied between waterbodies. Filterable reactive phosphorus is soluble and contains a high percentage of orthophosphate which is the form of phosphorus that most plants and algae will utilise immediately.

Despite differences in chemical affinity, the majority of both nitrogen and phosphorus loads in surface water are believed to be transported in catchments during high rainfall events (EPA SA 2004). Hence, knowledge of flow paths is important for nutrient management.

With the data available from the current study, no relationships between total nitrogen and phosphorus levels in the sediment and surface water was apparent on a subcatchment scale. However, total nitrogen and total phosphorus in the sediment tended to be high in the same drain sites. These may be sites with soil types suitable for nutrient storage, or sites where organic matter is collecting. The form in which the nitrogen is present in the sediment was not determined.

Organic carbon in a waterway may be derived from leaf litter, soil organic matter, plant roots and fungi, peat deposits, aquatic organisms and animal wastes (Barber 1995). It is a primary food source in the aquatic food web and an important component of the energy balance in waterways as heterotrophic bacteria gain energy through oxidising organic carbon (Meyer et al. 1998). Organic carbon is an important component of the acid-base chemistry of many low-alkalinity freshwater systems (Barber 1995). Organic carbon can affect the bioavailable concentrations of metals in water by forming soluble complexes with trace metals that affect their mobility and toxicity (Meyer et al. 1998). Carbon can also effectively bind organic pollutants and reduce their bioavailability (Meyer et al. 1998). The balance of organic carbon and dissolved oxygen in the water is critical to the health of a waterbody (Meyer et al. 1998).

Dissolved organic carbon was sampled in the surface water, and total organic carbon was sampled in the sediment in this study. There appeared to be no relationship between concentrations in the surface water and concentrations in the sediment. The highest levels of dissolved organic carbon in surface water were found in Ellen Brook and Bannister Creek.

Mineralisation of organic carbon by heterotrophic bacteria can result in high biological oxygen demand (Meyer et al. 1998). Hence, where organic carbon is high, biological oxygen demand may be expected to be similarly high. This relationship was investigated but no clear patterns were apparent across the subcatchments. Dissolved oxygen levels are greatly influenced by the time of day and weather conditions when samples are taken. These sites were not sampled under the same conditions. Thus dissolved oxygen concentrations can not be meaningfully compared to the dissolved organic carbon concentrations.

The highest levels of total organic carbon in sediment were found in Bennett Brook, Central Belmont Main Drain and Susannah Brook subcatchments. Sites with high total organic carbon levels in sediment also tended to have the highest concentrations of nutrients in the sediment. These are likely to be the waterways with the largest external inputs of organic material, suitable soils, and slow water movement, which allow materials to settle out of solution.

5 Conclusions

This study identified and quantified a range of surface water and sediment contaminants within the Swan Canning catchment drainage system. This information has enabled subcatchments to be prioritised for further investigation (Table 15) based on the types, concentrations and frequencies of contaminants found.

Table 15 Prioritisation of subcatchments and associated contaminants

Priority	Subcatchments	Contaminants
1	Helena River	PAHs, OC pesticides and metals plus a potential issue with herbicides
1	Lower Canning	OC pesticides and metals plus a potential issue with herbicides, petroleum hydrocarbons, anionic surfactants and PAHs (and nutrients)
1	Upper Swan	OC pesticides and metals plus a potential issue with herbicides, petroleum hydrocarbons and anionic surfactants (and nutrients)
1	Mills Street Main Drain	OC pesticides and metals plus a potential issue with herbicides, petroleum hydrocarbons and PAHs (and nutrients)
1	Central Belmont Main Drain	OC pesticides and metals plus a potential issue with herbicides, petroleum hydrocarbons and PAHs
1	Maylands	OC pesticides and metals plus a potential issue with herbicides, petroleum hydrocarbons and PAHs
1	Blackadder Creek	OC pesticides and metals plus a potential issue with herbicides, PAHs and anionic surfactants
2	Bayswater Main Drain	OC pesticides and metals plus a potential issue with herbicides and petroleum hydrocarbons
2	South Belmont	OC pesticides and metals
2	Central Business District	PAHs and metals (and nutrients)
2	Perth Airport South	PAHs and metals
3	Bull Creek	Metals plus a potential issue with anionic surfactants, PAHs and petroleum hydrocarbons (and nutrients)
3	Helm Street	Metals and a potential issue with herbicides
3	Bickley Brook	Metals and a potential issue with herbicides
3	Bannister Creek	Metals and a potential issue with herbicides
4	Upper Canning	Metals
5	Bennett Brook	Potential issues with petroleum hydrocarbons and herbicides
5	Ellen Brook	Potential issue with petroleum hydrocarbons (and nutrients)
5	Susannah Brook	Potential issue with petroleum hydrocarbons (and nutrients)
5	St Leonards Creek	Potential issue with herbicides (and nutrients)
5	Jane Brook	Potential issue with herbicides
5	Yule Brook	Potential issue with herbicides

In addition to the above:

1) microbial levels exceeded guidelines in all subcatchments.
2) there are potential issues with metals in all subcatchments (only the priority metal areas are listed above – those that were consistently high in metal concentrations and consistently exceeded guidelines).
3) acidification of sediments is not currently an issue. However, subcatchments that contain sites that may potentially be of concern if disturbed (and complete oxidation occurred) are: Helena River, Bennett Brook, South Belmont, Central Belmont, Ellen Brook, Blackadder Creek, Lower Canning, Bull Creek, South Perth and Mills Street Main Drain.
4) although nutrients were not the focus of this study, they were assessed at the request of the SRT to provide background information.

Of the contaminants assessed, it was concluded that the PAHs, petroleum hydrocarbons and OC pesticides were most likely to exist in the sediments; and the microbial parameters (faecal coliforms and enterococci), herbicides and anionic surfactants were most likely to exist in the surface water of the Swan Canning catchment drainage system. Metals were consistently detected in both water and sediments (with the exception of mercury that was only detected in the sediments). It was also concluded that lower limits of reporting than those available at the time of this study would be required to detect PCBs and OP pesticides within the Swan Canning catchment drainage system. Variability in concentrations of both sediment and surface water contaminants was high. Therefore it was concluded that subsequent studies should ensure adequate spatial replication.

Finally, it was concluded that further investigation was required based on the results of this and the parallel studies (*A baseline study of contaminants in groundwater at disused waste disposal sites in the Swan Canning catchment* – Evans 2009, and *A baseline study of organic contaminants in the Swan and Canning catchment drainage system using passive sampling devices* – Foulsham et al. 2009).

This further investigation (*A baseline study of contaminants in the sediments of the Swan and Canning estuaries* – Nice 2009) has subsequently targeted the receiving environment downstream of the higher priority subcatchments identified in this study. Based on the findings, specific recommendations have been provided for future biological assessment in the receiving environment (Nice 2009), thus introducing a *multiple lines of evidence* approach (e.g. Chapman et al. 1997) to determine the likely impact of non-nutrient contaminants on the system.

Figure 88 illustrates the separate components of the overall NNCP and the *multiple lines of evidence* approach adopted in this program.

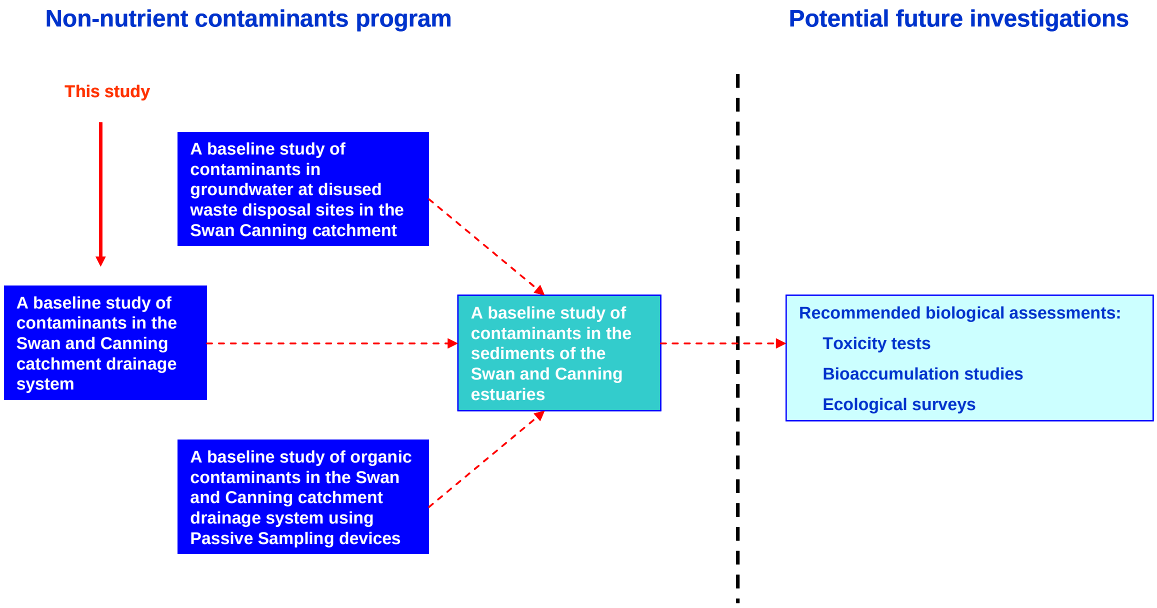

Figure 88 Multiple lines of evidence to determine impact of contaminants on the Swan Canning system.

The findings of the four components of the NNCP have been summarised by the SRT in *Non-nutrient contaminants in the Swan Canning river system: summary paper* (SRT 2009).

Appendices

Appendix A – Parameters and associated guideline values

Physical data (ANZECC and ARMCANZ 2000)

	South West Australia default trigger values lowland rivers	**Trigger values for freshwater 95% level of protection**	**Sediment quality guidelines ISQG – Low**	**Sediment quality guidelines ISQG – High**
Total suspended solids	No guideline	No guideline	No guideline	No guideline
Temperature	No guideline	No guideline	No guideline	No guideline
pH	Lower limit = 6.5 Upper limit = 8.0	No guideline	No guideline	No guideline
Electrical conductivity	No guideline	No guideline	No guideline	No guideline
Dissolved oxygen (% saturation)	Lower limit = 80 Upper limit = 120	No guideline	No guideline	No guideline
Biological oxygen demand	No guideline	No guideline	No guideline	No guideline

Microbial water quality (ANZECC and ARMCANZ 2000)

	Water quality guideline for recreational waters – primary contact	**Water quality guideline for recreational waters – secondary contact**
Faecal coliform organisms	150 faecal coliform organisms/100 mL	1000 faecal coliform organisms/100 mL
Enterococci organisms	35 enterococci organisms/100 mL	230 enterococci organisms/100 mL

Polycyclic aromatic hydrocarbons (Simpson et al. 2005; ANZECC and ARMCANZ 2000)

	Trigger values for freshwater 95% level of protection ug/L	**Sediment quality guidelines ISQG – Low normalised to 1% organic carbon (mg/kg)**	**Sediment quality guidelines ISQG – High normalised to 1% organic carbon (mg/kg)**
Acenaphthene	No guideline	0.016	0.5
Acenaphthylene	No guideline	0.044	0.64
Anthracene	0.4	0.085	1.1
Benzo(a)anthracene	No guideline	0.261	1.6
Benzo(a)pyrene	0.2	0.43	1.6
Benzo(b) &(k)fluoranthene	No guideline	No guideline	No guideline
Benzo(ghi)perylene	No guideline	No guideline	No guideline
Chrysene	No guideline	0.384	2.8
Dibenzo(a,h)anthracene {DBA} {DB(A,H)A}	No guideline	0.063	0.26
Fluoranthene	1.4	0.6	5.1
Fluorene	No guideline	0.019	0.54
Indeno(1,2,3-cd)pyrene	No guideline	No guideline	No guideline
Naphthalene	16	0.16	2.1
Phenanthrene	2	0.24	1.5
Pyrene	No guideline	0.665	2.6

Petroleum hydrocarbons (no ANZECC and ARMCANZ guidelines available)

	Trigger values for freshwater 95% level of protection	**Sediment quality guidelines ISQG – Low**	**Sediment quality guidelines ISQG – High**
TPH C6–C9	No guideline	No guideline	No guideline
TPH C10–C14	No guideline	No guideline	No guideline
TPH C15–C28	No guideline	No guideline	No guideline
TPH C29–C36	No guideline	No guideline	No guideline
Total TPH	No guideline	No guideline	No guideline

Polychlorinated biphenyls (Simpson et al. 2005; ANZECC and ARMCANZ 2000)

	Trigger values for freshwater 95% level of protection	**Sediment quality guidelines ISQG – Low**	**Sediment quality guidelines ISQG – High**
	ug/L	**mg/kg**	
Aroclor 1016	0.001	No guideline	No guideline
Aroclor 1221	1	No guideline	No guideline
Aroclor 1232	0.3	No guideline	No guideline
Aroclor 1242	0.3	No guideline	No guideline
Aroclor 1248	0.03	No guideline	No guideline
Aroclor 1254	0.01	No guideline	No guideline
Aroclor 1260	No guideline	No guideline	No guideline
Total PCBs	No guideline	0.023	No guideline

Organochlorine pesticides (Simpson et al. 2005; ANZECC and ARMCANZ 2000)

	Trigger values for freshwater 95% level of protection	**Sediment quality guidelines ISQG – Low**	**Sediment quality guidelines ISQG – High**
	ug/L	**ug/kg**	**ug/kg**
Aldrin	0.001	No guideline	No guideline
Chlordane (total)	0.08	0.5	6.0
p,p'-Dichlorodiphenyldichloroethylene (p,p-DDE)	0.03	2.2	27.0
1,1-dichloro-2,2-bis(4-chlorophenyl)ethane (p,p-DDD)	No guideline	2.0	20.0
Dichlorodiphenyltrichloroethane (p,p-DDT)	0.006	1.6	46.0
Dieldrin	0.01	0.02	8.0
Endosulphan sulphate	No guideline	No guideline	No guideline
Endosulphan-alpha {Alpha-endosulphan}	0.03	No guideline	No guideline
Endosulphan-beta {Beta-endosulphan}	0.03	No guideline	No guideline
Endrin (total)	0.01	0.02	8.0
Hexachlorocyclohexane (HCH)	No guideline	No guideline	No guideline
Lindane (gamma-BHC)	0.2	0.32	1.0
Heptachlor (total)	0.09	No guideline	No guideline
Heptachlor epoxide	No guideline	No guideline	No guideline
Hexachlorobenzene {HCB}	0.1	No guideline	No guideline
Methoxychlor	0.005	No guideline	No guideline
Organochlorine pesticides {OCs} (total)	No guideline	No guideline	No guideline

Organophosphorus pesticides (ANZECC and ARMCANZ 2000)

	Trigger values for freshwater 95% level of protection ug/L	**Sediment quality guidelines ISQG – Low**	**Sediment quality guidelines ISQG – High**
Bromophos-ethyl	No guideline	No guideline	No guideline
Chlorfenvinphos (total)	No guideline	No guideline	No guideline
Chlorpyrifos (total)	0.01	No guideline	No guideline
Chlorpyrifos-methyl	No guideline	No guideline	No guideline
Diazinon	0.01	No guideline	No guideline
Ethion	No guideline	No guideline	No guideline
Fenchlorphos	No guideline	No guideline	No guideline
Fenitrothion	0.2	No guideline	No guideline
Malathion	0.05	No guideline	No guideline
Mevinphos (total)	No guideline	No guideline	No guideline
Parathion (total)	0.004	No guideline	No guideline
Parathion-methyl	No guideline	No guideline	No guideline
Tetrachlorvinphos	No guideline	No guideline	No guideline

Herbicides (ANZECC and ARMCANZ 2000)

	Trigger values for freshwater 95% level of protection **ug/L**	**Sediment quality guidelines ISQG – Low**	**Sediment quality guidelines ISQG – High**
Atrazine	13	No guideline	No guideline
Diuron	0.2	No guideline	No guideline
Hexazinone	75	No guideline	No guideline
Metolachlor	0.02	No guideline	No guideline
Molinate	3.4	No guideline	No guideline
Simazine	3.2	No guideline	No guideline
Prometryn	No guideline	No guideline	No guideline
Metribuzin	No guideline	No guideline	No guideline
Trifluralin	2.6	No guideline	No guideline
Dicamba	No guideline	No guideline	No guideline
Monochlorophenoxyacetic acid (MCPA)	1.4	No guideline	No guideline
Dichlorprop	No guideline	No guideline	No guideline
2,4-dichlorophenoxyacetic acid (2, 4-D)	280	No guideline	No guideline
2,4-5-trichlorophenoxyacetic acid (2, 4, 5-T)	36	No guideline	No guideline
Silvex 2-(2,4,5-Trichlorophenoxy) propionic acid (2, 4, 5 – TP)	No guideline	No guideline	No guideline
4-(2,4-dichlorophenoxy)butyric acid (2, 4 – DB)	No guideline	No guideline	No guideline
Mecoprop 2-(2-Methyl-4-chlorophenoxy)propionic acid (MCPP)	No guideline	No guideline	No guideline
Triclopyr	No guideline	No guideline	No guideline

Anionic surfactants (no ANZECC and ARMCANZ guidelines available)

	Water quality guideline for recreational waters mg/L	Trigger values for freshwater 95% level of protection	Sediment quality guidelines ISQG – Low	Sediment quality guidelines ISQG – High
MBAS	0.2	No guideline	No guideline	No guideline

Metals (Simpson et al. 2005; ANZECC and ARMCANZ 2000)

	Trigger values for freshwater 95% level of protection mg/L	Sediment quality guidelines ISQG – Low mg/kg	Sediment quality guidelines ISQG – High mg/kg
Aluminium	0.055	No guideline	No guideline
Arsenic	0.013	20	70
Cadmium	0.0002	1.5	10
Chromium	0.001	80	370
Cobalt	0.09	No guideline	No guideline
Copper	0.0014	65	270
Iron	0.3	No guideline	No guideline
Lead	0.0034	50	220
Manganese	1.9	No guideline	No guideline
Mercury	0.00006	0.15	1
Molybdenum	0.034	No guideline	No guideline
Nickel	0.011	21	52
Selenium	0.011	No guideline	No guideline
Zinc	0.008	200	410

Major ions (no ANZECC and ARMCANZ guidelines available)

	South West Australia default trigger values lowland rivers	Trigger values for freshwater 95% level of protection	Sediment quality guidelines ISQG – Low	Sediment quality guidelines ISQG – High
Alkalinity as CaCO3	No guideline	No guideline	No guideline	No guideline
Sulphate	No guideline	No guideline	No guideline	No guideline
Chloride	No guideline	No guideline	No guideline	No guideline
Fluoride	No guideline	No guideline	No guideline	No guideline

Nutrients (ANZECC and ARMCANZ 2000)

	South West Australia default trigger values lowland rivers (ug/L)	Sediment quality guidelines ISQG – Low	Sediment quality guidelines ISQG–High
Total nitrogen	1200	No guideline	No guideline
Total oxidised nitrogen	150	No guideline	No guideline
Ammonium	80	No guideline	No guideline
Organic nitrogen – filterable	No guideline	No guideline	No guideline
Total phosphorus	65	No guideline	No guideline
Filterable reactive phosphorus as P	40	No guideline	No guideline

Appendix B – Number of samples (n) for each parameter group

Subcatchments and corresponding n values for physical data

Subcatchment	n	Subcatchment	n	Subcatchment	n
Bayswater MD	9	Maylands	16	Bull Creek	25
Bennett Brook	8	Perth Airport North MD	6	Helm St MD	3
Blackadder Creek	8	Perth Airport South MD	5	Lower Canning	30
Central Belmont MD	10	South Belmont MD	7	Mills Street MD	8
Central Business District	6	St Leonards Creek	1	South Perth	6
Ellen Brook	8	Susannah Brook	1	Southern River	2
Helena River	3	Upper Swan	19	Upper Canning	5
Henley Brook	2	Bannister Creek	10	Yule Brook	4
Jane Brook	2	Bickley Brook	2		

Drains and corresponding n values for BOD data

Subcatchment	Drain site code	n
Bayswater MD	BWDESOUT	5
Blackadder Creek	BCPPB	4
Central Belmont MD	CBCPO	4
Central Belmont MD	CBSLO	4
Helena River	HRJSB	4
Henley Brook	HBBROCK	2
Maylands	MLMDOUT	4
Upper Swan	SRMDO	4
Bickley Brook	BBCM1	2
Helm Street MD	HSGSO2	3
Lower Canning	LAMDO	4
Lower Canning	MENDD	4
Lower Canning	MENEDGCBOUT	1
Lower Canning	TGDSDPOUT	4
Mills Street MD	MSMILCBOUT	4

Subcatchments and corresponding n values for microbial water quality data

Subcatchment	n	Subcatchment	n	Subcatchment	n
Bayswater MD	6	Maylands	15	Lower Canning	21
Bennett Brook	4	Perth Airport North MD	6	Mills Street MD	4
Blackadder Creek	8	Perth Airport South MD	2	South Perth	10
Central Belmont MD	6	South Belmont MD	6	Southern River	1
Central Business District	4	Upper Swan	16	Upper Canning	3
Ellen Brook	3	Bannister Creek	3	Yule Brook	3
Helena River	4	Bickley Brook	1		
Henley Brook	1	Bull Creek	21		
Jane Brook	1	Helm St MD	2		

Subcatchments and corresponding n values for sediment metal data.

Subcatchment	n	Subcatchment	n	Subcatchment	n
Bayswater MD	12	Maylands	16	Bull Creek	19
Bennett Brook	5	Perth Airport North MD	4	Helm St MD	2
Blackadder Creek	7	Perth Airport South MD	3	Lower Canning	20
Central Belmont MD	6	South Belmont MD	5	Mills Street MD	7
Central Business District	2	St Leonards Creek	1	South Perth	3
Ellen Brook	4	Susannah Brook	1	Southern River	2
Helena River	4	Upper Swan	19	Upper Canning	4
Henley Brook	1	Bannister Creek	5	Yule Brook	4
Jane Brook	1	Bickley Brook	1		

Subcatchments and corresponding n values for surface water metal data

Subcatchment	n		n		n
Bayswater MD	12	Maylands	16	Bull Creek	26
Bennett Brook	6	Perth Airport North MD	6	Helm St MD	3
Blackadder Creek	8	Perth Airport South MD	4	Lower Canning	29
Central Belmont MD	8	South Belmont MD	7	Mills Street MD	8
Central Business District	4	St Leonards Creek	1	South Perth	6
Ellen Brook	5	Susannah Brook	1	Southern River	2
Helena River	4	Upper Swan	20	Upper Canning	5
Henley Brook	2	Bannister Creek	5	Yule Brook	4
Jane Brook	1	Bickley Brook	2		

Subcatchments and corresponding n values for chromium reducible sulphur suite data

Subcatchment	n	Subcatchment	n	Subcatchment	n
Perth Airport North	4	Blackadder Creek	8	Bull Creek	20
Perth Airport South	3	Susannah Brook	1	South Perth	3
South Belmont	6	Bayswater Main Drain	12	Mills St Main Drain	8
Central Belmont	8	Maylands	18	Yule Brook	4
Ellen Brook	4	Central Business District	2	Bickley Brook	1
Henley Brook	1	Helena River	4	Helm St	2
St Leonards Creek	1	Jane Brook	1	Upper Canning	4
Upper Swan	21	Lower Canning	23	Southern River/Wungong	1
Bennett Brook	5	Bannister Creek	6		

Subcatchments and corresponding n values for major ions data

Subcatchment	n	Subcatchment	n	Subcatchment	n
Bayswater Main Drain	16	Perth Airport North	5	Lower Canning	34
Bennett Brook	8	Perth Airport South	4	Mills St Main Drain	8
Blackadder Creek	8	South Belmont	8	South Perth	7
Central Belmont	8	St Leonards Creek	1	Southern River/Wungong	2
Central Business District	5	Susannah Brook	1	Upper Canning	5
Ellen Brook	5	Upper Swan	23	Yule Brook	5
Helena River	4	Bannister Creek	5		
Henley Brook	2	Bickley Brook	2		
Jane Brook	1	Bull Creek	29		
Maylands	17	Helm St	3		

Subcatchments and corresponding n values for nutrient data

Subcatchment	n for surface waters	n for sediments
Bayswater MD	17	10
Bennett Brook	10	5
Blackadder Creek	8	5
Central Belmont MD	10	4
Central Business District	5	2
Ellen Brook	7	3
Helena River	4	4
Henley Brook	2	1
Jane Brook	1	1
Maylands	17	13
Perth Airport North MD	6	3
Perth Airport South MD	5	2
South Belmont MD	9	4
St Leonards Creek	1	1
Susannah Brook	2	1
Upper Swan	25	17
Bannister Creek	11	4
Bickley Brook	2	1
Bull Creek	30	12
Helm St MD	3	1
Lower Canning	35	14
Mills Street MD	8	7
South Perth	7	3
Southern River	2	1
Upper Canning	5	3
Yule Brook	4	3

Drains and corresponding n values for net potential acidity data

Subcatchment	Drain site code	n	Subcatchment	Drain site code	n
Perth Airport North	PAN01	3	Jane Brook	JBGNH	1
Perth Airport North	PAN02	1	Lower Canning	LAMDO	5
Perth Airport South	PAS01	3	Lower Canning	LAMDPPCBO	1
South Belmont MD	SBMD1	4	Lower Canning	MENDD	4
South Belmont MD	SBMD3	2	Lower Canning	WHMANCBOU T	1
Central Belmont MD	CBSLO	4	Lower Canning	WHADD	0
Central Belmont MD	CBCPO	4	Lower Canning	TGDSDPOUT	3
Ellen Brook	EBN20	3	Lower Canning	BWAMDO	2
Ellen Brook	EBN18	1	Lower Canning	LACDD	3
Henley Brook	HBBROCK	1	Lower Canning	LIEP6	4
St Leonards Creek	STLEONCG	1	Bannister Creek	BNC01	1
Upper Swan	BSMDO	4	Bannister Creek	BNCADEN	5
Upper Swan	CSMDREID	4	Bull Creek	RRMDOUT	2
Upper Swan	CSMDO	6	Bull Creek	MAMDO	3
Upper Swan	BWD9	4	Bull Creek	MOMDO	3
Upper Swan	SRMDO	4	Bull Creek	BAMDOUT	3
Bennett Brook	BBCSVBRD	1	Bull Creek	SAMDOUT	2
Bennett Brook	BBDSLORD	4	Bull Creek	BCMDBPI	3
Blackadder Creek	BCWETB	5	Bull Creek	BWMDBPI	3
Blackadder Creek	BCPPB	3	South Perth	MANMD1	1
Susannah Brook	SBRRB	1	South Perth	CPMD1	1
Bayswater MD	BWDESOUT	4	South Perth	WIFRD	1
Bayswater MD	PSDTBMD	1	Mills Street MD	MSMILCBOUT	5
Bayswater MD	BWDRPBD	8	Mills Street MD	MSCWW	3
Maylands	SLMBAIGIN	4	Yule Brook	YBMD25	4
Maylands	CAMDOUT	4	Bickley Brook	BBCM1	1
Maylands	MIMDOUT	4	Helm Street MD	HSG02	2
Maylands	MLMDOUT	6	Upper Canning	WPMDO	1
Central Business District	MBMDOUTW	1	Upper Canning	RSMDOUT	2
Central Business District	MBMDOUTE	1	Southern River	SRMDCOR	1
Helena River	HRJSB	4			

Glossary and acronyms

Acid sulphate soils	Acid sulphate soils are naturally occurring soils, sediments and peat that contain iron sulphides. When exposed to the atmosphere through lowering of the watertable or excavation, oxygen reacts with the iron sulphides in the soil. This oxidation reaction results in the production of sulphuric acid which can cause a breakdown of the soil structure releasing metals, precipitates and nutrients with potentially adverse environmental impacts.
Acidity	The state, quality, or degree of being acid (that is, a substance that yields hydrogen ions when dissolved in water). pH values below 7.
AASS	Actual acid sulphate soils.
Acute toxicity	A substance that is acutely toxic induces harmful effects in an organism through a single or short-term exposure.
ADWG	Australian Drinking Water Guidelines.
Alkalinity	The quantitative capacity of aqueous media to react with hydroxyl ions. The equivalent sum of the bases that are titratable with strong acid. Alkalinity is a capacity factor that represents the acid-neutralising capacity of an aqueous system.
ANC	Acid neutralising capacity.
ANZECC	Australian and New Zealand Environment and Conservation Council.
ANZFA	Australia New Zealand Food Authority.
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand.
ASS	Acid sulphate soils.
Benthic flux	Movement of substance between the sediments of aquatic habitats and the water interface.
Bioaccumulation	The increasing concentration of a compound in the bodies of living organisms at successively higher levels in the food chain.
Bioavailable	The fraction of the total chemical in the surrounding environment that can be taken up by organisms.
BOD	Biological oxygen demand.
BOM	Bureau of Meteorology.
BTEX	Benzene, toluene, ethylbenzene, xylenes.

Carcinogenic	A cancer causing substance or agent.
Catchment	The area of land which intercepts rainfall and contributes the collected water to surface water or groundwater.
SCr	Chromium reducible sulphur suite. This is a set of independent analytical methods each of which determines a component of the acid sulphate soils.
Chronic toxicity	Property of a substance that has toxic effects on a living organism, when that organism is exposed to the substance continuously or repeatedly often at sub-lethal concentrations.
Concentration	The quantifiable amount of chemical in the water or sediment.
Compensating basin	Many stormwater drains discharge into compensating basins to allow temporary storage of runoff and reduce the need for large capacity stormwater drains.
Contaminant	A substance which has the potential to present a risk of harm to human or environmental health.
Detection limit	The smallest concentration or amount of a substance that can be reported as present with a specified degree of certainty by definite complete analytical procedures.
Diffuse source	A source of pollution that cannot be attributed to a clearly identifiable, specific physical location or a defined discharge channel, including the nutrients that enter waterways from any land use.
DO	Dissolved oxygen.
DoAg	Department of Agriculture.
DOC	Dissolved organic carbon.
DOE	Department of Environment.
DOW	Department of Water.
Drain site	In the current investigation this includes waterways such as man-made pipes or channels, brooks, creeks and compensating basins.
Ecotoxicology	The study of the toxic effects of chemicals upon ecosystems and indicator organisms.
Endocrine disruptor	A foreign substance or mixture that alters function(s) of the endocrine (hormone) system, consequently harming an individual life form, its offspring, or populations.

EPA SA	Environment Protection Authority, South Australia.
Eutrophication	Nutrient enrichment of a waterway, often accelerated as a result of human activity.
FRP	Filterable reactive phosphorus.
Hermaphrodite	An organism that possesses both male and female reproductive systems, producing both eggs and sperm.
Hydrocarbon	Organic compounds composed of carbon and hydrogen atoms.
Hydrophobic	'Water hating' – hydrophobic molecules tend to be nonpolar and thus prefer other neutral molecules and nonpolar solvents. Hydrophobic molecules in water often cluster together. Water on hydrophobic surfaces will exhibit a high contact angle.
Inorganic	Not containing carbon.
Ions	Electrically charged particles. Many chemicals are present as ions when dissolved in water.
ISQG	Interim Sediment Quality Guidelines
Leaching	The removal of (nutrients) by water percolating through soil.
Limit of reporting	Lowest level of detection achievable by the laboratory. This is the level that another laboratory should reach given the same instrument, method and sample matrices.
Lipophilic	'Fat loving'. Those materials that attract non-polar organic compounds, most notably oils, fats, greases, and oily substances. Lipophilic materials and compounds tend to be hydrophobic.
MBAS	Methylene blue active substances.
Microbial	Pertaining to microorganisms, organisms that are microscopic in size.
Molecular weight	The sum of the atomic weights of all the atoms in a molecule.
Mutagenic	An agent, such as a chemical that can induce or increase the frequency of mutation in an organism.
NHMRC	National Health and Medical Research Council.
NNCP	Non-Nutrient Contaminants Program.
OC pesticide	Organochlorine pesticide.
OP pesticide	Organophosphorus pesticide.

Organic	Containing carbon and includes most molecules associated with living organisms.
Oxidation	The combination of oxygen with a substance, or the removal of hydrogen from it or, more generally, any reaction in which an atom loses electrons.
Oxides	A compound of oxygen with another element that has a greater tendency to release electrons.
PAH	Polycyclic aromatic hydrocarbons.
PASS	Potential acid sulphate soils.
PCB	Polychlorinated biphenyls.
Ped	A natural soil aggregate.
Persistent	Any toxic substance with a half-life in water, sediment, soil, air or biota of greater than eight weeks.
pH	A measure of acidity, neutrality or alkalinity. Measured on a logarithmic scale of 1 to 14 where an acid solution is one with a pH less than 7 and an alkaline solution has a pH greater than 7. A neutral solution has a pH of 7.
Physiochemical	Refers to the physical and chemical characteristics of a substance.
Phytoplankton	Free floating or weakly mobile photosynthetic organisms, usually single-celled or chain-forming.
Phytotoxic	Toxic to plants.
Point source	A source of pollution that can be attributed to an identifiable source such as an outfall.
QA	Quality assurance.
QC	Quality control.
Reduction	A gain of electrons or a decrease in oxidation number.
SAP	Sampling and analysis plan.
SCCP	Swan Canning Cleanup Program.
Sediment	Loose particles of sand, clay, silt and other substances that settle at the bottom of a body of water. Sediment can be derived from the erosion of soil or from the decomposition of plants and animals.
Spatial	Relating to space.

Subcatchment	Distinct drainage areas that form components of the overall catchment for a river or other body of water.
Temporal	Relating to, or limited by time.
Teratogenic	Able to cause defects to a developing embryo.
TOC	Total organic carbon.
TPH	Total petroleum hydrocarbons.
Trigger level	The concentrations (or loads) of the key performance indicators measured for the ecosystem, below which there exists a low risk that adverse biological (ecological) effects will occur. They indicate a risk of impact if exceeded and should ‘trigger’ some action, either further ecosystem specific investigations or implementation of management/remedial actions.
Tributary	A stream that flows into a larger stream or other body of water.
TSS	Total suspended solids.
UPRCT	Upper Parramatta River Catchment Trust.
USEPA	United States Environmental Protection Authority.
WHO	World Health Organisation.

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