Department of Water
Government of Western Australia

Contaminants in Stormwater Discharge, and Associated Sediments, at Perth's Marine Beaches

Beach Health Program 2004-06

April 2007

Australian Government

Government of Western Australia

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Funding

The study was funded by the Swan Catchment Council and the Department of Water. The microbial analyses were funded by the Department of Health.

April 2007

Cover photograph

Scarborough Beach, Perth, Western Australia: aerial view of the coastal roads, car parks and reserves that make up the catchments for drains discharging to the beach. Inset: Department of Water Officer sampling stormwater at SCBO3. Photographs by Dieter Tracey.

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Summary

Stormwater and associated sediments at Perth's marine beaches are contaminated predominantly with microbes and heavy metals. Nutrients, petroleum hydrocarbons, organic chemical compounds and suspended solids are also present in stormwater but to a lesser extent.

These findings were a result of the first comprehensive baseline study of the types and concentrations of contaminants in and around 65 stormwater drains in the Swan Region. The drains were located in nine regions defined by the Cities of Wanneroo and Joondalup and the Towns of Cambridge and Cottesloe. The City of Stirling was further divided into the regions of Stirling and Scarborough, and the City of Rockingham into the regions of Rockingham, Shoalwater and Safety Bay. The catchments for these drains consisted mostly of coastal roads, public car parks and reserves. Although the types of contaminants reflected those expected from these types of catchments, the concentrations of some of the contaminants were far greater than expected.

The study highlights areas of concern at both a regional and site scale to aid local government in managing stormwater. To summarise:

- Microbial quality (enterococci concentrations) in stormwater from drains was extremely poor – with recordings of around 20 times the guideline for secondary contact (ie fishing or boating) in six regions. This result may have more serious implications – since pools or channels of stormwater can attract children to engage in primary contact (ie swimming and splashing).
- Microbial quality in the swash zone, an area where swimming is most likely, was also poor with seven of the nine regions exceeding primary contact guidelines. Four regions (Rockingham, Safety Bay, Stirling and Cottesloe) exceeded these guidelines by at least six-fold.
- Total metal concentrations (aluminium, copper, iron and lead) in stormwater in four of the nine regions (Joondalup, Stirling, Scarborough and Cottesloe) were consistently higher than other regions, exceeding environmental guidelines by up to 21-fold. These regions were north of the Swan River.
- Conversely, total metal concentrations in sediment were higher in three regions south of the Swan River. And although none exceeded the environmental guidelines, three specific sites exceeded recreational or health guidelines for Cu (STG06) and Pb (COT02, COT10).
- Nutrient concentrations were generally low relative to the other contaminants and their guidelines. However, there were some notable exceptions:
  - Dissolved nutrient concentrations were high in Cambridge (nitrogen oxides by six-fold), Scarborough and Safety Bay (ammonia by four-fold); and Cottesloe (filterable reactive phosphorous by two-fold) relative to guidelines. Total phosphorus concentrations in all of the regions except

Cambridge, exceeded environmental guidelines by up to two-fold. This was mostly due to particulate phosphorous.

- Total petroleum hydrocarbons, although below detection limits in the majority of drains, were particularly high, north of the Swan River in Joondalup, Stirling and Cottesloe.
- Sites of concern include one in Stirling (STG06) that consistently exceeded guideline levels for petroleum hydrocarbons as well as heavy metals in stormwater (aluminium, copper, iron, and lead) and in sediment (copper); and the site in Cambridge (HMD) which, unlike most drains, flows continuously and where NOx levels exceeded guidelines by six-fold. Another site in Cottesloe (COT05) exceeded guidelines for enterococci; nutrients (TP, FRP); metals in stormwater (aluminium, copper, iron and zinc), as well as total petroleum hydrocarbons.

A summary of the key contaminant issues for each region is provided below:

Local Government	**Microbial Quality**	**Metals**	**Nutrients**	**Hydrocarbons**
All regions	in drains	Al, Fe, Cu, Zn	see below	see below
Wanneroo	as above	Pb	NH4 and TP	below detection
Joondalup	as above	Pb	NH4 and TP	total petroleum hydrocarbons
Stirling	in swash	Pb	All	total petroleum hydrocarbons
Cambridge	not an issue	highly variable	NOx	below detection
Cottesloe	in swash	Pb	FRP	total petroleum hydrocarbons
Rockingham	in swash	Pb	NH4	below detection

In most cases, concentrations of contaminants were compared to relevant environmental or recreational guideline values. However, there are no guidelines specifically for contaminants in the drains themselves. In order to provide an indication of where local governments should focus their efforts in managing stormwater contaminants, concentrations were compared to the most appropriate guidelines for drain water.

The effect of time scale on concentration of contaminants was examined in a few select drains. The data showed that large variations in concentrations can occur within the space of a few days and quite late in the rainy season. This suggests that at some drains, the quality of stormwater should be managed throughout the rainy season, not just at the first flush.

In addition to the baseline stormwater contaminant sampling, a pilot study was initiated to assess the impact of these contaminants on near-shore coastal ecosystems. The most significant finding was that lead in near-shore sediments appears to limit the productivity of microalgae (microphytobenthos) that live in these sediments.

This study was based on the assumption that the productivity of the microphytobenthos would alter in response to changes in nutrient and heavy metal inputs from stormwater and that particle size would be linked to contaminant concentrations. However, there were no consistent trends between microphytobenthos and the other variables in relation to their proximity to stormwater drains. This was probably due to the sampling design not taking into account the water circulation patterns that may have altered the flow of stormwater discharge and therefore contaminants in the study area.

Despite not being able to find a direct relationship between drain location and lead concentration, the source of lead in near-shore sediments is most likely to be from stormwater that flows over heavily used coastal roads and car parks. At the location of the study, it could also be from runoff associated with a service station located nearby. This hypothesis is supported by the fact that lead was found in concentrations above guideline levels in the drains that flow into this region. The high turnover of sediments in the swash zone of this area also suggests that the lead is most likely from a recent rather than historical source.

Regardless of the source of lead, it is important to investigate this contamination further. Microphytobenthos form the basis of the marine food chain and can therefore pass on toxicants to invertebrates and other organisms that rely on them as a food source.

In conclusion, the Beach Health Program has shown that contaminant concentrations can exceed recreational as well as environmental guidelines by many times, depending on the region, site and rainfall event. This information will be essential for local governments in developing plans for managing stormwater. Based on the results from this study, the City of Rockingham has already commenced an assessment of its stormwater management.

The study was funded by the Swan Catchment Council and the Department of Water with the microbial analyses funded by the Department of Health.

Recommendations

1. The Beach Health Program has shown that contaminant concentrations in and around drains can exceed recreational as well as environmental guidelines by many times. Since many of these drains flow to areas accessible to the public and to sensitive marine environments, we recommend that local governments investigate the sources of these contaminants and reduce them to manage the risks associated with these areas. It is also essential that local government monitor and maintain the relevant infrastructure or management practice, at regular intervals, to assess how effective they are. These are the elements of best practice methods for managing stormwater as described in the *Stormwater Management Manual for Western Australia* (DoW 2004-).

2. Diverting stormwater to groundwater, as a means to reduce the impacts of its contaminants on recreational activities and the environment, without controlling and treating the sources of contaminants, is not recommended. Some local governments are currently diverting stormwater this way and others are planning to implement this practice. This is not recommended because we do not know the degree of connection between stormwater, groundwater and near-shore coastal zones, nor what happens to the contaminants as they make their way through these different water bodies.

1 Introduction

1.1 Background

Stormwater runoff is a potential threat to the quality of coastal systems, waterways and estuaries in many parts of urban Australia. Stormwater comprises all forms of runoff from urban areas where flows are exacerbated by the increasing network of impervious surfaces such as roads, roofs, footpaths and car parks. Stormwater is essentially pure rainwater, plus anything else collected from these surfaces. The water flows through a network of drains and pipes, sometimes via groundwater, to receiving waters, carrying with it contaminants collected along the way. A list of common contaminants and possible sources is provided below:

Contaminant – most common examples	Sources for coastal drains
Metals – zinc, cadmium, copper, chromium, arsenic and lead	Vehicle use, wear and tear, including: brake pad and tyre deterioration (cadmium, copper, iron, lead and zinc). Exhaust (nickel and lead). Engine wear (iron, manganese, nickel, lead and zinc). Other sources of metals include: used motor oil, diesel oil and grease. Infrastructure deterioration including pipes and roof tops.
Toxicants – household chemicals, garden pesticides and herbicides	Garden landscaping (fertilizers and pesticides). Cleaning cars, verges and driveways (detergents, bleach and other chemicals).
Pathogens – viruses, bacteria and protozoa	Pets at parks and dog beaches. Bird congregations. Garden manures. Sewer overflows. Degraded sanitary infrastructure and septic systems.
Nutrients – nitrogen and phosphorus	Fertilisers. Organic matter including leaves and clippings raked into stormwater drains. Vehicle exhausts (nitrogen). Degraded sanitary infrastructure and septic systems (mainly nitrogen).
Sediment – soil, sand and silt	Construction activity (particulates).
Petroleum products – hydrocarbons, oil and grease	Vehicle use; maintenance; disposal of used oil and other fluids; transmission and engine leaks. Gas vapours from filling tanks. Car washing. Industrial discharges.
Litter	Visible pollution (paper cups; cigarette butts; cans; wrappers).

Increasing urbanisation leads to an increase in runoff and this process concentrates freshwater flows to localised receiving waters, including man made systems (retention ponds and basins) and natural environments (lakes, estuaries and near-shore coastal waters). As a result, contaminants become localised in areas causing a reduction in water quality, sediment quality and/or causing ecosystem changes, such as reduced species biodiversity or a change in species composition. Local communities may also be affected through social impacts, including health warnings and beach/ river closures.

The Swan Region Strategy for Natural Resource Management (SCC, 2004) has identified that a major gap exists concerning baseline understanding of stormwater quality at beach outfalls and potential impacts on near-shore marine environments. There is currently only patchy monitoring of the stormwater drains that discharge into the ocean at metropolitan beaches and no research has been done on the impacts of stormwater discharges on coastal ecosystems in Western Australia.

Water Corporation collects water quality data from several Water Corporation Main Drains that discharge along the metropolitan coast. In addition, JDA Consultant Hydrologists on behalf of the Western Suburbs Regional Organisation of Councils (WESROC) sampled two stormwater outfalls along Cottesloe beach in 2004 and in 2006 (JDA, 2007).

The amount of impervious surface within a catchment, coupled with volume of rainfall and therefore stormwater volume and velocities, would result in increased energy to mobilise pollutants within the catchment. While the Swan Coastal Plain is becoming increasingly urbanised the impact of stormwater on local receiving waters, specifically marine environments, may not be as big an issue for beach goers as in other States. This is due to the nature of Perth’s rainfall, being low annually and also not prone to high flooding events as seen on Australia’s east-coast. Furthermore, from a health perspective stormwater flows to local beaches are minimal in the summer months when beaches are busiest.

Stormwater discharge can enter the marine environment, either through direct discharge to the ocean or as surface runoff via channels cut down the beach, as formed by the volume and velocity of stormwater flows. Stormwater can also enter the marine environment indirectly through sub-marine discharges, such as through groundwater. The latter is possibly the most dominant scenario in the Swan region due to the porous sandy soils of the Swan coastal plain and the underlying limestone caste system, which facilitates the storage and movement of shallow groundwater. A conceptual model has been drawn to highlight the primary pathways of stormwater contamination in the coastal zone, and the near-shore habitats that could be affected (Figure A 1). The model shows that in the Swan Catchment Council natural resource management region, 13 drains discharge to vegetated swale areas, 20 discharge to the dunes some distance from the beach, 39 discharge to the beach and only 5 discharge direct to water (numbers encircled). The remaining drains in the region discharge to artificially constructed environments such as marinas and boat harbours.

This model was used to select sites for the water and sediment quality sampling program (Part A — Water and sediment quality sampling program) and for the pilot study of potential impacts on near-shore habitats (Part B — Impacts on near-shore marine habitats — a pilot study).

The main catchments for stormwater drains discharging to coastal beaches and/or marine waters consist of urban roads, reserves and car parks. Thus, the suite of parameters chosen as indicators of stormwater and sediment quality are based on contaminants expected from these areas.

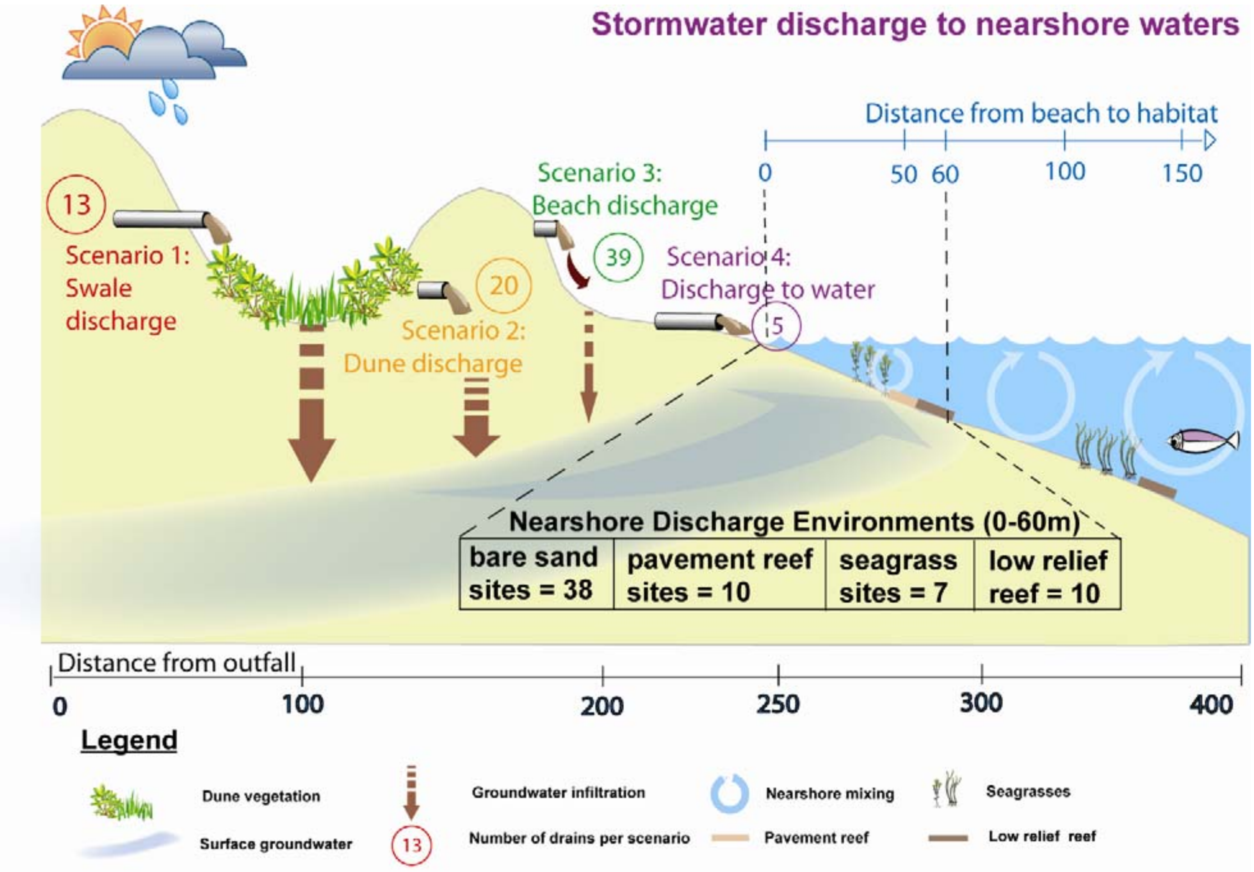


Figure A 1. Conceptual model: fate of stormwater discharge in the Swan Coastal Region

1.2 Beach Health Program

In 2003, the Western Australian State Government made a $50 000 commitment, in consultation with local government, to the Beach Watch program to identify any possible contaminants that might be in stormwater and adjacent sediments at local beaches. This State funding was used to leverage a further $230 000 of federal funds from the National Action Plan for Salinity and Water Quality, National Heritage Trust and National Landcare Program. With these funds, the Beach Health Program was initiated and administered by the Swan Catchment Council. Further assistance was provided by the Department of Health in meeting the analysis costs for microbial water and sediment quality.

Several other collaborators contributed to the Program: Coastcare officers were an integral part of the sampling effort; local government officers and the Rottnest Island Authority were instrumental in providing information on drainage systems as well as assisting with sampling; and UWA examined contaminant loads discharging from the drains.

The Beach Health Program was initiated to investigate:

- water quality – bacteria, nutrients, heavy metals and petroleum product concentrations in the stormwater in coastal drains;
- sediment quality – heavy metals and bacteria in sediments adjacent to these drains; and the
- effects of contaminants on near-shore coastal marine environments.

1.3 Purpose of the monitoring

The purpose of the Beach Health stormwater assessment was to:

a. Create an inventory of stormwater drains discharging to the Swan coastal region.

b. Establish baseline water and sediment quality at prioritised drains to assist local government to prepare stormwater management plans;

c. Create an inventory of and identify drains that discharge to the near-shore marine environment with sufficient flow to justify further investigation into their potential impact; and

d. Investigate the impact of stormwater on near-shore marine ecosystems.

This report is written in two parts. Part A is the water and sediment quality program to assess contaminant concentrations in water and sediment at the stormwater drains (a. and b. above) and Part B investigates the potential impact of contaminants on near-shore marine ecosystems (c. and d. above).

1.4 Environmental and human health guidelines applied

In general, there were no guidelines available specifically for stormwater contaminants. We therefore used the most appropriate guidelines that were available. They are used as a means of highlighting areas of concern to local government, not, for example, to close down beaches. The justifications for using these guidelines are discussed in detail in this section. Note that averages, rather than medians, were compared to guideline values since 80 per cent of the sites were sampled ≤ three times each. ANZECC & ARMCANZ (2000) recommend that at least five data points be used to calculate a median for comparison to guidelines.

1.4.1 Nutrients, heavy metals, organic contaminants and total suspended solids in drain water

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality were applied for the drain water contaminants (nutrients, heavy metals and organic contaminants) (ANZECC & ARMCANZ, 2000) (Table A 2). These guidelines have trigger values for fresh and marine waters and in the case of nutrients have trigger values for lakes, wetlands, rivers, estuaries and marine waters. Nutrient values used are specific to the south west of WA (ANZECC & ARMCANZ, 2000). For this study, guideline trigger values for metals in freshwater and nutrients in lowland river waters were applied.

This decision was based on three considerations. Firstly, mixing with marine waters does not occur instantaneously at most outlets. Stormwater remains in freshwater pools at the source or infiltrates to the groundwater via channels cut down the beach. And, on categorising the drains according to their point of discharge, it can be seen that direct flow to marine waters is not the norm except during large storm events or where the outlet discharges directly to the ocean: most do not (Figure A 1).

Secondly, freshwater trigger values were applied because councils are increasingly opting to remove stormwater outlets from beaches, removing direct discharge to marine waters, but increasing discharge to groundwater. As a result of this, and given retention times in this medium and relatively slow flow rates to marine waters, the behaviour and toxicity of contaminants in this shallow subterranean aquifer is of concern. Groundwater flow rates in the Rockingham region in Safety Bay sand have been estimated at 10-100 m/year (Trefry *et al*. 2006).

Finally, guideline values are established to protect the receiving waters from contaminants. In the Beach Health Program, the application of these guideline values to stormwater must be treated with caution and consideration should be given to mixing and dilution effects with marine waters, and retention times within sheltered or highly exposed coastal environments.

With our application of the guidelines, we have taken a less conservative approach by using the freshwater values. It can be seen from a comparison of the nutrient data exceeding fresh and marine water guideline values for one drain at Scarborough (SCB02) that the freshwater guidelines are higher than the marine (Table A 1). And therefore, although all of the nutrient data exceed the freshwater guidelines, none exceed by more than 10 or 100 times as they do when compared to the marine guidelines.

Table A 1. A comparison of fresh (FW) and marine water (MW) environmental guideline levels (EGLs) for nutrient concentrations (mg/L) at one site (SCB02)

(ANZECC & ARMCANZ, 2000)

Nutrients	Actual data	FW EGL	MW EGL
NOx	0.151	0.150	0.005
TN	2.35	1.200	0.230
NH4	1.034	0.080	0.005
TP	0.211	0.065	0.020
FRP	0.130	0.040	0.005

Exceeds guideline
>10 x guideline
>100 x guideline

The guidelines (ANZECC & ARMCANZ, 2000) stress that environmental values are not intended for direct application to stormwater quality, unless there is considered conservation value. Many of the sites selected for the study occur within the Swan region, in coastal areas with high recreation value. Many also occur in marine protected areas for example Shoalwater Island Marine Park, Marmion Marine Park and Cottesloe Fish and Fish Habitat Protection Area. And therefore we have applied the ANZECC & ARMCANZ (2000) guidelines to the drains in this study (Table A 2). From this point on environmental guideline trigger values will be referred to as environmental guideline levels (EGL) or guidelines.

1.4.2 Microbial quality in drain, swash and sediment

Indicator bacteria are a component of water quality that is used to determine the suitability of a water body for recreational purposes. High levels of bacteria indicate an increased risk of becoming ill 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 & ARMCANZ 2000).

The purpose of this component of the study was to examine indicator bacteria levels in stormwater runoff in relation to human health, in this case at the local marine beaches (swash waters and sediment) of the Swan coastal region.

Perth beaches are popular recreational outlets for adults and children. Stormwater from these drains may not always reach the swash zone where users may be swimming but may filter into the beach sand and/or collect in large pools, which may result in direct contact.

The ANZECC & ARMCANZ (2000) recreational water quality guidelines are largely based on recommendations from the World Health Organisation (WHO) including draft WHO *Guidelines for Safe Recreational-water Environments: Coastal and Fresh Waters* and WHO *Health-based Monitoring of Recreational Waters: The Feasibility of a New Approach (The 'Annapolis' Protocol)* (WHO 1999) (ANZECC & ARMCANZ 2000). New guidelines for the management of recreational waters are now also available from the National Health and Medical Research Council (NHMRC 2005) based on WHO (2003). As this study was commenced before the new guidelines were released, we will continue to refer to the ANZECC & ARMCANZ (2000) guidelines.

The indicator bacteria tested for are thermotolerant coliforms and enterococci. Both are tested for in stormwater, which represents freshwater conditions. While only enterococci are tested for in the receiving marine and sediment environments as they persist for longer in saline conditions. These indicator bacteria are not defined as the causative agents of illnesses in swimmers, but appear to correlate with the diseases (Prüss 1998 in NHMRC 2005).

Guidelines for recreational waters are divided into two categories — primary and secondary contact (Table A 2). Primary contact includes activities such as swimming, bathing and other direct water contact sports. Secondary contact guidelines are in most cases less stringent and refer to activities such as fishing and boating — activities that would involve less contact with the water (ANZECC & ARMCANZ 2000). The exception is when shellfish might be taken from the environment, as consumption would translate into direct contact.

Although we have interpreted the data with respect to the ANZECC & ARMCANZ recreational guidelines, the following should be noted:

The guidelines only refer to recreational waters (swash) and not stormwater or sediment. However, there are no other applicable guidelines for stormwater or sediment quality.

The guidelines refer to a median value over a bathing season. Median values require at least five observations. In this study, and for most of the sites (80%), we use an average based on three or fewer observations per site, the remaining 20 per cent were based on four or more observations.

Data collected in this study has been rain event driven and not specific to a Perth bathing season, in an attempt to capture flows from stormwater drains. We would expect bacteria levels to be higher during rain events. Although we have not sampled during the main bathing season many bathers and surfers do make use of local beaches all year round. Surfers in particular enjoy the winter conditions as swell often increases at that time of year.

It should also be noted that we have not measured how long these bacteria persist in the receiving environments (swash and sediment) and therefore it is more difficult to assess the level of risk associated with high numbers of bacteria.

1.4.3 Heavy metals in sediment

Sediment samples collected in the drain channel were analysed for heavy metals and compared to health-based investigation levels (or HILs) compiled by the National Environment Protection Council Assessment of Contaminated Sites (NEPM, 1999).

Standard residential trigger values were applied to each metal and a recreational open space trigger value was applied to nickel (Table A 2).

The health as opposed to environment guidelines (ANZECC & ARMCANZ, 2000) were applied in favour of guidelines for the protection of marine and freshwater values for the following reasons: a) sediments adjacent to outfalls were generally higher up on the beach, not in marine waters affecting near-shore marine sediments and habitats, b) sediments impacted by stormwater form part of the recreational beach area and children playing with sand in the drain channel, were considered at greater potential risk from sediment contamination than near-shore environments c) even though at some sites wave action might resuspend sediments, potentially resuspending metals, none of the data at any of the sites exceeded environmental guidelines.

1.4.4 Petroleum hydrocarbons in drain

The ANZECC & ARMCANZ guidelines (2000) do not contain any environmental levels for total petroleum hydrocarbons (TPHs) in marine or freshwaters. However, one Australian reference (Tsvetnenko, 1998), has provided an advisory water quality criterion to protect warm water marine organisms from unacceptable levels of ambient TPH, this value was calculated as 0.007mg/L (Table A 2). However, the application of this guideline value must be treated with caution as it does not apply to stormwater concentrations, only ambient water quality in the receiving environment and is below the detection limits used in this study. As mentioned earlier it assists in highlighting areas of concern to local government.

1.4.5 Organic chemical compounds in drain

For benzene, toluene, ethylene and zylene (BTEX) and polyaromatic hydrocarbons (PAHs) (eg naphthalene, acenapthalene etc), a freshwater low reliability trigger value for ecosystem protection was used (ANZECC & ARMCANZ, 2000 – Section 8.3) (Table A 2).

1.4.6 Total suspended solids

There are no guidelines for total suspended solids specifically in stormwater. However, ANZZEC & ARMCANZ (2000) do provide a range of values for turbidity (measured in nephelometric turbidity units – NTU) in different water bodies. They also state that the range of values for suspended particulate matter or total suspended solids (TSS) are similar to those for turbidity and therefore the range for lowland rivers in the south-west of Australia will be used for comparison to drain values (10 to 20 NTU). The guideline should be applied with caution as it was given in NTU units, which are not directly comparable to TSS measured in mg/L unless a calibration has been performed on the sampled water.

Table A 2. Water and sediment quality parameters with Recreational (RGL), Environmental (EGL) and Health-based Investigation Guideline Levels (HIL).

Parameter	RGL/EGL
Indicator Bacteria	**RGL** **Contact type (organisms/100 mL)**
Enterococci (confirmed) (mpn/100mL)	Primary – 35 Secondary – 230
Thermotolerant coliforms (presumptive) (cfu/100 mL)	Primary – 150 Secondary – 1000
Nutrients (Lowland river)	EGL mg/L
NOx (Total oxidised nitrogen)	0.150
Kjel (Total Kjeldahl nitrogen) (calculated)	-
TN (Total nitrogen)	1.200
NH_4 (Ammonium nitrogen)	0.080
TP (Total phosphorus)	0.065
FRP (Soluble reactive phosphorus)	0.040
BTEX	**EGL mg/L**
Benzene	0.950
Toluene	0.180
Ethylbenzene	0.080
Xylene	No Data
Polycyclic aromatic hydrocarbons (PAH)	**EGL mg/L**
(Naphthalene)	0.016
Total petroleum hydrocarbons (TPH), mg/L**	0.007

Parameter		EGL/HIL
Metals – water		**EGL mg/L**
All metals – freshwater, 95% protection trigger value.	Al	0.0550
	As (III)	0.0240
	Cd	0.0002
Cr (III) – marine, 95% protection trigger value (in the absence of a freshwater value).	Cr (III)*	0.0274
	Cu	0.0014
	Fe*	0.300
	Pb	0.0034
	Mn	1.900
	Hg	0.0006
	Ni	0.0110
	Zn	0.0080
Metals – sediment		**HIL mg/kg*****
All metals – HIL standard residential trigger value.	Al	No Data
	As (III)	No Data
Ni only – HIL recreational open space trigger value.	Cd	20
	Cr (III)	No Data
	Cu	1000
	Fe	No Data
	Pb	300
	Mn	1500
	Hg	15
	Ni	600
	Zn	7,000
TSS (Lowland rivers, South West Australia)	10 to 20 NTU (as a turbidity measure)	

All guidelines from ANZECC & ARMCANZ (2000) except where marked with an asterisk. See below.

* CCREM 1991. *Canadian water quality guidelines*. Canadian Council of Resource and Environment Ministers, Inland Waters Directorate, Environment Canada, Ottawa,

** Advisory water quality criterion for marine organisms (Tsvetnenko, 1998).

*** Health-based investigation levels (HILs), standard residential trigger value. (National Environment Protection (Assessment of Site Contamination) Measure, 1999).

Part A — Water and sediment quality sampling program

Drain (NSTO3) at Sorrento Beach showing channel formed by flowing stormwater. Photograph by Helen Astill.

2 Methods

The aim of this work was to evaluate the pollution potential of stormwater drains and provide the incentive for pollution reduction strategies. Sampling occurred in response to rainfall events. Approaching fronts were identified using Bureau of Meteorology radar images http://mirror.bom.gov.au/weather/radar which are updated every 10 minutes. In most cases grab samples were taken during, or shortly after, heavy rainfall – within a few hours of flow commencing.

2.1 Stormwater drain inventory and prioritisation

Approximately 100 stormwater drains, spanning 90 km of coastline north and south of the Swan River, discharge to the coast of the Swan region (Figure A 2 and Figure A 3). The list of drain locations was compiled with the assistance of local councils, Water Corporation and from viewing relevant engineering maps of local drain networks. The drains were categorised, and some were removed from the target list using the following criteria:

- ability to locate drains – low priority drains were those that were missing as a result of outdated engineering plans, that were removed during the course of the monitoring program, or temporarily buried due to extensive and seasonal sand movement
- access to drains – low priority drains may have poor access for collecting samples. The drain may be in a dangerous location or may be overgrown with vegetation and therefore not accessible/easy to sample.
- their point of discharge – ie whether the drain emptied to the dunes, beach or direct to the ocean; and the total distance from the beach/ocean, eg a drain was considered low priority if it only drained a small car park and was located 100 m from the beach;
- environmental/ecological priority – low priority drains may discharge to marinas or other man made environments and high priority drains may include drains with direct discharge to a popular surfing beach or to a seagrass meadow;

Following this assessment, the number of stormwater drains available for sampling as part of the program was reduced. This report provides water and sediment quality data for these drains. They span nine regions as defined by the Cities of Wanneroo (WAN) and Joondalup (JND and NST) and the Towns of Cambridge (HMD) and Cottesloe (COT). The City of Stirling was further divided into the regions of Stirling (STG) and Scarborough (SCB), and the City of Rockingham into the regions of Rockingham (ROC), Shoalwater (SHL); and Safety Bay (SB and WK). Note that the drains in the City of Fremantle were not included in the sampling program because they discharge into highly disturbed environments: – marinas and harbours (Figure A 2).

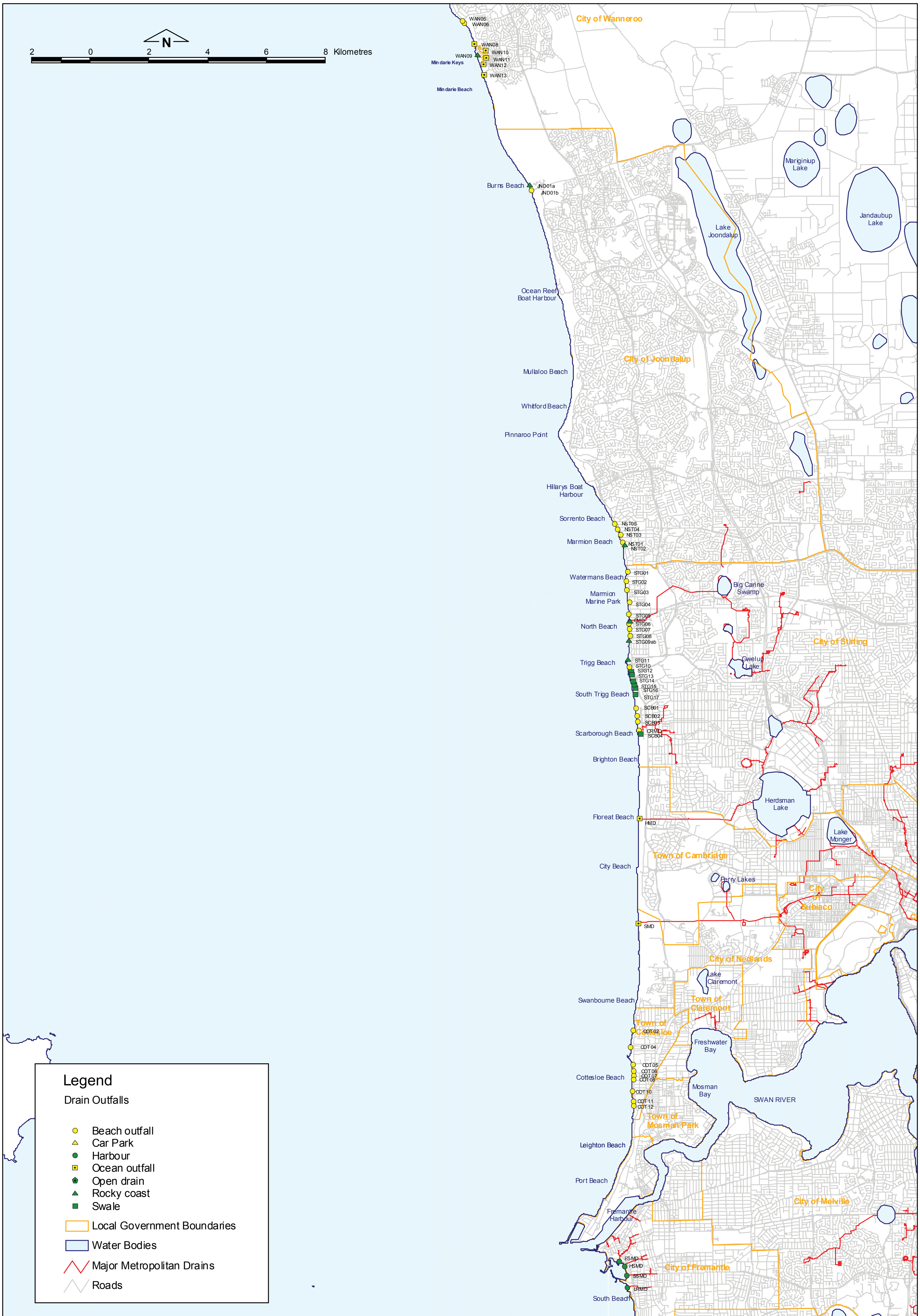


Figure A 2 Location of stormwater drains north of the Swan River: Wanneroo (WAN), Joondalup (JND), north Stirling (NST), Stirling (STG), Carine Main Dain (CMD), Scarborough (SCB), Colin Road Main Drain (CRMD), Herdsman Main Drain (HMD), Subiaco Main Drain (SMD), Cottesloe (COT), Essex Street MD(ESMD), Howard Street MD (HSMD), South Street MD (SSMD) and Lefroy Road MD (LRMD).

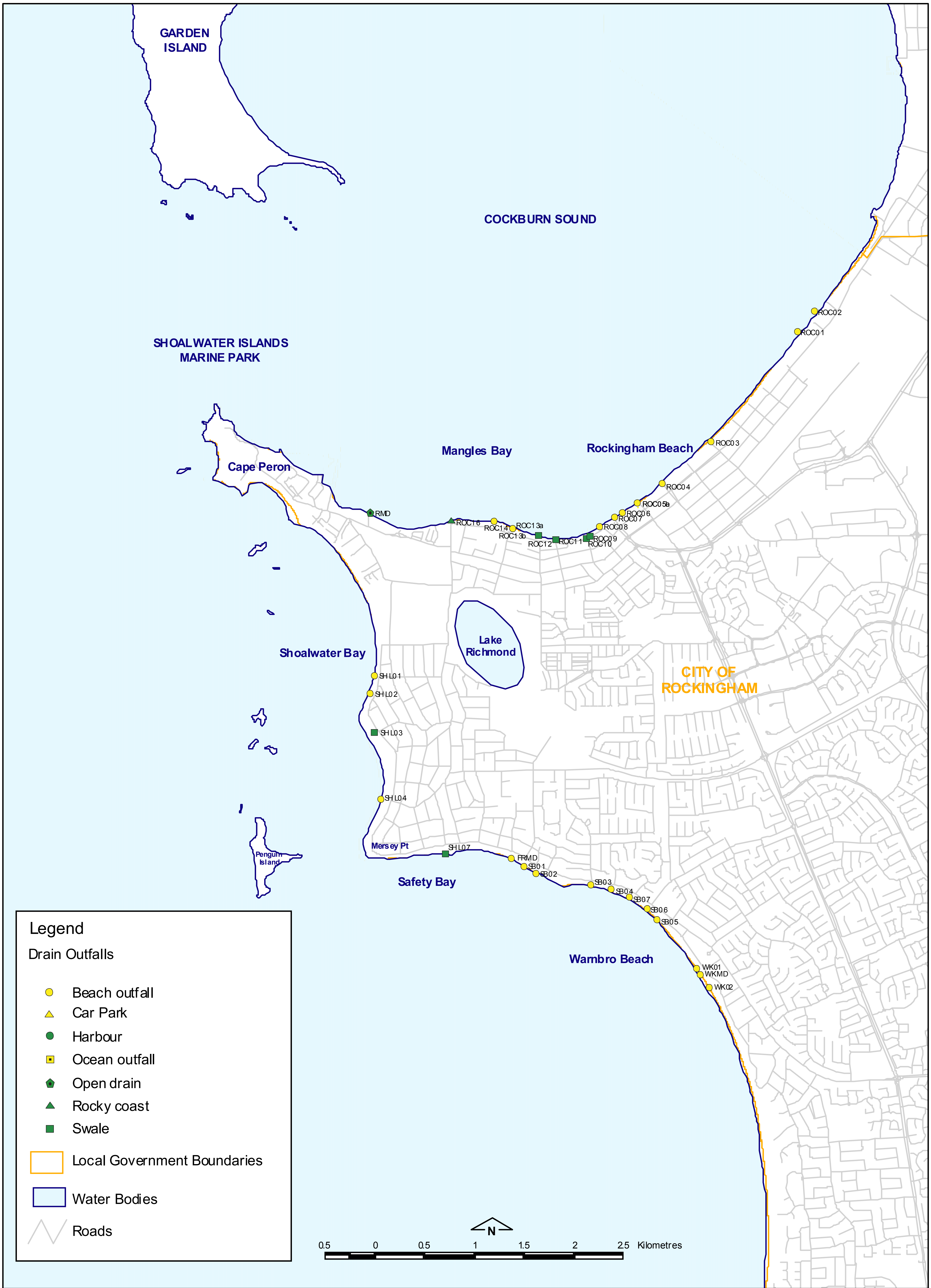


Figure A 3 Location of stormwater drains south of the Swan River: Rockingham (ROC), Rockingham Main Drain (RMD), Shoalwater (SHL), Forrest Road Main Drain (FRMD), Safety Bay (SB), Waikiki (WK) and Waikiki Main Drain (WKMD).

2.2 Water and sediment quality parameters

The parameters identified as of potential concern in stormwater discharge were chosen based on the catchments, their use as recreation areas and their proximity to near-shore marine ecosystems. The catchments for these drains mostly consisted of suburban coastal roads, public car parks and reserves. In addition to stormwater, the sediment immediately beneath the drains was also sampled for potential contaminants. This decision was based on observations at local beaches where beach goers were regularly seen recreating (playing, picnicking, building sand castles and swimming) in stormwater pools and channels cut down the beach. Where possible all parameters were analysed at each site to establish baseline information and to identify any possible areas of concern at Perth metropolitan beaches.

Nutrients, heavy metals, petroleum hydrocarbons, organic compounds, total suspended solids and microbial quality in stormwater were measured. In addition, heavy metals and microbial quality in sediments beneath the drain; and microbial quality in the oceanic swash zone adjacent to drains, were also measured. A majority of the drains were sampled at least three times.

Water and sediment samples were taken to NATA accredited laboratories within 24 h for analysis of the parameters. The parameters, their description and method of analysis and their limits of reporting are recorded in Table A 3. Microbial quality using bacteria indicators were analysed by Path West (Nedlands Western Australia). Please note that the units for indicator bacteria are either cfu/100 mL (thermotolerant coliforms in water) or mpn/100 mL (enterococci in water) and mpn/g (enterococci in sediment) (Table A 3). In all subsequent sections, organisms/100 mL or organisms/g were used for simplicity. Other parameters for Part A — Water and sediment quality sampling program were analysed by the National Measurement Institute (Kensington, Western Australia).

Chlorophyll a and phaeophytin and sediment particle size were analysed for Part B — Impacts on near-shore marine habitats — a pilot study (Table A 3). The plant pigments were analysed by the Marine and Freshwater Research Laboratory (Murdoch, Western Australia) and the particle sizes were measured by CSIRO Division of Minerals (Kensington, Western Australia).

Table A 3. Water and sediment quality parameters, analytical methods and limits of reporting (LOR).

Parameter	Description and Method of Analysis	LOR
Indicator Bacteria: **a) Thermotolerant coliforms (presumptive)** **b) Enterococci (confirmed)**	a) These are nonpathogenic faecal indicator microorganisms. Faecal coliforms detected in marine waters indicate a recent pollution event. They are measured in number of colony forming units/mL (cfu/100 mL). b) Enterococci have a higher tolerance for marine waters and so indicate residual contamination (they can survive in marine waters for as long as some pathogens). b) Enterococcus is a sub-group of faecal streptococci and are differentiated from other faecal streptococci by growth in the laboratory at higher temperature and salt concentrations. They are measured in mean probable number/100 mL (mpn/100 mL) or /g of sediment.	**Water and sediment** **Min (cfu/100 mL)** **< 10** **Max** **> 24000** **Min (mpn/100 mL or /g)** **<10** **Maximum** **> 24000**
Total oxidised nitrogen (NO_x-N), or Nitrate + Nitrite	Cadmium reduction method 4500-NO_3^- F. (APHA, 1998). Nitrate is reduced quantitatively to nitrite in the presence of cadmium. Concentrations of Fe, Cu or other metals above several mg/L lowers reduction efficiency. Oil and grease will coat cadmium surface. Remove interfering turbidity by filtration through a 0.45 μm cellulose nitrate filter paper.	**0.010 mg/L**
Total Kjedahl nitrogen	Kjeldahl nitrogen includes all dissolved nitrogen in the trinegative oxidation state (ammonium, ammonia, urea, amines etc.) and not including (nitrate, nitrite, azo compounds, etc.) TKN was determined by subtraction.	**0.025 mg/L**
Total nitrogen (TN)	TN includes all forms of nitrogen, like (in order of decreasing oxidation state) nitrate, nitrite, ammonia, and organic nitrogen. Alkaline Persulfate digestion method 4500-N C. (APHA, 1998), and the cadmium reduction method 4500-NO_3^- F (APHA, 1998). TN autoclave digestion with persulphate, then measured with spectrophotometer used at 400 nm (UV-vis detection) with a flow-through-cell. Alkaline oxidation at 121°C converts organic and inorganic nitrogen to nitrate. Total nitrogen is determined by analysing the nitrate in digestate. The persulphate method determines total nitrogen by oxidation of all nitrogenous compounds to nitrate. Nitrate is reduced quantitatively to nitrite in the presence of cadmium.	**0.025 mg/L**
Ammonium nitrogen (NH_3-N/NH_4-N)	Nitrogen is readily available to plants and algae in this form. Ammonium and ammonia species are determined using the same analytical method. Analytically they are the same species. At pH 5-8, the species exists as predominantly ammonium (NH_4^+). Phenate method 4500-NH_3 G. (APHA, 1998). Spectrophotometer used at 640 nm (UV-vis detection) with a flow-through-cell. An intensely blue compound indophenol is formed by the reaction of ammonia hypochlorite, and phenol catalysed by sodium nitroprusside. No interference from other trivalent forms of nitrogen. Remove interfering turbidity by filtration through a 0.45 μm cellulose nitrate filter paper.	**0.010 mg/L**
Total phosphorous (TP)	Phosphorus occurs in natural waters and in wastewaters almost solely as phosphates. These are classified as orthophosphates (PO_4^{3-}), condensed phosphates (pyro-, meta-, and other polyphosphates), and organically bound phosphates. They occur in solution, in particle or detritus, or in the bodies of aquatic organisms. Persulfate digestion method 4500-P B.5. (APHA, 1998), and the	**0.005 mg/L**

Parameter	Description and Method of Analysis	LOR
	automated ascorbic acid reduction method 4500-P F. (APH, 1998). TP autoclave digestion with persulphate, then measure with spectrophotometer with an infra-red phototube used at 880 nm (UV-vis detection) with a flow-through-cell. Hydrolysis of phosphorus content of a sample to reactive phosphorus. The reactive phosphorus is determined by the ascorbic acid colorimetric method.	
Filterable reactive phosphorus (FRP)	Or soluble reactive phosphorus describes the dissolved phosphates that respond to colorimetric tests without preliminary hydrolysis or oxidative digestions of the sample are termed 'reactive phosphorus'. Generally, reactive phosphorus is largely a measure of orthophosphate (PO_4^{3-}); however, a small fraction of any condensed phosphate present is usually hydrolysed unavoidably in the analysis procedure. Reactive phosphorus occurs in both dissolved and suspended phosphorus. Automated Ascorbic Acid Reduction 4500-P F. (APHA, 1998).	**0.005 mg/L**
Total heavy metals (unfiltered water)	**Water**: Method WL272 (USEPA 200.7) was used for total metals (except arsenic and mercury). Samples were digested in HNO3/HCl acid and analysed by ICP-AES. Arsenic method is WL272 (APHA 3114C, 21st ed. and USEPA 200.7) using hydride generation. Samples are digested in HCL and analysed by hydride generation and ICP-AES. Mercury method is WL41 (modified USEPA 245.1.) using the Cold Vapour Atomic Absorption Spectrometric method. Samples are digested using HCl and bromide/bromate solution and analysed by CVAAS. *As, Cd and Ni were analysed at a lower LOR on some occasions, as shown in brackets.	**Water (mg/L)** **Al 0.005** **As* 0.005 (and 0.001)** **Cd* 0.002 (and 0.0001)** **Cr 0.005** **Cu 0.005** **Fe 0.005** **Hg 0.0001** **Mn 0.001** **Ni* 0.005 (and 0.001)** **Pb 0.010** **Zn 0.005**
Total heavy metals (sediment)	**Sediment:** Method WL273 (USEPA 200.8) was used for metals analysis (except Arsenic). Samples digested in HNO3/HCl diluted and analysed by ICP-AES. Method NT2_49 for Arsenic (USEPA 200.8), with samples sent to NMI's NSW laboratory. Samples digested in HNO3/HCl (as above) diluted and analysed by ICP-MS.	**Sediment (mg/kg)** **Al 1.00** **As 0.50** **Cd 1.00** **Cr 1.00** **Cu 1.00** **Fe 1.00** **Hg 0.10** **Mn 1.00** **Ni 1.00** **Pb 1.00** **Zn 1.00**
Total petroleum hydrocarbons (TPH) **and C10 to C36** **(see BTEX for C6-C9)**	Water samples are extracted with dichloromethane by separatory funnel (USEPA Method 3510). Extracts are concentrated and where necessary diluted. Prepared extracts are injected into a GC where separation of individual components is achieved with a non-polar capillary column and detection by flame ionisation.	**Water mg/L** **TPH 0.250** **C10-14 0.025** **C15-28 0.100** **C29-36 0.100**
Polycyclic aromatic hydrocarbons	A measured volume of sample (at a specified pH if required) is serially extracted with Methylene chloride (DCM) using a separating funnel. The extract is dried over sodium sulphate, concentrated and analysed by GCMS. If necessary, the extract is exchanged into a solvent	**Water mg/L** **Napthalene 0.001**

Parameter	Description and Method of Analysis	LOR
(PAHs)	compatible with further analysis. The matrix is extracted using dichloromethane/acetone after the addition of appropriate surrogates. The prepared extracts are analysed using the MSD/MS in a SIM mode for Naphthalene, Acenaphthylene etc. (USEPA Method 8100).	
Benzene, toluene, ethylbenzene and xylene (BTEX) **(and C6 – C9)**	An inert gas (Helium) is bubbled through the water sample (5mL) at ambient temperature at a pre-determined rate. The volatile compounds are transferred efficiently from the aqueous phase to the vapour phase. The vapour is swept through a sorbent trap resulting in the trapping of the volatile compounds onto the sorbent material (OV-1, Tenax-GR and Silica Gel). After purging is complete, the sorbent trap is rapidly heated and back flushed with inert gas to desorb the compound onto a gas chromatography column. The volatile compounds are separated on the GC column and detected using a Mass Selective Detector (MSD). (USEPA Method 5030A).	**Water mg/L** **BTEX (Total) 0.005** **C6-9 0.025**
Chlorophyll *a* and phaeophytin	Chlorophyll a was extracted from filter papers kept for 24 hours in the dark at 4°C, after grinding in 90% acetone and measured spectrophotometrically (Varian Cary 50 Spectrophotometer; Greenberg et al., 1992). Greenberg, A.E et. al. (1992). Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Maryland, USA.	**Sediment** **0.1 µg/L**
Particle size analysis	Particle size measurements using laser diffraction: 20nm to 2mm (aqueous/solvent borne particulates). CSIRO's particle analysis service.	**Sediment** **20nm to 2mm**

2.3 Rainfall and sampling dates

During rain events, samples were collected from flowing stormwater drains, or, if flow had ceased, from the pools formed below the outlets. Due to the patchy nature of rain events in Perth and the relatively small catchments of most drains, flows often stopped within minutes of rain ceasing. In many cases, the low flow volumes meant that samples could not be collected at all. Given this, sample collection spanned the latter part of winter 2004 and most of winter 2005 over 20 rain events to ensure that all sites were adequately sampled within the Swan region. A total of 224 drain visits were made (between 65 sites), with 11 samples collected per site (grab and sediment) and about 2,500 samples analysed in total. Most sites were sampled at least three times.

Rainfall data was collected for 2005 from the Bureau of Meteorology Garden Island weather station for the sites south of the Swan River (Figure A 4); and from the Swanbourne weather station for the sites north of the Swan River (Figure A 5).

The Figures show the daily rainfall totals (5am to 5am) and the monthly totals as well as the dates that water and sediment quality samples were collected (arrows). On these dates, specific sites were sampled within the nine regions that span the coastal area of the Swan catchment (Table A 4, Figure A 2 and Figure A 3). Sites were identified by codes based on the local government area, or, in the case of Water Corporation main drains, by the nearest road: Wanneroo (WAN), Joondalup (JND), north Stirling (NST), Stirling (STG), Carine Main Dain (CMD), Scarborough (SCB), Colin Road Main Drain (CRMD), Herdsman Main Drain (HMD), Cottesloe (COT), Rockingham (ROC), Rockingham Main Drain (RMD), Shoalwater (SHL); Forrest Road Main Drain (FRMD), Safety Bay (SB), Waikiki (WK) and Waikiki Main Drain (WKMD).

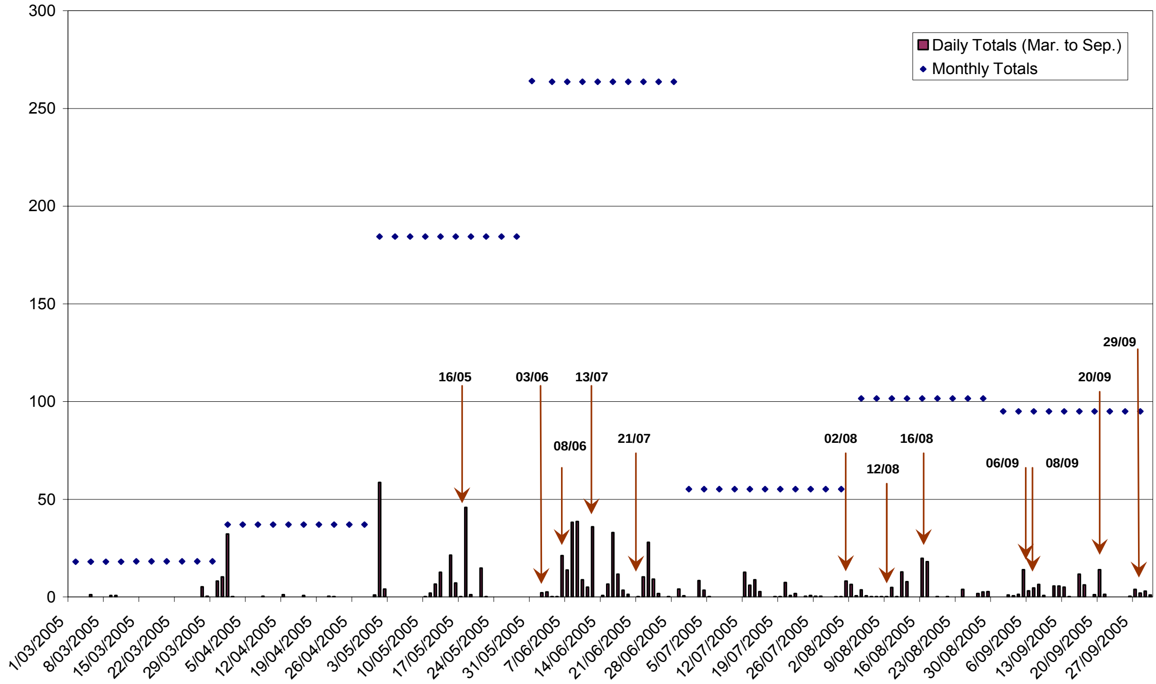


Figure A 4. Garden Island station: rainfall (mm) and sampling dates 2005.

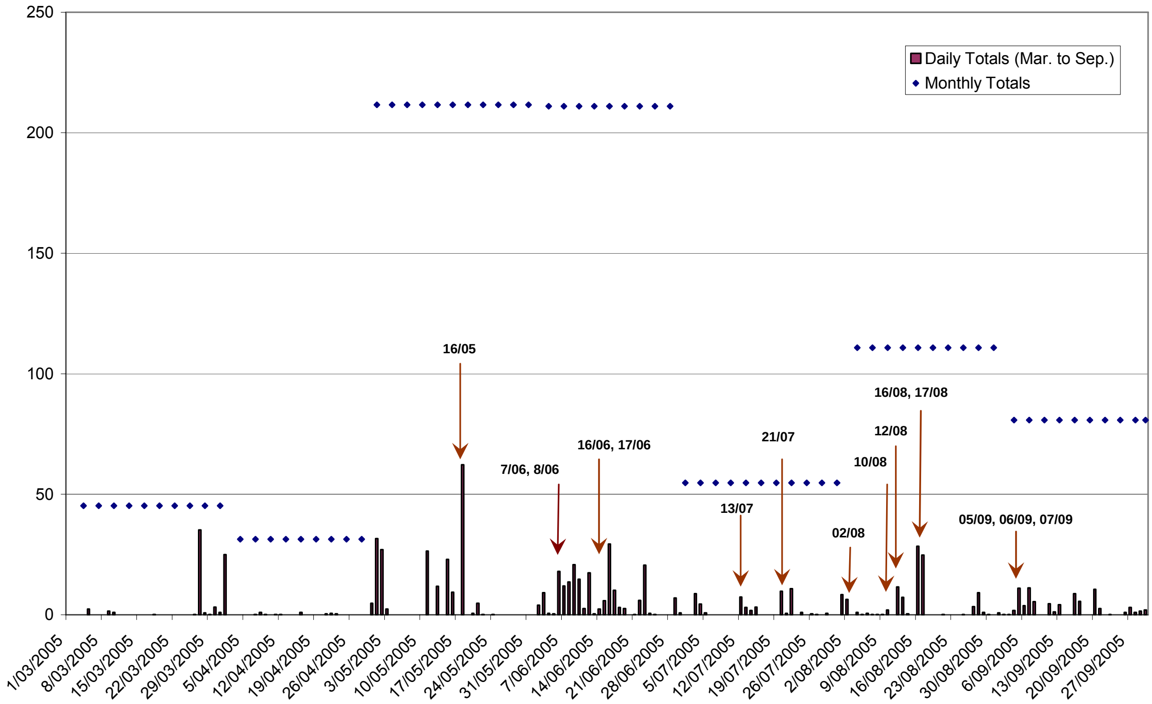


Figure A 5. Swanbourne station: rainfall (mm) and sampling dates 2005.

Table A 4. Dates and sites sampled for water and sediment quality analysis.

Date	LG[1]	Site sampled
8/08/04	C	COT02, COT04, COT10, COT11
	W	WAN08, WAN13
6/09/04	Ca	HMD
	J	NST01, NST03, NST04
	St	CRMD, SCB01, SCB03, STG01, STG03, STG05, STG07, STG08, STG10
16/05/05	C	COT02, COT05, COT06, COT08, COT10
	St	STG09, CRMD, SCB01, SCB02, CRMD
	R	ROC03, ROC07, ROC14, SHL01
03/06/05	R	ROC01, ROC02, ROC03, SB02, RMD
07/06/05	Ca	HMD
	C	COT07, COT08, COT10
	W	WAN05
08/06/05	Ca	HMD
	J	NST03, NST04, NST05
	St	SCB03

Date	LG	Site sampled
02/08/05	Ca	HMD
	J	NST04
	W	WAN08, WAN13
	R	ROC01, ROC14, ROC16, RMD, SHL01, SB03, FMD
10/08/05	C	COT02, COT04, COT05, COT06, COT07, COT08, COT10
12/08/05	C	COT02, COT04, COT05, COT06, COT07, COT08, COT10
	St	CRMD, SCB01, SCB02, SCB03, STG05, STG06, STG07, STG08, STG09, STG10, STG11
	R	SHL07, SB01, SB03, SB04, SB05, SB06
16/08/05	Ca	HMD
	C	COT2, COT04, COT05, COT06, COT07, COT08, COT10
	J	NST01, NST03, NST04, NST05
	St	STG01, STG03, STG06, STG10, STG11, SCB01, SCB02, SCB03, CRMD
	W	WAN05, WAN06
	R	ROC02, ROC03, ROC04, ROC05, ROC06, ROC07, ROC08, ROC10, ROC12, ROC14, ROC16
17/08/06	J	JND01a, JND01b, NST01, NST03, NST04, NST05

Date	LG[1]	Site sampled	Date	LG	Site sampled
	R	ROC06, ROC08, ROC12, ROC13, SB01, SB03, SB04, SB05, SB06, SB07		St	STG01, STG03, STG05, STG06, STG07, STG08, STG10, STG11
16/06/05	J	JND01a, JND01b		W	WAN03, WAN04, WAN05, WAN06, WAN08, WAN13
	St	STG05, STG06, STG07, STG9, STG10, STG11	05/09/05	J	JND01a, JND01b
	W	WAN05, WAN06		St	STG03
17/06/05	J	NST01		W	WAN03, WAN04, WAN06, WAN08
	St	STG01, STG08	07/09/05	C	COT04
	W	WAN13		St	STG03, STG16, STG17
13/07/05	R	ROC01, ROC02, ROC04, RMD		W	WAN03, WAN04, WAN08
21/07/05	Ca	HMD	08/09/05	R	SB01, SB04, SB05, SB06, SB07, WK01, WKMD, WK02
	C	COT11, COT12	20/09/05	R	ROC04, ROC05, ROC06, ROC07, ROC10, ROC12, SHL01, SHL02, SHL04, SHL07
	St	CMD, STG03	29/09/05	R	ROC10, WK01, WK02, WKMD, SB01, SB02, SB05, FRMD, SHL04, SHL07
	R	ROC05, ROC16, SB03, SB07			

Local Government (LG): Ca = Cambridge, C =Cottesloe, J = Joondalup, St = Stirling, W =Wanneroo, R = Rockingham.

2.4 Statistical analysis

Regional data was analysed using one-way analysis of variance and presented graphically with vertical bars depicting 0.95 per cent confidence intervals. Scheffé's test was applied to determine significant differences between regions.

A region was defined by the boundaries of the local government authority, except for the City of Stirling and the City of Rockingham. Due to the placement of outfalls within these two regions, the City of Stirling outfalls are presented as Stirling and Scarborough and the City of Rockingham outfalls are presented as Rockingham, Shoalwater and Safety Bay (which includes Waikiki drains).

3 Results

3.1 Stormwater drain assessment

Of the apparent 99 stormwater drains present on the coast of the Swan Region, 65 drains were targeted as part of the water and sediment quality sampling program (Appendix A Part 1). Photographs of each of the drains were taken to aid in identifying them (Appendix A Part 2). The remaining 34 drains (Appendix B) were removed from the field study for the following reasons:

- Ability to locate– 27 per cent could not be located, or were removed, buried or back-filled;
- Accessibility – 21 per cent were not easily accessible for sampling stormwater quality, were dangerous to access or were completely submerged;
- Distance from beach/ocean – 40 per cent discharged to the dunes a large distance from the beach (>100 m) and were therefore highly unlikely ever to discharge onto the beach or reach the ocean directly; and
- Low priority marine areas – 12 per cent discharge to a marina or harbour (considered highly disturbed and which could prove confounding when investigating potential impacts on the near-shore environments). These were all in the City of Fremantle.

3.2 Water and sediment quality across regions

Microbial quality (indicator bacteria), heavy metals, nutrients, total petroleum hydrocarbons (TPHs), benzene, toluene, ethylene and zylene (BTEX), polyaromatic hydrocarbons (PAHs) and total suspended solids (TSS), were averaged across all drains within the boundary of each local government authority (LGA) to provide a comparison of contaminant concentrations at a regional scale.

A summary of the sampling effort is provided to show the number of drains and the total number of times that they were sampled within each region (Table A 5).

Table A 5. List of regions within each local government authority (LGA), abbreviation used, number of stormwater drains and total number of times sampled in each region.

LGA/Region	Abbreviation	No. drains sampled (Total no. times sampled)
City of Wanneroo	WAN	6 (18)
City of Joondalup	JND, NST	5 (21)
City of Stirling:		
Stirling	STG	12 (39)
Scarborough	SCB	4 (13)
Town of Cottesloe	COT	8 (32)
Town of Cambridge	HMD	1 (5)
City of Rockingham:		
Rockingham	ROC	13 (40)
Shoalwater	SHL	5 (9)
Safety Bay	SB (and WK)	11 (28)
Total		65 (205)

Besides presenting the average concentrations of indicator bacteria, metals and nutrients at a regional scale, they are also presented as averages on a site-by-site basis in tables on maps of each region (Appendix C to Y Regional maps with contaminant data for each site). The concentrations of contaminants within regions and on a site-by site-basis will be discussed later (Section 3.4).

3.2.1 Microbial water quality (enterococci)

As expressed in Section 1.4.2, the enterococci data has been compared to the recreational guideline for secondary contact for all samples (drain, swash zone and sediment). While this guideline does not relate directly to stormwater in drains or the adjacent sediment, the data does provide an indication of sites with relatively high enterococci concentrations. This will assist with stormwater management.

Although a second set of indicator bacteria, thermotolerant coliforms, were measured in stormwater, they are not discussed further in this report. However, their average concentrations are presented in Appendix C to Appendix Y. They are not discussed as the new guidelines for recreational water quality describe thermotolerant coliforms as unreliable indicators (NHMRC, 2005) because: a) there are no adequate studies on which to base the guidelines; b) the process incorporates and analyses organisms not faecally derived; and c) thermotolerant coliforms are not stable in seawater.

In the following sections, the enterococci data is presented to show regional as well as site trends in concentrations. Furthermore, the data relates to enterococci concentrations of samples collected from the three zones (stormwater, swash zone and sediments). Please note that although concentrations are measured in mean probable number (mpn)/100 mL or /g, for ease of reading they have been referred to as organisms/100 mL or /g. Refer to Table A 3 for further explanation.

Regional trends — Enterococci concentrations

Stormwater: The average concentration of enterococci in stormwater in drains in all regions exceeded secondary recreational guideline levels (230 organisms/100 mL) by at least five-fold (ie >1000 organisms/100 mL) (Figure A 6 a). The only exception was in Cambridge, which is represented by only one drain – the Herdsman Main Drain (HMD). It exceeded the guideline for primary (35 organisms/100 mL) but not secondary contact. This may be because of the large volume of water that flows continuously from this drain, therefore diluting the concentrations of indicator bacteria.

Swash zone: The average concentrations of enterococci in the swash zone exceeded the secondary contact guidelines in Rockingham and Safety Bay (Figure A 6 b). Stirling and Cottesloe fell just short of this limit, with an average of ~200 organisms/100 mL. However, given that the swash zone is the area in which people are most likely to engage in primary contact (swimming), the number of regions exceeding this guideline rises to six with four regions exceeding by at least six-fold (ie Rockingham, Safety Bay, Cottesloe and Stirling). Conversely, average concentrations in Joondalup and Scarborough were significantly lower than the other regions and remained below the primary contact guidelines.

Sediments: The average concentrations of enterococci in sediments exceeded secondary contact guidelines in all regions, except in Stirling and Scarborough (Figure A 6 c). Again, as for the drains, Cottesloe, Rockingham and Safety Bay exceeded these guidelines by at least five-fold.

a)

b)

c)

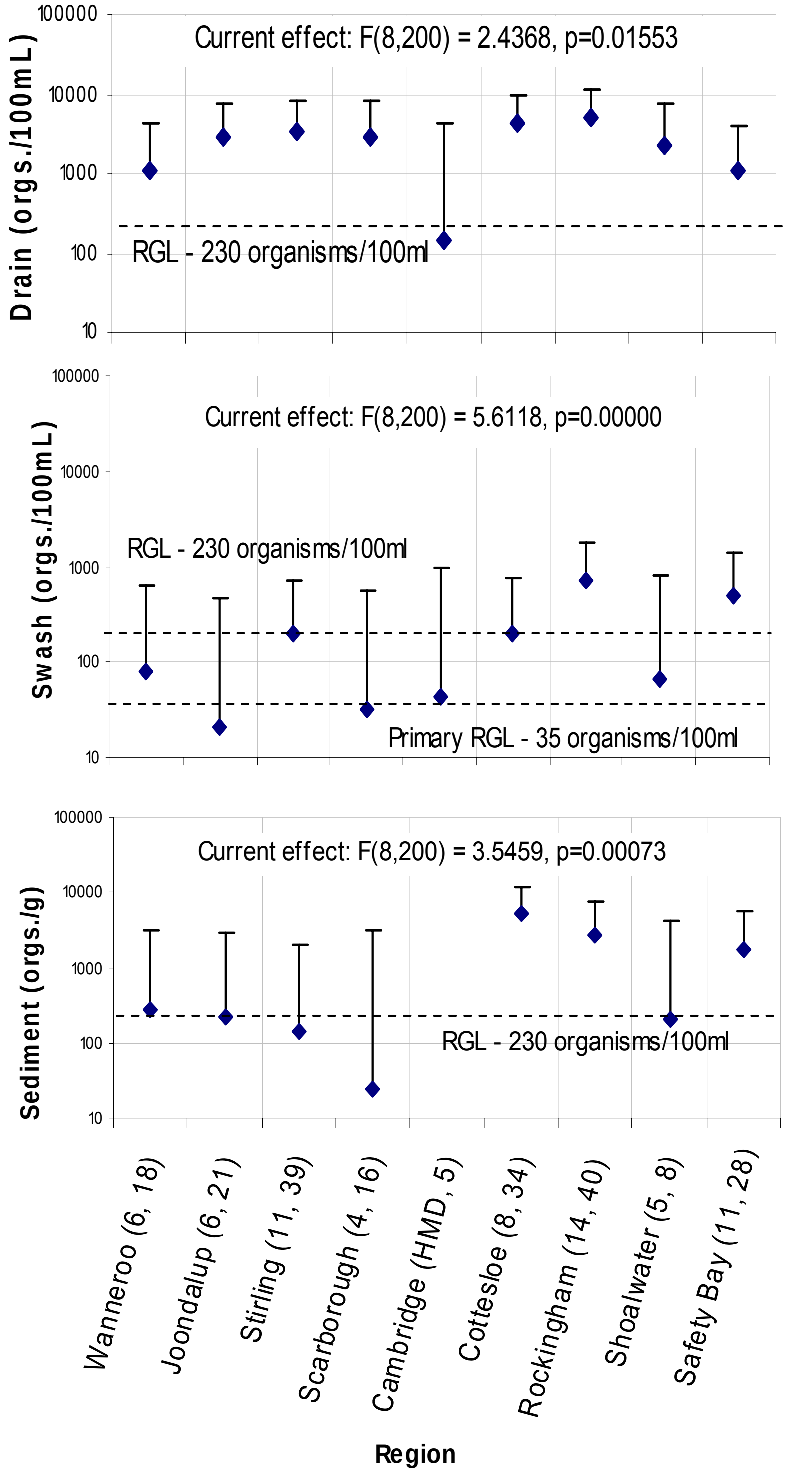


Figure A 6 (a to c). Regional trends – average enterococci concentrations (organisms/100 mL or /g) in drain stormwater, swash and sediment. (number of drains sampled in region, total number of times drains sampled). RGL = secondary recreational guideline.

Site specific trends – Enterococci concentrations

A number of sites in the Swan region recorded enterococci concentrations above guideline limits. Refer to regional maps with tables of average enterococci concentrations at each site (Appendix C; Appendix F; Appendix I; Appendix L; Appendix O; Appendix R; Appendix S; and Appendix T).

Refer also to selected tables in Section 3.4 (Table A 13, Table A 15,Table A 17,Table A 19 and Table A 21). They identify specific sites of concern within each region, which have breached guidelines for contaminant concentrations, including enterococci. The current section provides a regional comparison but showing site-specific enterococci concentrations for stormwater, swash zone and sediment (Table A 6, Table A 7 and Table A 8)

Stormwater drain: Of the 65 drains sampled, about 90 per cent exceeded the guideline limit for secondary contact (230 organisms/100 mL). The application of this guideline for water collected directly from the drains is not helpful for decision making. In the absence of an actual stormwater guideline, a value of 1,000 organisms/100 mL has been used to help identify drains with high enterococci concentrations compared to other sites (Table A 6). Furthermore, a value of 10,000 organisms/100 mL has been used to further classify drains with very high concentrations (Table A 6). One site in Stirling, one in Cottesloe and two in Rockingham had very high enterococci concentrations in the stormwater (>10,000 organisms/100 mL).

Swash zone: Enterococci concentrations in the swash zone tell a similar story with numerous sites in the Rockingham area, four sites in Stirling and one in Cottesloe exhibiting concentrations greater than 230 organisms/100 mL (Table A 7). Ten of 14 sites north of Cape Peron in Rockingham exceeded the guideline within the swash zone, with four sites showing concentrations greater than 1000 organisms/100 mL (Table A 7, Appendix R). South of Cape Peron, one of three sites entering Shoalwater Island Marine Park and five of 13 sites along Safety Bay and Warnbro Beach exceeded the guideline (Appendix T and Appendix U). Two sites of concern in this area are SB03 and SB07 where enterococci concentrations were greater than 1,000 organisms/100 mL.

The Cottesloe site (COT07) averaged over 1,300 organism per 100 mL in the swash zone. Three of the four Stirling sites with high enterococci concentrations are located north of Trigg Island. There were no sites of concern in Wanneroo or Joondalup. See section 1.4.2 for application criteria associated with this recreational guideline limit.

Sediment: In the absence of other guidelines, a sediment enterococci concentration of 1,000 organisms/g has been used as a guide to compare sites. Of particular concern to management are the extremely high sediment concentrations found at four sites in Cottesloe and five sites in the Rockingham area (Table A 8). Three sites within each region even exceed 10,000 organisms/g. All of the Cottesloe sites with high sediment enterococci concentrations occur in areas where dogs are prohibited and public toilets do not feature. This is different to the Rockingham area where it appears sites with high sediment concentrations have facilities close by (eg toilets and boat ramps) or are used by dogs and even horses (eg ROC01). It is not known whether septic leachate in shallow groundwater aquifers might contribute to the high concentrations in sediment in these areas.

Table A 6. Site specific trends – stormwater drain: average enterococci concentrations of sites exceeding 1000 organisms/100 mL.

LGA Region	Outfalls exceeding 1000 organisms/100 mL (regular font) and >10,000 organisms/100 mL (bold font)
Wanneroo	WAN05 (2080) and WAN06 (1095)
Joondalup	NST01 (1887), NST03 (6575), NST04 (4262) and NST05 (1330)
Stirling	STG01 (2825), STG03 (2125), **STG05 (16425),** STG07 (3655), STG08 (2785), STG11 (2932), STG17 (1000), SCB01 (1725), SCB02 (5100), SCB03 (2380) and CRMD (2455)
Cambridge (HMD)	HMD not above secondary guideline
Cottesloe	COT02 (2450), COT04 (4040), COT05 (6290), COT06 (1075), COT07 (3240), COT08 (7477), COT10 (2846) and **COT11 (11000)**
Rockingham Shoalwater and Safety Bay	ROC01 (1776), **ROC02 (13633),** ROC03 (1520), ROC05 (7333), ROC06 (8433), ROC07 (6302), ROC08 (2840), ROC10 (1530), ROC12 (5300), **ROC13 (20000)**, ROC14 (3166), SHL01 (6123), SHL04 (2500), SHL07 (4750), SB02 (1165), SB03 (2285), SB05 (2250), SB06 (1166) and SB07 (1713).

Table A 7. Site specific trends – swash zone: average enterococci concentrations of sites exceeding the secondary guideline of 230 organisms/100 mL.

LGA Region	Outfalls exceeding 230 organisms/100 mL (number organisms/100 mL)
Wanneroo	No outfalls above guideline
Joondalup	No outfalls above guideline
Stirling	STG03 (416), STG09ab (621), STG11 (1062*)*, CRMD (230)
Cambridge (HMD)	HMD not above guideline
Cottesloe	COT07 (1395)
Rockingham Shoalwater and Safety Bay	ROC01 (230), ROC02 (351), ROC05 (1123), ROC06 (735), ROC07 (340), ROC08 (295), ROC12 (427), ROC13a (3600), ROC14 (1450), ROC16 (3712), SHL01 (240), SB03 (1362), SB04 (407), SB05 (272), SB06 (477) and SB07 (1350).

Table A 8. Site specific trends – sediment: average enterococci concentrations of sites exceeding 1000 organisms/g.

LGA Region	Outfalls exceeding 1000 organisms/g, (number organisms/g)
Wanneroo	No outfalls above guideline
Joondalup	No outfalls above guideline
Stirling	STG17 (1400)
Cambridge (HMD)	HMD not above guideline
Cottesloe	COT05 (16006), COT07 (6212) and COT08 (12385) *and* COT10 (12105)
Rockingham and Safety Bay	ROC01 (11083), ROC10 (16003), ROC12 (16273), SB03 (8084) and SB04 (8024)

3.2.2 Total metals

Where sufficient data was available total metal concentrations have been plotted to show regional averages. The following metals are presented in this way: aluminium (Al), copper (Cu), iron (Fe), lead (Pb), manganese (Mn) and zinc (Zn) (Figure A 7a to f). Insufficient data was available to do this for the remaining metals (As, Cd, Cr, Hg and Ni) and results will be depicted for specific sites only. Site specific trends will also be highlighted in this section. Furthermore, the data relates to metal concentrations of samples collected from two zones (stormwater drain and sediments).

Regional trends — metal concentrations

Stormwater drain: Concentrations of aluminium in stormwater within drains exceeded environmental guidelines across all regions except Herdsman Main Drain (HMD) in Cambridge (Figure A 7a). As for enterococci, the volume of water passing through this main drain aids in reducing the metal concentrations. Of note, aluminium concentrations in stormwater in Stirling were significantly higher ($F_{8,201}$=5.9456, P=0.00000) than all other regions.

Concentrations of copper were significantly higher at Scarborough than all other regions ($F_{8,201}$=9.6649, P=0.00000) (Figure A 7b). Wanneroo, Joondalup, Stirling and Cottesloe exceeded the guidelines for copper, while Rockingham, Shoalwater, Safety Bay and HMD remained below the guideline. Once again, the volume of water passing through HMD aids in keeping concentrations of copper within the drain low. High copper concentrations in Scarborough are probably as a result of vehicles — tyre and brake wear, combustion of lubricating oils and engine wear (Duncan, 2003), associated with a high use and large car parking area.

Concentrations of iron were significantly higher at Stirling, Scarborough, Cottesloe and Shoalwater than Rockingham and Safety Bay ($F_{8,195}$=3.1163, P=0.00246), exceeding EGLs for iron (Figure A 7c).

Concentrations of lead were significantly higher at Scarborough than all other regions ($F_{8,198}$=4.2437, P=0.00010) (Figure A 7d). Joondalup, Stirling, Scarborough and Cottesloe exceeded the EGL, while other regions remained just within the EGL.

Manganese concentrations across all regions were significantly lower than the guideline, although comparatively concentrations in Rockingham and specifically, the Shoalwater area were higher than at other regions (Figure A 7e).

Concentrations of zinc were significantly higher at Scarborough than all other regions ($F_{8,197}$=4.4261, P=0.00006), at levels considerably higher than the guidelines. All other regions remained below the guidelines (Figure A 7f).

Mercury was not present in detectable concentrations in any samples from any regions.

Arsenic, chromium and nickel were recorded in levels above the LOR at some sites, although concentrations were generally a magnitude lower than the guidelines. The guideline for arsenic is 0.0240 mg/L and this was never exceeded. The highest arsenic concentration obtained during this sampling program was 0.0031 mg/L and this occurred only once.

The guideline for chromium is 0.0274 mg/L and this was exceeded at one site on one sampling occasion only, STG06 (0.05mg/L). The guideline for nickel is 0.011 mg/L and this was exceeded twice, on one sampling occasion only at SCB02 (0.044mg/L) and ROC02 (0.016mg/L).

With respect to the metals data, there were some inconsistencies with the analysis of samples. The limits of reporting (LORs) used for copper, cadmium and lead were above the chosen guideline values (Table A 2 and Table A 3). For example the guidelines for copper, cadmium and lead respectively are 0.0014, 0.0002 and 0.0034mg/L and the LORs used for analysis were 0.005, 0.002 and 0.010 mg/L respectively (Table A 2 and Table A 3). Therefore, concentrations falling between these values have not been detected and the potential risk for these metals in stormwater has not been fully evaluated.

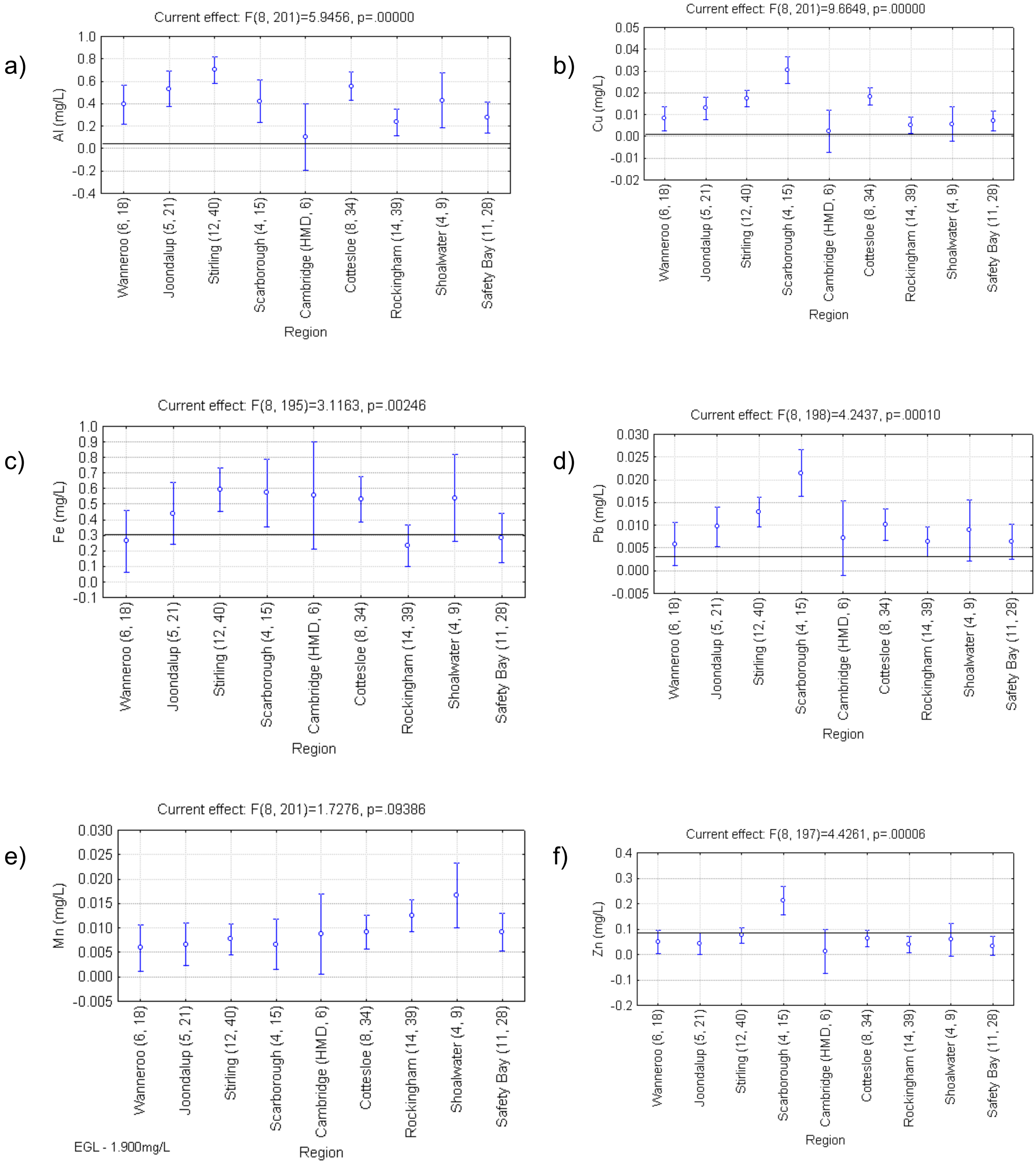


Figure A 7 (a to f). Average concentrations of Al, Cu, Fe, Pb, Mn and Zn (mg/L) in stormwater for each region. Region (number drains sampled in region, total number of times drains sampled in region). Solid lines on graphs indicate environmental guideline level (EGL), except for Mn where value is noted.

Sediment: Total metals in sediments beneath the drain were sampled and analysed at the same time as metals in stormwater. Ninety per cent of the samples collected during 162 drain visits showed low concentrations of most metals in sediments, well below current environmental and recreational guideline levels. Where sufficient data was available, total metal concentrations were plotted to show regional averages (Figure A 8).

As mentioned earlier, environmental guidelines were not used for comparing metals in sediment (Environmental and human health guidelines applied) as the risk was perceived to be primarily recreational or health-based. Therefore, Health-based Investigation Levels (HILs) were used where available. They were not available for aluminium, chromium or iron in sediment. In the case of aluminium and iron, these metals are naturally abundant and occur at high background levels.

Of the three metals that had guidelines, none of the regions had concentrations of metals in sediment that exceeded them. However, Shoalwater was notable in having higher concentrations of arsenic, chromium, iron and manganese than any other region. This was statistically significant for all of these metals except for iron. Rockingham and Safety Bay showed a similar pattern with respect to arsenic, chromium and manganese. This trend is worth investigating further.

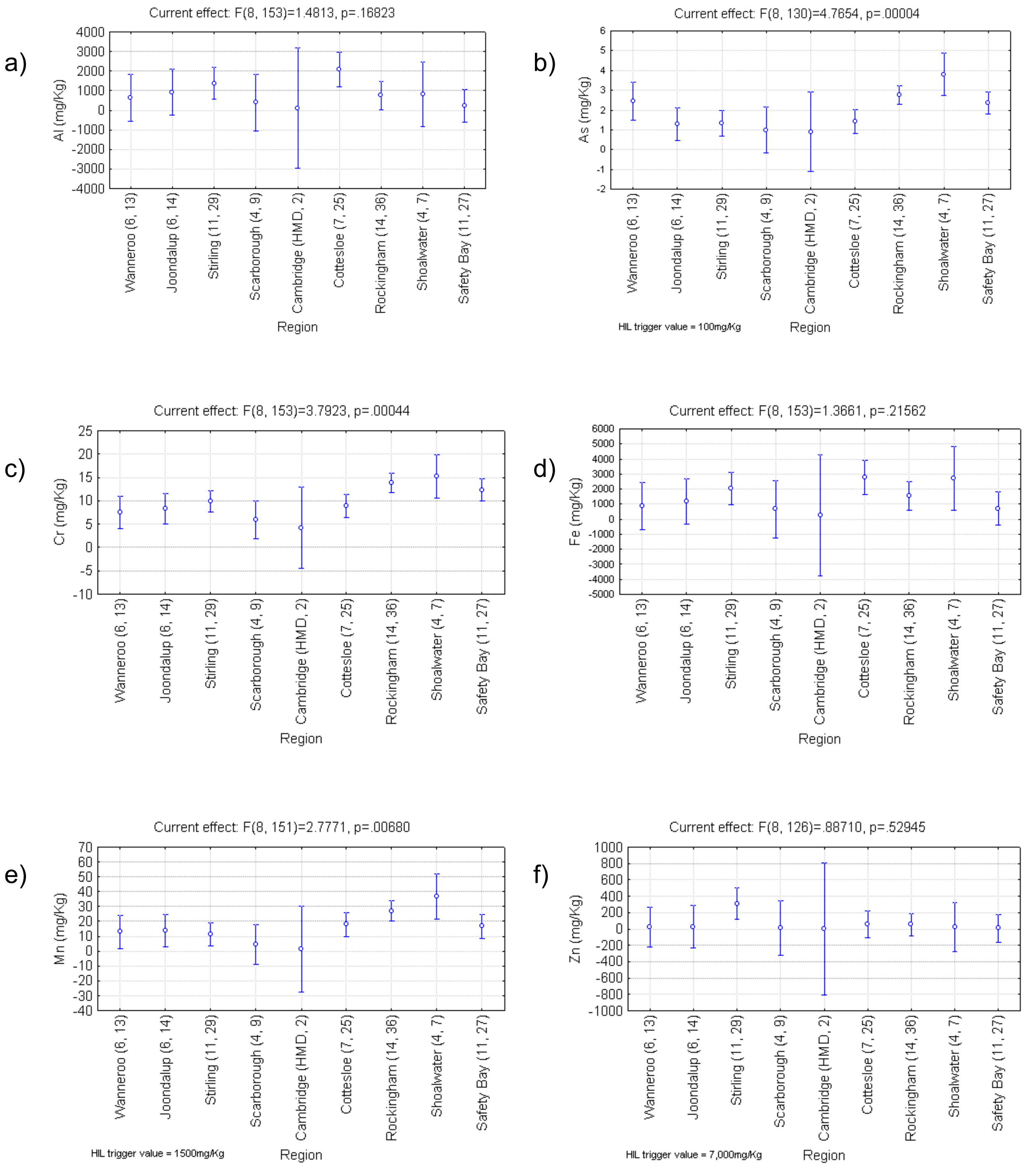


Figure A 8 (a to f). Average concentrations of heavy metals (mg/kg) in sediments for each region. Region (number drains sampled in region, total number of times drains sampled). Health-based investigation levels (HIL trigger value) noted below relevant graphs.

Site specific trends — metal concentrations

Data has also been presented for individual sites which had significantly higher concentrations of sediment metals than the grouped average of remaining sites. This data has been presented to facilitate management by highlighting these high concentrations, even though for many metals there are currently no established guidelines. The data may suggest on-going point source pollution, from either near-by residential areas or industry (eg. service stations) or activities (eg. illegal dumping).

A summary of sites with high concentrations of metals in sediments has been prepared (Table A 9). The following section clarifies the contents of the table and the data contained within:

Column 2 – lists sites with high sediment metal concentrations. The site name may be repeated if a high concentration was recorded on more than one sampling occasion (eg. STG06 was sampled four times and on each occasion high sediment metal concentrations were recorded).

Row 3 (in italics) shows the average concentration for that metal. This average is referred to as the group average and has been calculated from 146 drain visits across 54 sites (although not including the 11 sites listed in column 2) and includes the standard deviation. This information provides the basis to compare this group average with the sites listed in column 2.

The table shows that on 17 sampling occasions, 11 sites recorded high concentrations of some sediment metals. Four sites recorded these high concentrations on more than one sampling occasion (WAN04, STG06, COT05 and COT10). The table applies two criteria to identify sites with high metal concentrations in the sediment.

Criteria 1: sites where available guidelines were breached, metal concentrations highlighted with red shading and bold font.

Criteria 2: sites where concentrations were comparatively higher than other sites (at least 5 times higher than the group average listed in Row 3), metal concentrations highlighted with orange shading and standard font.

If the concentration provided in the table is unshaded and in standard font, then it did not breach either criteria 1 or criteria 2 above and has been included for comparative purposes only.

Table A 9. Average total metal concentrations (mg/kg) for sediments at specific sites.

		Metal concentration (mg/kg)								
		Al*	**As**	**Cr***	**Cu**	**Fe***	**Mn**	**Pb**	**Ni**	**Zn**
Group average (Std. Dev.)		515 (668)	1.96 (1.23)	10.05 (4.94)	16.94 (37.02)	1003 (1093)	15.17 (11.97)	13.47 (30.84)	7.14 (19.07)	26.33 (54.54)
LGA Region	Site									
Wanneroo	**WAN04**	2700	2.7	17	16	4200	50	77	2.9	120
	WAN04	1700	13	12	14	2800	33	74	1.9	95
Stirling	**STG06**	7600	5.4	28	73	7900	81	280	6.5	320
	STG06	6600	1.0	15	21	11000	48	45	2.7	150
	STG06	6000	ND	22	22000	41	ND	34	110	4500
	STG06	2.9	ND	54	10000	98	ND	92	200	0
	STG11	270	1.5	8.5	ND	450	5.6	ND	ND	3.4
	STG11	190	ND	5.2	ND	370	2.8	ND	ND	ND
	STG11	6000	2.5	16	21	22000	33	41	2.2	110
	STG17	6900	2	10	76	5600	26	23	3.2	43
Cottesloe	**COT02**	7200	5	22	72	8600	87	710	8.5	280
	COT05	370	0.85	7.2	12	5500	28	8.1	3.5	15
	COT05	21000	3.8	22	23	19000	55	53	3.8	99
	COT10	360	0.92	6.3	2.2	490	6.1	9.4	ND	9
	COT10	5100	3.4	27	160	9200	33	770	8.2	210
	COT10	7400	5.1	28	220	9000	38	950	12	350
	COT10	470	ND	4.5	2.4	670	7.5	4.5	ND	10
Rockingham	**ROC01**	8700	2.8	34	59	11000	210	40	350	1400
	ROC10	2200	2.5	17	18	3400	58	89	6	100
	ROC10	1500	3.6	15	5.8	4300	40	46	2.4	72
	ROC10	1600	2.7	14	13	2800	47	39	4	94
	ROC12	720	2.2	16	3.4	1400	29	10	200	24
	SHL07	1400	1.4	22	5	6400	51	19	ND	37
	SHL07	1800	3.2	10	7.2	3700	84	14	1.7	61
	SHL07	1100	2	7	4.2	3900	41	16	ND	31
Joondalup		No outfalls breached criteria 1 or 2 (see text)								
HIL (mg/Kg)		ND	100	ND	1000	ND	1500	300	600	7000
Limit of Reporting (mg/Kg)		1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00

(HIL) – Health-based Investigation Level, *No HIL has been set for Al, Cr or Fe ND – No data.

Cadmium and mercury concentrations were below the limit of reporting for sediments (1.00 mg/kg and 0.1 mg/kg respectively, Table A 3) at all sites so these data have not been reported in Table A 9.

Copper concentrations exceeded the guideline at only one site in Stirling (STG06) and on two different sampling occasions. Concentrations of copper exceeded the guideline by 22 times and exceeded the group average by as much as 1300 times.

Manganese concentrations exceeded guidelines at four sites (STG06, COT02, ROC1 and SHL07) and for each site, this occurred on only one sampling occasion. Values were between five and 14 times higher than the group average.

Lead concentrations exceeded the guideline at COT02 on one sampling occasion and on two occasions at COT10. Values were between 52 and 73 times higher than the group average.

Although there were no recreational guideline levels available for aluminium, chromium or iron, it is interesting to compare concentrations at the 11 sites with the average group concentrations. The following refer to concentrations that exceeded the average across the other sites. Of the 11 sites listed, aluminium concentrations were between 1.4 and 40 times, chromium between 1.2 and five times and iron between 1.4 and 22 times higher than the respective group averages.

A number of sites in the Swan region recorded metal concentrations above guideline limits for at least one metal from the suite analysed. For site averages, refer also to regional maps with tables of average metal concentrations (Appendix E; Appendix H; Appendix K; Appendix N; Appendix Q; Appendix W; Appendix X; and Appendix Y). Refer also to selected tables in Section 3.4 (Table A 13, Table A 15,Table A 17,Table A 19 and Table A 21). Section 3.4 identifies specific sites of concern within regions, having breached guidelines for various contaminants including metals.

3.2.3 Nutrients (TN, TP, NOx, NH4, FRP)

Where sufficient data was available, nutrient concentrations have been plotted to show regional trends. The following nutrients are presented in this way: total phosphorus (TP), filterable reactive phosphorous (FRP), total nitrogen (TN), nitrogen oxides (NOx) and ammonia (NH_4), (Figure A 9a to e). Unlike the metal contaminants, nutrient concentrations were collected for stormwater samples only. Site specific trends will also be highlighted in this section.

Regional trends — nutrient concentrations

Where sufficient data was available, total nutrients were plotted to show regional averages (Figure A 9a to e).

The average total phosphorus (TP) concentrations in stormwater drains across all regions exceeded environmental guideline levels, except for Herdsman Main Drain (HMD) in Cambridge (Figure A 9a). As mentioned previously, the large volume of water continually passing through the HMD acts to dilute contaminants before mixing with marine waters. There were no significant differences in TP concentrations between the different regions and the majority of phosphorous was in the particulate form as shown by the proportion of the dissolved fraction – filterable reactive phosphorous (FRP).

The average concentration of FRP (the form easily used by plants and algae) exceeded the guideline in Wanneroo, Scarborough, Cottesloe and Safety Bay (Figure A 9b). However, concentrations across most regions were comparable with the exception of Cottesloe, which had a significantly higher concentration of FRP than all other regions and was twice that of the guideline. This may be due to fertiliser applied to the golf course in this region.

The average concentration of total nitrogen (TN) was below the guideline for all regions except Scarborough and Cambridge, which only just exceeded it (Figure A 9c).

The average concentration of the dissolved oxidised fraction of nitrogen (NOx) was just below the guideline across all regions except for HMD in Cambridge, Scarborough and Stirling. HMD was significantly higher than all other regions and exceeded the guideline value of 0.150 mg/L six-fold (Figure A 9d). The Herdsman Lake, which feeds the HMD, may be the main sink for NOx from the surrounding suburbs.

Ammonia (NH_4) was recorded in concentrations above the guideline for all regions except Wanneroo, Stirling and Shoalwater, which were just below it (Figure A 9e). Scarborough and Safety Bay exceeded the guideline for ammonia by four-fold. This may be an indication of the presence of septic systems.

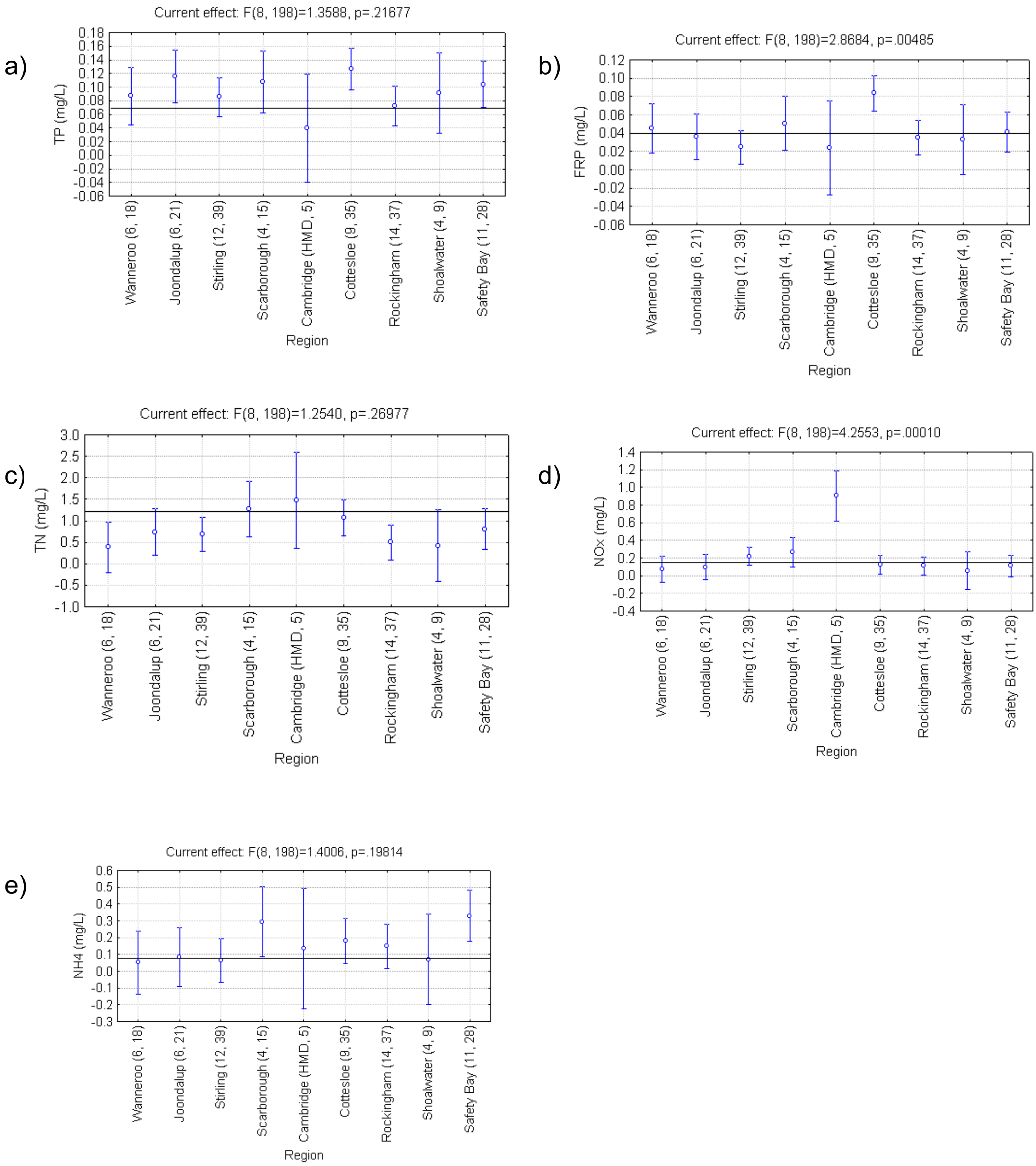


Figure A 9 (a to f). Average concentrations of nutrients (mg/L) in stormwater for each region. Region (number drains sampled in region, total number of times drains sampled). Solid lines on graphs indicate environmental guideline level.

Site specific trends — nutrient concentrations

Specific sites north of the Swan river with particularly high nutrient concentrations include: SCB01 and SCB02 for all nutrients although especially for TN; STG08 with high NOx and TN; CRMD with high NOx; HMD in Cambridge with high NOx and COT05 for all nutrients and especially ammonia.

Specific sites south of the river with particularly high nutrient concentrations include: ROC02 with high ammonia and TN; ROC01 with high ammonia and SB06 with high TN driven by ammonia levels.

Other sites north and south of the Swan River have also breached guideline levels although concentrations are not as high as those listed above. For these sites, refer also to the regional maps with tables of average nutrient concentrations (Appendix D, Appendix G, Appendix J, Appendix M, Appendix P, Appendix U and Appendix V). Refer also to selected tables in Section 3.4 (Table A 13, Table A 15, Table A 17, Table A 19 and Table A 21). Section 3.4 identifies specific sites of concern within regions, having breached guidelines for various contaminants including nutrients.

3.2.4 Petroleum products, organic compounds and suspended solids (TPH, PAH, BTEX, TSS)

In the following sections, data has been presented for individual sites only – there are no regional trends recorded as for the previous contaminants. The reason for this is the low number of sites within each region with recorded high concentrations of these contaminants. Furthermore, in the absence of guideline values for some contaminants, sites with comparatively higher concentrations when compared to a group average, have been highlighted to assist with managing localised stormwater impacts.

Total petroleum hydrocarbons (Total, C36, C28, C14 and C9)

All drains were sampled and tested for total petroleum hydrocarbons (TPH) and individual hydrocarbons with chain lengths ranging from six (C6) to 36 (C36) carbons long. The concentrations of hydrocarbons at most of the sites were below detection limits (limits of reporting) which ranged from 0.025 to 0.25 mg/L (Table A 3 and Table A 10). However, sites where concentrations were above limits of reporting were found in Joondalup, Stirling, Scarborough and Cottesloe (Table A 10). Most of the hydrocarbons in these regions were of longer chain lengths (predominantly C29-36 and C15-28). Because hydrocarbons are a volatile group of compounds the shorter chains, in particular, are hard to detect. The major source of these compounds is from petroleum.

As described in the first section, the applied guideline for TPH is 0.007mg/L - this has been used for comparative purposes in Table A 10 and, as discussed, this guideline should be applied with caution (Section 1.4.4). The concentrations of TPH at all sites far exceeded the advisory limit proposed by Tsvetnenko (1998) (Table A 10). Average concentrations of TPH in the drain water were between 16 and 220 times higher than the proposed environmental limit. Sites with the higher concentrations of TPH (NST01, SCB03 and COT10) are adjacent to car parks.

Table A 10. Average concentrations of petroleum hydrocarbons (mg/L) in stormwater.

LGA Region	Site (No. samples)	Average concentration (mg/L)				
		TPH	C29-36	C15-28	C10-14	C6-9
Joondalup	JND01a (1)	0.180	0	0.180	0	0
	NST01 (2)	2.250	1.350	0.900	0	0
Stirling	STG06 (1)	0.110	0	0	0	0.110
	STG10 (2)	0.480	0.310	0.170	0	0
	STG16 (1)	0.770	0.440	0.330	0	0
	STG17 (1)	0.390	0.230	0.160	0	0
	SCB01 (2)	0.405	0.095	0.155	0.155	0
	SCB02 (2)	0.425	0.240	0.185	0	0
	SCB03 (3)	1.533	0.780	0.753	0	0
Cottesloe	COT02 (3)	0.482	0.195	0.177	0.025	0.085
	COT04 (1)	0.236	0.200	0	0	0.036
	COT05 (3)	0.492	0.253	0.200	0	0.039
	COT06 (2)	0.360	0.125	0.235	0	
	COT07 (1)	0.410	0	0.410	0	
	COT10 (2)	1.045	0.540	0.505	0	0
Wanneroo	-	Concentrations below detection limits (LOR)				
Cambridge	-	Concentrations below detection limits (LOR)				
Rockingham	-	Concentrations below detection limits (LOR)				
WQ criteria (mg/L)		0.007	No value	No value	No value	No value
Limit of Reporting (mg/L)		0.250	0.100	0.100	0.025	0.025

WQ criteria – advisory water quality criterion for TPH (Tsvetnenko, 1998).

Polycylic aromatic hydrocarbons (PAHs)

All drains were sampled and tested for polycyclic aromatic hydrocarbons (PAHs) including napthalene, acenaphthylene and acenapthene. Of the suite of PAHs analysed, only napthalene was recorded in detectable levels as defined by the limits of reporting (Table A 11). Of the 65 sites sampled, only four had levels above the limit of reporting. In addition, of the 20 rain events during which sampling occurred, these values were obtained at these sites on only two sampling occasions, August 16 and 17 (Table A 11). When the low reliability trigger value of 0.016mg/L was compared to the data, all four sites fell below this value by between 2.5 and 12 times, indicating that napthalene, acenaphthylene and acenapthene may not be an issue for local government.

Table A 11. Concentrations of naphthalene (mg/L) in stormwater.

LGA Region	Site	16/8/05	17/08/05
Wanneroo	WAN06		0.0025
Stirling	STG01		0.0013
	SCB01	0.0045	
Cottesloe	COT02	0.0064	
Joondalup	No outfalls	Concentrations below Limit Of Reporting	
Cambridge (HMD)	No outfalls	Concentrations below Limit Of Reporting	
Rockingham	No outfalls	Concentrations below Limit Of Reporting	
Low reliability trigger value		0.016 mg/L	
Limit Of Reporting		0.001 mg/L	

Benzene, toluene, ethylbenzene and xylene (BTEX)

All drains were sampled and tested for the organic chemical compounds benzene, toluene, ethylbenzene and xylene (BTEX), with 126 samples collected across all sites during 2005. Only one site had concentrations above the limits of reporting and this was at STG06, within the Stirling region. Detectable levels were recorded on only one occasion at the site (Table A 12).

The guidelines (ANZECC & ARMCANZ, 2000) do not have any limits for BTEX, although low reliability trigger values (LR) are available (Table A 2). Concentrations did not exceed these trigger values at STG06 (Table A 12). There was no guideline for xylene. Once again, it appears that BTEX compounds are not an issue for local stormwater managers.

Table A 12. Concentrations of BTEX (mg/L) in stormwater at STG06

Date	Benzene	Toluene	Ethylbenzene	Xylene
16/06/05	0.006	0.017	0.0034	0.029
LR value	0.950	0.180	0.080	No Data
LOR	<0.001	<0.001	<0.001	<0.002
LR value – low reliability trigger value, freshwater. LOR = limit of reporting.				

Total suspended solids (TSS)

As discussed previously the guideline range for TSS (lowland rivers during base-flow conditions) has been applied (Section 1.4.6 Total suspended solids). All of the regions except for Cambridge exceeded the guideline range (Figure A 10). Again, the large volume of water present in the Herdsman Main Drain in this region may dilute the concentrations of suspended solids. There were no statistically significant differences in concentrations of TSS across the regions as the variability was so great; however, Stirling and Safety Bay had higher averages than the other regions (Figure A 10).

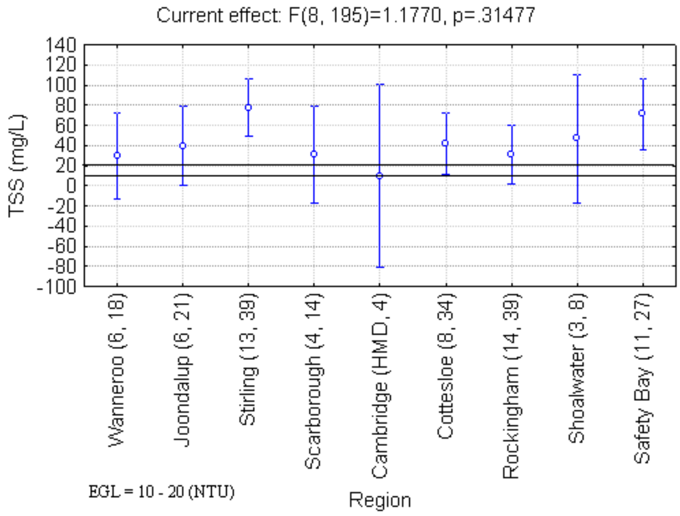


Figure A 10. Average concentration of total suspended solids (TSS) (mg/L) in stormwater for each region. Region (number drains sampled in region, total number of times drains sampled). A guideline range of 10-20 is marked with bold lines.

3.3 Variation in contaminant concentrations over time

How concentrations of contaminants vary over time is important for best practice stormwater management. For example, if concentrations are high at the beginning of a wet season but low for the remaining season, then local government could concentrate on managing the stormwater from the first rainfall or 'first flush' at is commonly known.

Drains from the Cottesloe region were selected to illustrate trends in contaminant concentrations over time because of the greater number of samples taken at these sites. However, similar trends might be expected in other regions.

The discussion centres around short (≤4 days) and medium-term time scales (1-3 months). It also considers variation in concentrations of nutrient species and individual metals as well as variations in contaminants from different sources — drain, swash and sediment.

3.3.1 Variation in nutrients in drains, metals in drains and sediment

Concentrations of nutrients and metals in specific drains in Cottesloe (COT04, COT05, COT06, COT07, COT08 and COT10) have been plotted against date of sampling (Figure A 11 and Figure A 12). The graphs have different *x* axes, as drains were sampled on different days.

Short term time scales (≤4 days)

Significant variability in contaminant concentrations does occur over short time scales (≤4 days) (Figure A 11 and Figure A 12). For example, there was a high rainfall event on the 12/13 August and another on 16 August, with little rain falling between these dates (Figure A 5). As illustrated by the data from COT05 there was a significant spike in concentrations of nutrients and metals in the drain and in the sediment beneath, when samples were collected within this period (Figure A 11a, b and c). This trend was also apparent at COT06, COT07, COT08 and COT10 for metals in the drain (Figure A 11b and Figure A 12b). Nutrients in the drain decreased at COT04 (Figure A 11a) but remained fairly constant at COT07, COT08 and COT10 (Figure A 12a). Interestingly, a downward spike was evident in metals in sediment over this time at COT07 and COT10(Figure A 11c and Figure A 12c).

Data was also collected prior to these spikes and trend data is available for samples collected on 10 August and again on 12 August. As described above, there was high rainfall on 12 August, and before this light intermittent rain for a few days (Figure A 5). However, there were no spikes in any contaminant concentrations at COT04, COT07, COT08 or COT10 (Figure A 11 and Figure A 12)

Medium term time scales (1-3 months)

Looking at medium term trends (1 to 3 months between sampling), data is available for COT04 (1 month), COT05 and COT06 (3 months), COT07, COT08 and COT10 (2 months). In all cases, concentrations of nutrients and metals in drain water and sediments remained relatively constant (Figure A 11 and Figure A 12) prior to 12 August spike. With the exception of COT10 metals in sediment, which increased quite dramatically between June and August (Figure A 12c).

Variation in nutrient species and metals

The concentrations of the different nutrient species (TN, TP, NOx, NH4 and FRP (SRP in legend)) followed the same pattern over time. This was also evident for the different metals (Al, Cu, Cr, Fe, Pb, Hg and Zn). However, the nutrients followed a different pattern to the metals over time except in the case of COT05 and COT06. Management practices can take this into account when attempting to reduce contaminants in stormwater.

Variation in contaminants from different sources (drain, swash or sediment)

The variation in concentrations of contaminants did not follow a particular pattern over time for each source. Rather the site and dates sampled seemed to determine the pattern of variation.

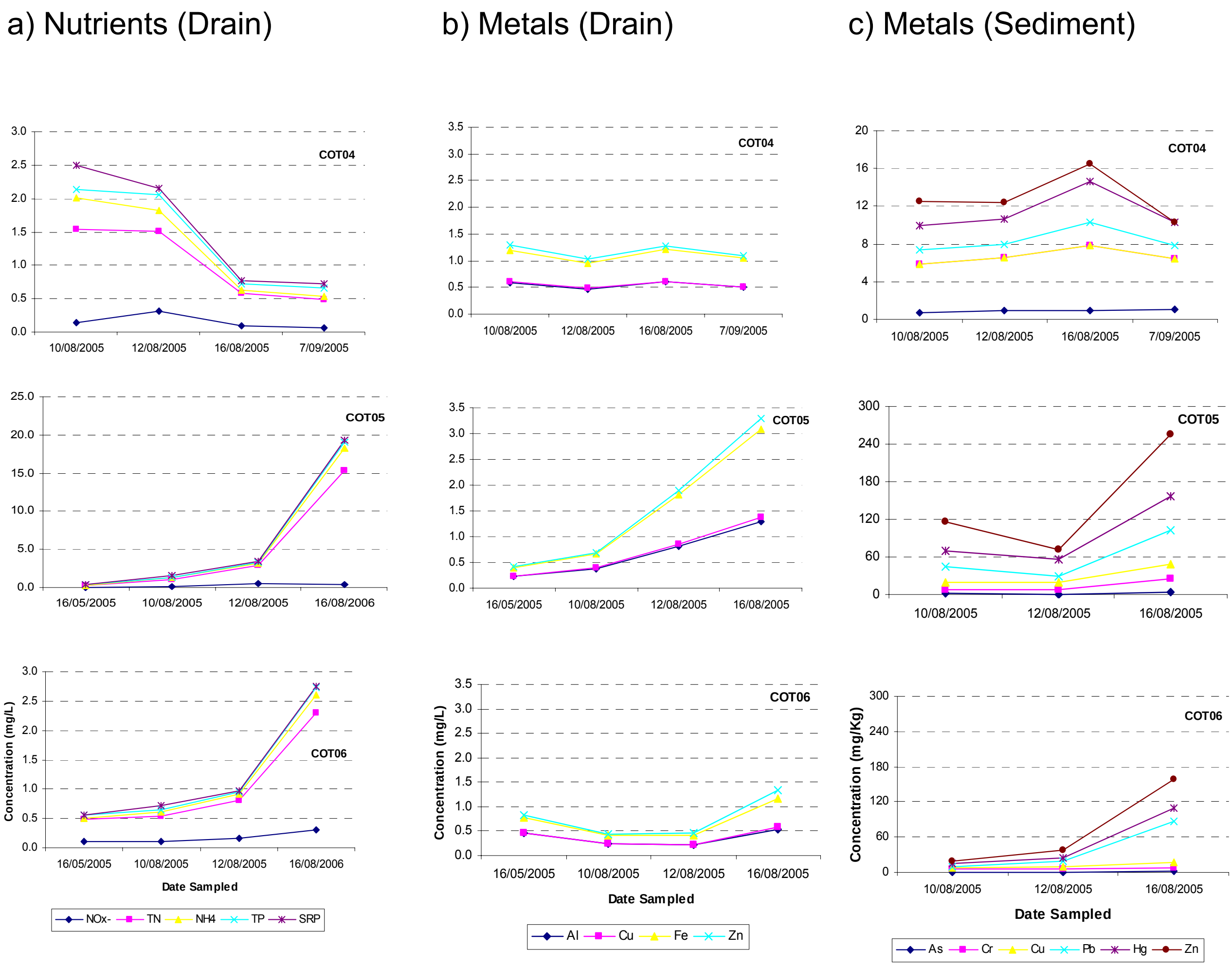


Figure A 11 (a to c). Variation in concentrations of nutrients and metals over time for selected sites (COT04, 05 and 06) (mg/L in drain, mg/kg in sediment).

a) Nutrients (Drain) b) Metals (Drain) c) Metals (Sediment)

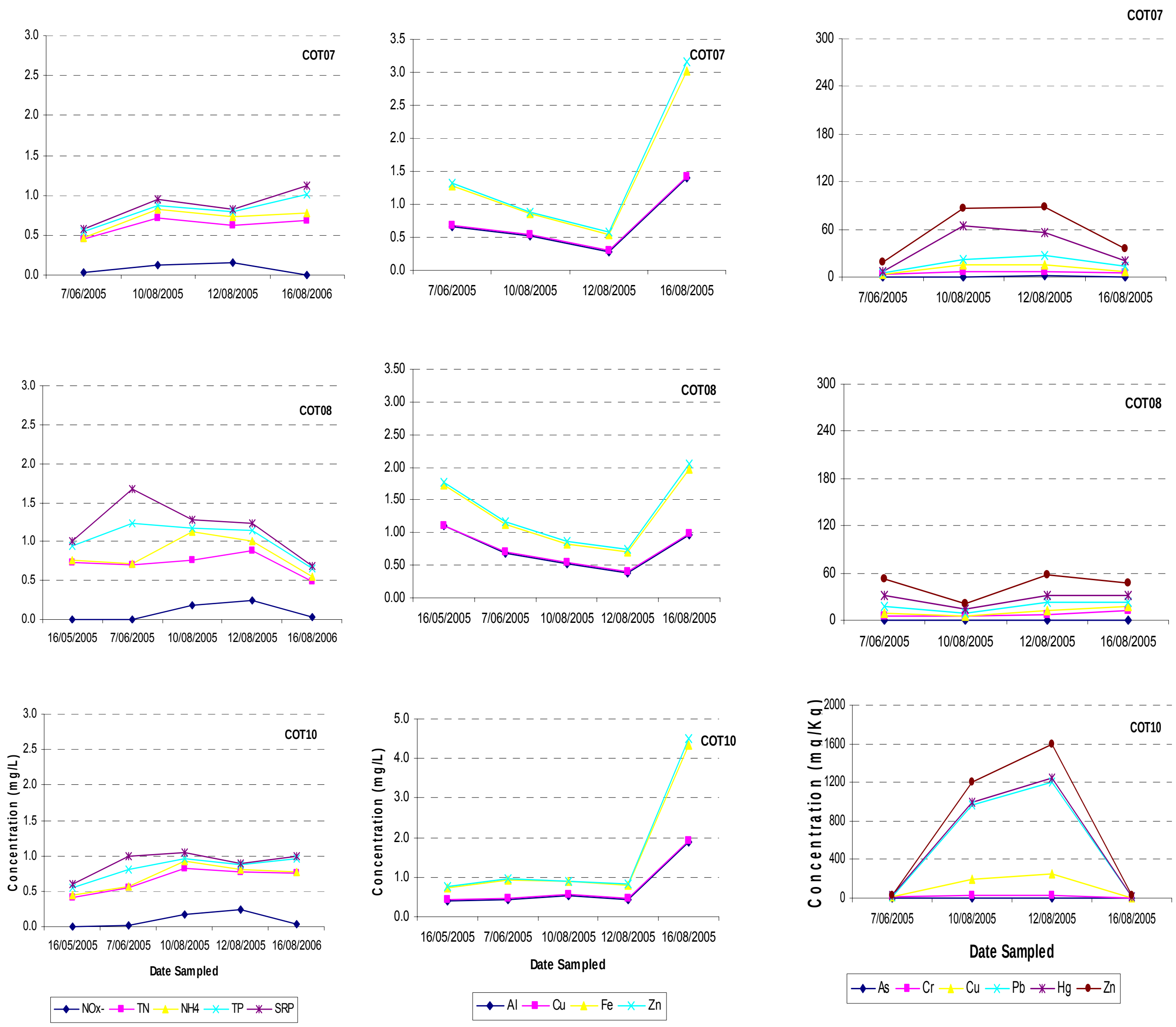


Figure A 12 (a to c). Variation in concentrations of nutrients and metals over time for selected sites (COT07, 08 and 10) (mg/L in drain, mg/kg in sediment).

3.3.2 Variation in enterococci in drains, swash and sediment

The concentrations of enterococci did not seem to spike between 12 and 16 August (Figure A 13) as they did for nutrients and metals (Figure A 11 and Figure A 12). However, there was a slight decrease in enterococci concentrations at COT04, 06, 07 and 08 (Figure A 13a, c, d and e) and a slight increase at COT05 (Figure A 13b).

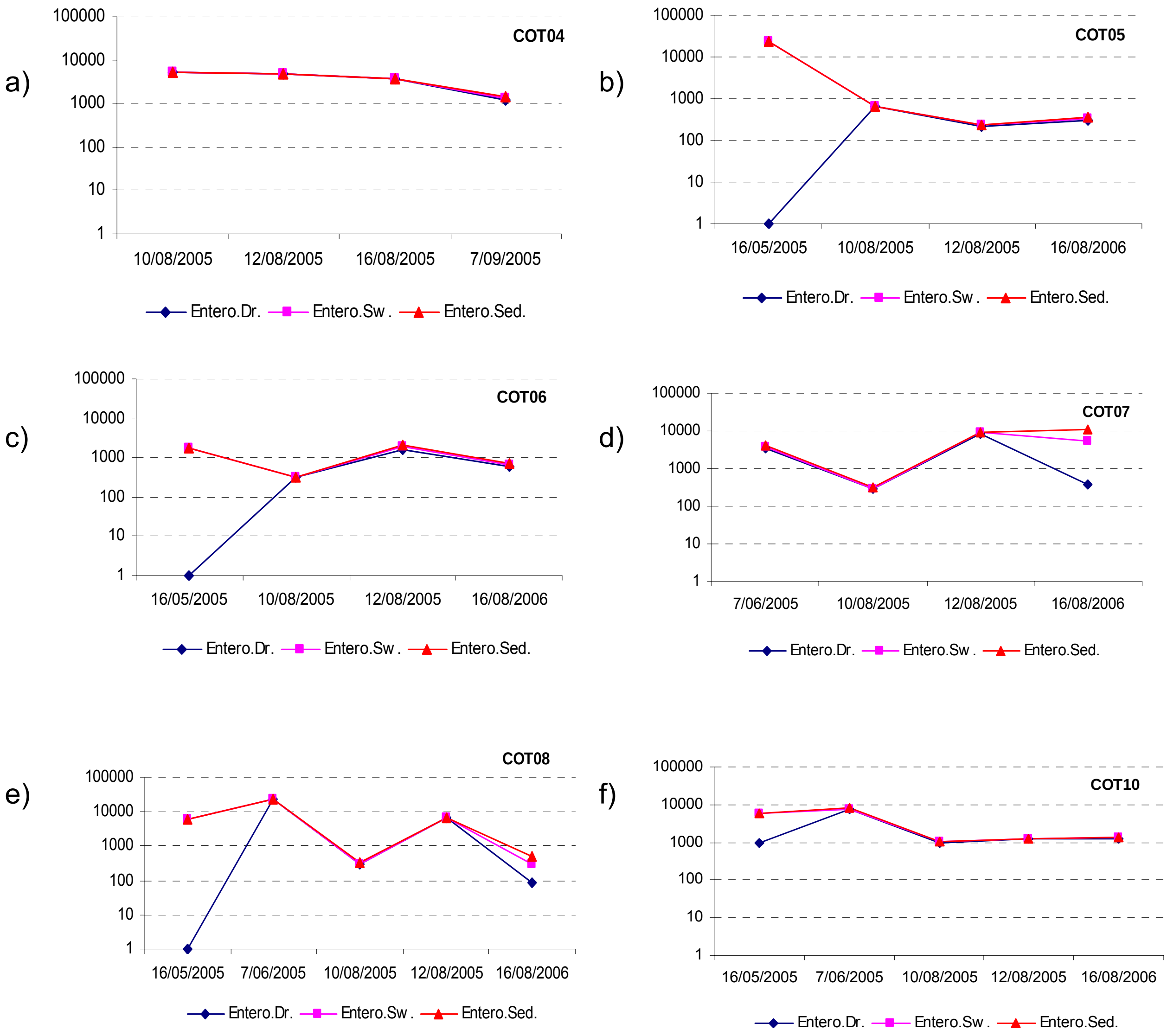


Figure A 13 (a to f). Variation in concentrations of enterococci over time for selected sites (COT04, 05, 06, 07, 08 and 10) (organisms/100 ml in drain and swash or /g in sediment). Dr = drain, Sw = swash, Sed = sediment.

There was a consistent drop in concentrations of enterococci between June and August for COT07, COT08 and COT10 (Figure A 13d, e and f).

The concentrations of enterococci in stormwater drain, swash zone and sediment generally followed similar trends over time at these Cottesloe sites. This suggests a strong link between enterococci concentrations in these three areas and may aid in stormwater management at these sites.

3.4 Water and sediment quality within regions

The following section provides an overview of stormwater contaminants within each region to assist with the stormwater management planning process, focusing on contaminants at sites that breach guidelines.

Concentrations of nutrients, metals in drains and indicator bacteria are presented as averages on a site-by-site basis in tables on maps of each region (Appendix C to Y Regional maps with contaminant data for each site). The tables also show the coefficient of variation (COV) and the number of samples that were taken. The COV is calculated by dividing the standard deviation by the average concentration and multiplying by 100 per cent. This measure of variation was used because of the number of decimal places required to show standard errors or standard deviations. It shows, as a simple percentage, how much the individual values vary from the average concentration. Therefore, if an average value of 0.005±0.0005 standard deviations was obtained for three samples, then it would be shown in the table as 0.005±10(3). This means that the actual values varied by 10 per cent from the average concentration.

Some contaminant trends are common to all regions – these will not be included in the summaries for individual local governments (Table A 13, Table A 15, Table A 17, Table A 19 and Table A 21). Instead, they will be described below.

Average concentrations of aluminium, copper and zinc in the stormwater breached guidelines at all sites in all regions, with the exception of two of the main drains in the City of Rockingham (RMD and WKMD) (Appendix E; Appendix H; Appendix K; Appendix N; Appendix Q; Appendix W; Appendix X; and Appendix Y).

Average concentrations of enterococci in the stormwater drains breached the secondary contact guideline at most sites, with the exception of the main drains (CMD in Stirling, HMD in Cambridge, RMD and WKMD), one site in Wanneroo (WAN04), and two sites in Warnbro Sound, Rockingham (WK01, WK02) (Appendix C; Appendix F; Appendix I; Appendix L; Appendix O; Appendix R; Appendix S; and Appendix T).

Since the average concentrations of enterococci in drains at most sites were high, only sites exceeding the following criteria were included in the summaries for each local government (Table A 13, Table A 15, Table A 17, Table A 19 and Table A 21), those exhibiting:

High stormwater drain concentrations (10 000 organisms/100 ml) and/or;

High swash zone enterococci concentrations, above the secondary contact guideline (>230 organisms/100 ml); and/or

High sediment concentrations (>10 000 organisms/g).

The summary tables (Table A 13, Table A 15, Table A 17, Table A 19 and Table A 21) also include information on possible sources of contaminants (Duncan, 2003) as this will aid local governments in either reducing the sources (eg providing pet faeces bags for owners to use while walking their pets) or in choosing appropriate trapping systems that capture the particular contaminants of concern.

Estimates of contaminant loads have been calculated for 21 of the 65 drains sampled as part of the Beach Health Program and presented in a report (Doucette and Oswald (2006), Appendix Z). These drains were chosen based on the availability of catchment area information. The area of catchments in Cottesloe were obtained from a drainage study (McDowall Affleck Pty. Ltd., 1995 cited in Appendix Z), while areas of catchments in Wanneroo, Joondalup and Stirling were measured from drainage charts obtained from the relevant local governments. Unfortunately areas were not available for sites sampled in the Rockingham region; however, loads for a six-week period for ROC04 have been estimated from actual water depths measured from a pressure sensor in that particular drain (Appendix Z). Information from the report was summarised for selected sites and contaminants (Table A 14, Table A 16, Table A 18 and Table A 20).

3.4.1 City of Wanneroo

Overall the concentrations of stormwater contaminants in the region were comparatively low compared with other areas to the south. The outfall at WAN06 provides the most notable source of stormwater nutrients in the region. Other sites – WAN03, WAN04 and WAN08, showed high average concentrations of iron and lead, exceeding guideline levels.

Table A 13. City of Wanneroo, sites with high average contaminant concentrations (where guideline values are breached) and possible sources.

Contaminant/s	Site/s	Concentration* mg/L (>EGL)	Possible source
Nutrients: NOx **NH_4** **TP** **FRP**	WAN06 WAN06 WAN06 WAN06	0.181 0.141 0.279 0.235	Drain adjacent to Quinns Rock caravan park and public toilet block on ocean side of park. NOx may be from these areas, other nutrients may be from fertiliser.
Metals: iron	WAN04, WAN08	0.455, 0.365	Possibly corrosion of infrastructure.
lead	WAN03, WAN04	0.009, 0.012	May be petrol derived as drains street, car parks.
Nutrients: TP	All sites except WAN13	> 0.065	Regional trend, maybe due to fertilisers.
***Concentrations taken from Appendix C to E unless otherwise stated. Units = mg/L unless otherwise stated. EGL = environmental guideline level.**			

When contaminant concentrations are extrapolated against catchment size and yearly rainfall for selected drains, the potential loads to marine waters become evident (Table A 14 and Appendix Z).

Table A 14. City of Wanneroo contaminant concentrations, catchment size and estimated annual loads.

Site	Catchment size (ha)	Contaminant	Concentration (mg/L)	Estimated annual load (kg)
WAN03	3.6	TN	0.362	2.2
		TP		
		Aluminium	0.835	5.1
		Copper	0.018	0.109
		Iron	0.205	1.3
		Lead	0.01	0.058
WAN04	1.3	TN		
		TP		
		Aluminium	0.54	1.2
		Copper	0.006	0.014
		Iron	0.455	1.0
		Lead	0.013	0.028

3.4.2 City of Joondalup

Overall, the concentrations of stormwater contaminants in the region were comparatively low compared with other areas to the south. Outfalls at JND01a and NST03 provide the most notable stormwater contaminant source to the region with high nutrient concentrations (Table A 15). Overall concentrations of iron and copper seem comparatively high across the region where guidelines were exceeded at most outfalls.

Table A 15. City of Joondalup, sites with high average contaminant concentrations (where guideline values are breached) and possible sources.

Contaminant/s	Site/s exceeding EGL	Concentration*, mg/L (>EGL)	Possible source
Nutrients: NH_4 **TP** **FRP**	JND01a; NST03 JND01a; NST03 JND01a; NST03	0.192; 0.079 0.141; 0.220 0.044; 0.067	For the LGA to determine but fertilisers may be the main source.
Total Petroleum Hydrocarbons	JND01a NST01	0.180 3.150 (Table A 10)	For the LGA to determine but probably from car parks.
Metals: lead	NST01, NST03, NST04	0.011, 0.022, 0.006	For the LGA to determine but probably from West Coast Highway and/or petrol station.
Nutrients: TP	All sites	> 0.065	Regional trend. May be due to fertiliser application.
Metals: iron	All sites except NST01	>0.300	Regional trend. Could be corrosion of vehicles, drains, other infrastructure etc.
***Concentrations taken from Appendix F to H unless otherwise stated. Units = mg/L unless otherwise stated. EGL = environmental guideline level.**			

When contaminant concentrations are extrapolated against catchment size and yearly rainfall for selected drains, the potential loads to marine waters become evident (Table A 16 and Appendix Z).

Table A 16. City of Joondalup contaminant concentrations, catchment size and estimated annual loads.

Site	Catchment size (ha)	Contaminant	Concentration (mg/L)	Estimated annual load (kg)
NST03 (shared stormwater with NST01 and possibly other drains connected as well)	11.1	TN	1.273	24.2
		TP	0.22	4.18
		Aluminium	0.778	14.8
		Copper	0.013	0.237
		Iron	0.7	13.3
		TPH	4.400	2.375
NST04	15.7	TN	0.58	15.5
		TP	0.088	2.34
		Aluminium	0.723	19.3
		Copper	0.015	0.401
		Iron	0.423	11.3
NST05	9.1	Aluminium	0.457	7.1
		Copper	0.012	0.186
		Iron	0.41	6.4

3.4.3 City of Stirling

The current sampling program has shown that generally outfalls in the City of Stirling contain comparatively higher concentrations of some contaminants when compared to other regions. In general, when compared to other regions there appears to be a regional trend with high concentrations of total phosphorus, iron, lead and copper in stormwater.

Specifically overall nutrient concentrations at SCB01, SCB02 and STG08 are very high and selected nutrients are high at STG05, STG07, SCB03 and CRMD. A range of contaminants are above guidelines at STG06, predominantly hydrocarbons and metals. Enterococci concentrations at STG05, STG09 and STG11 are also very high.

Table A 17. City of Stirling, sites with high average contaminant concentrations (where guideline values are breached) and possible sources.

Contaminant/s	Site/s	Concentration*, mg/L (>GL)	Possible source
Nutrients: **TN** **NOx** **NH_4** **TP** **FRP** **TPH** **Metals: nickel**	 SCB01;SCB02 SCB01;SCB02 SCB01;SCB02 SCB01;SCB02 SCB01;SCB02 SCB01;SCB02 SCB02	 1.29; 2.35 0.276; 0.151 0.094; 1.034 0.098; 0.211 0.044; 0.130 0.655; 0.425 (Table A 10) 0.016	For the LGA to determine but TPH and Ni probably due to vehicle wear, leaks etc in car park. Nutrients may be from public open space, dog faeces or domestic application of fertiliser. NOx may be leaking septic systems.
TPH **Metals:** **iron** **lead** **aluminium** **Metals (sediment):** **copper** **aluminium**	STG06 STG06 STG06 STG06 STG06 STG06	0.110 (Table A 10) 0.637 0.013 1.22 (one of only 3 sites to exceed 1.00 mg/L) > 10000 mg/kg (Table A 9) > 6000 mg/kg (Table A 9)	For the LGA to determine but it appears that some illegal dumping may be occurring in this drain.
Metals: aluminium	STG01	1.015 (one of only 3 sites to exceed 1.00 mg/L)	For the LGA to determine.
Metals (sediment): **aluminium**	STG17	6900 mg/kg (Table A 9)	For the LGA to determine.

Contaminant/s	Site/s	Concentration*, mg/L (>GL)	Possible source
Enterococci (stormwater drain) **Nutrients: NOx** **NH_4**	STG05 STG05 STG05	57200 organisms/100 mL 0.172 0.118	For the LGA to determine. For the LGA to determine. These may be due to toilet block/septic systems.
Nutrients: NH_4	STG07	0.083	For the LGA to determine.
Nutrients: **TN** **NOx**	 STG08 STG08	 1.665 1.195	For the LGA to determine. Again toilet block, septic system may contribute.
Nutrients: NOx	CRMD	0.366	For the LGA to determine.
Enterococci (swash zone)	STG09	621 organisms/100 mL	For the LGA to determine.
Metals (sediment): **aluminium** **Enterococci (swash)**	 STG11 STG11	 6000 mg/kg (Table A 9) 1062 organisms/100 mL	 For the LGA to determine but may be due to bird use of Trigg Island..
TPH	STG10;STG16, STG17;SCB03	0.480; 0.770 (Table A 10) 0.390; 0.533	For the LGA to determine.
Nutrients: TP	All sites except STG16, STG17	> 0.065	Regional trend.
Metals: iron	All sites	>0.300	Regional trend.
lead	All sites except CMD	0.0034 (see also Figure A 7d)	Regional trend. Probably vehicle related.
***Concentrations taken from Appendix I to K unless otherwise stated. Units = mg/L unless otherwise stated. GL = guideline (may be environmental, recreational or health-based).**			

When contaminant concentrations are extrapolated against catchment size and yearly rainfall for selected drains, the potential loads to marine waters become evident (Table A 18 and Appendix Z).

Table A 18. City of Stirling contaminant concentrations, catchment size and estimated annual loads.

Site	Catchment size (ha)	Contaminant	Concentration (mg/L)	Estimated annual load (kg)
STG06	0.3	TPH (C9 only)	0.110	0.064
		Iron	0.638	0.3
		Lead	0.014	0.007
		Aluminium	1.22	0.6
STG05	4.4	TN	0.625	4.7
		TP	0.069	0.52
		Enterococci (Drain)	13140	7,517 m^3/year
STG07	4.4	TN	1.00	7.5
		TP	0.082	0.61
STG08	5	TN	1.665	14.2
		TP	0.064	0.54
STG09	8.8	Enterococci (Drain)	470	15,034 m^3/year

3.4.4 Town of Cambridge (HMD)

Herdsman main drain flows continually for most of the year and this may be reflected in the results – the data shows high variability and in the case of most contaminants sampled, the concentrations were low (Appendix L to N). Given this, there was one significant exception with the nutrient data where concentrations of nitrogen oxides (NOx), were well above guidelines. The average concentration far exceeded concentrations from any other region at approximately 0.9 mg/L (Figure A 9c).

3.4.5 Town of Cottesloe

Overall nutrient concentrations at COT05 are high and selected nutrient concentrations are high at COT04, COT06, COT07, COT08 and COT10. The drain at COT05 also had high levels of TPH in stormwater and compared to all other regions and outfalls, very high levels of aluminium in the sediment. In addition, COT05, COT07 and COT08 showed very high levels of either sediment or swash zone enterococci concentrations.

Regional trends appear evident including high concentrations of enterococci in stormwater at all outfalls sampled (>1000 organisms/100 mL) and high levels of FRP, iron, lead and copper at most sites.

Table A 19. Town of Cottesloe, sites with high average contaminant concentrations (where guideline values are breached) and possible sources.

Contaminant/s	Site/s	Concentration*, mg/L (>GL)	Possible source
Nutrients: **TN** **NOx** **NH_4** **TP** **FRP** **TPH** **Metals (sediment): aluminium**	 COT05 COT05 COT05 COT05 COT05 COT05 COT05	 4.632 0.291 0.838 0.267 0.167 0.492 (Table A 10) 21000 mg/kg (Table A 9)	For the LGA to determine, but fertilisers (from golf course) and septic systems may be the sources. TPH may be from car park and Marine Pde.
Nutrients: NH4 **TP** **FRP**	COT04 COT04 COT04	0.184 0.128 0.117	For the LGA to determine, Possibly fertilisers from public open space.
Nutrients: NOx **NH4**	COT06 COT06	0.170 0.130	For the LGA to determine, see above.
Nutrients: NH4 **TP** **FRP**	COT07 COT07 COT07	0.083 0.103 0.061	For the LGA to determine, see above.
Nutrients: NH4 **TP** **FRP**	COT08 COT08 COT08	0.117 0.201 0.146	For the LGA to determine., see above
Nutrients: TP **FRP**	COT10 COT10	0.118 0.062	For the LGA to determine, see above.
Enterococci (swash zone)	COT07	1395 organisms/100 mL	For the LGA to determine.
Enterococci (sediment)	COT05	16006 organisms/100 mL	For the LGA to determine.
Enterococci (sediment)	COT08	12385 organisms/100 mL	For the LGA to determine.
Enterococci (sediment)	COT10	12105 organisms/100 mL	For the LGA to determine but may be due to dog beach.
Nutrients: FRP	Cottesloe, most sites.	>0.08 (Figure A 9b)	Regional trend.
Metals: iron	All sites except COT11	>0.300	Regional trend.
lead	All sites except COT04 and COT10	0.0034	Regional trend. Possibly vehicle related.
***Concentrations taken from Appendix O to Q unless otherwise stated. Units = mg/L unless otherwise stated. GL = guideline (may be environmental, recreational or health-based).**			

When contaminant concentrations are extrapolated against catchment size and yearly rainfall for selected drains, the potential loads to marine waters become evident (Table A 20 and Appendix Z).

Table A 20. Town of Cottesloe: contaminant concentrations, catchment size and estimated annual loads.

Site	Catchment size (ha)	Contaminant	Concentration (mg/L)	Estimated annual load (kg)
COT04	6.5	TN	0.758	18.6
		TP	0.129	3.15
		Aluminium	0.47	11.5
		Copper	0.015	0.357
		Iron		
		Lead		
		Enterococci (Drain)	3367 organisms/100 mL	24476 m^3/year
COT05	0.6	TN	4.633	4.7
		TP	0.267	0.27
COT10	7.9	TN	0.537	7.2
		TP	0.118	1.59
		Aluminium	0.65	8.8
		Copper	0.019	0.254
		Iron	0.673	9.1
		Lead	0.014	0.184

3.4.6 City of Rockingham

Overall, 15 of 29 sites in Rockingham exhibited at least two nutrient parameters exceeding guidelines. The drain at ROC02 exceeded the guidelines for all nutrients measured and the drains at SB06, WK01, ROC01, ROC14 and SB02 exceeded nutrient concentrations for most parameters. Of greatest concern in Rockingham are the high levels of enterococci concentrations in the swash zone, with 10 outfalls exceeding guidelines for secondary contact and an additional six exhibiting very high concentrations in the swash zone (>1000 organisms/100 mL).

In addition to enterococci concentrations regional trends indicate high levels of iron and copper across most sites.

Table A 21. City of Rockingham, sites with high average contaminant concentrations (where guideline values are breached) and possible sources.

Contaminant/s	Site/s	Concentration*, mg/L (>GL)	Possible source
Nutrients: **TN** **NOx** **NH4** **TP** **FRP**	 ROC02 ROC02 ROC02 ROC02 ROC02	 0.778 0.315 1.51 0.118 0.074	For the LGA to determine but near industrial area including fertiliser plant.
Nutrients: **TN** **NH4** **TP** **FRP**	 SB06 SB06 SB06 SB06	 1.886 1.134 0.177 0.067	For the LGA to determine, possibly fertilisers from reserve.
Nutrients: **NOx** **NH4** **TP** **FRP**	 WK01 WK01 WK01 WK01	 0.170 0.237 0.244 0.077	For the LGA to determine, as above.
Nutrients: **NOx** **NH4** **FRP** **Metals (sediment):** **aluminium**	 ROC01 ROC01 ROC01 ROC01	 0.17 0.403 0.04 8700 mg/kg (Table A 9)	For the LGA to determine, has grain from silos in pool beneath drain, also near reserve.
Nutrients: **NH4** **TP** **FRP**	 ROC14 ROC14 ROC14	 0.102 0.089 0.057	For the LGA to determine, possibly fertilisers from reserve.
Nutrients: **NH4** **TP** **FRP**	 SB02 SB02 SB02	 0.094 0.100 0.057	For the LGA to determine, see above.
Nutrients:	ROC06, ROC16, SHL01, SHL07, SB01, SB02, SB04, SB07 and FRMD	Exceeded EGL values for two nutrients.	For the LGA to determine, see above, septics may also be indicated by NOx, and FRMD may drain Hawker St reserve.
Nutrients: TP	Most sites except SHL02, FRMD, SB05 and WKMD.	> 0.065	Regional trend south of Cape Peron, may be fertiliser related.
Enterococci (swash zone)	ROC01, ROC02, ROC06, ROC07, ROC08, ROC12, SHL01, SB04, SB05, SB06	All above 230 organisms/100 mL	For the LGA to determine.

Contaminant/s	**Site/s**	**Concentration*, mg/L (>GL)**	**Possible source**
Enterococci (swash zone)	ROC05, ROC13, ROC14, ROC16, SB03, SB07	All above 1000 organisms/100 ml	For the LGA to determine
Enterococci (stormwater drain)	ROC02 ROC13	13633 20000 organisms/100 ml	For the LGA to determine.
Enterococci (sediment)	ROC01 ROC10	11083 16003 organisms/100 ml	For the LGA to determine, ROC 01 near dog beach.
Metals: lead	SB03 SB04 SB06 SHL07	0.009 0.013 0.009 0.011	For the LGA to determine. Possibly vehicle related – boat and car fuel, tyres
iron	Two thirds of sites	>0.300	Regional trend.
*** Concentrations taken from Appendix R to Y unless otherwise stated. Units = mg/L unless otherwise stated. GL = guideline (may be environmental, recreational or health-based).**			

4 Discussion

The information provided in Part A of this report (Part A — Water and sediment quality sampling program) includes the stormwater drain prioritisation for the Swan region and stormwater contaminant data for 65 drains sampled between Wanneroo and Rockingham. The information was presented at a regional scale as well as for individual outfalls.

A comprehensive sampling program for part of winter 2004 and all of winter 2005 provided over 2,500 samples across 65 different stormwater outfalls. Analysis included microbial quality (enterococci), nutrients, heavy metals, total suspended solids (TSS), polycyclic aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPH) and organic chemical compounds (BTEX). The information generated from this sampling program highlights regional trends in stormwater contaminants and pin points specific outfalls with high contaminant concentrations.

The following sections discuss the results from the current study in relation to other studies — both local and international.

Microbial quality — Swash zone

Surveys of microbial quality at Perth's coastal beaches have been conducted by the Department of Health (DOH) between 1996 and 2005 (DOH, unpublished data). A total of 73 sites were sampled across the metropolitan area, between Burns Beach and Rockingham over the warmer, drier months (ie excluding May, June and July). The samples were collected monthly (and sometimes twice a month) from the swash zone at selected sites. Enterococci concentrations at most sites were generally between 10 and 30 organisms/100 mL (raw ocean data 2002-2005, DOH, unpublished), remaining below the primary contact guideline of 35 organisms/100 mL. However, Fishing Boat Harbour, parts of Hillarys Marina, Mindarie Quay (south) and Rockingham Beach were all above 100 organisms/100 ml with only Rockingham Beach also exceeding the secondary contact guideline of 230 organisms/100 mL. The Beach Health data, collected over the colder and wetter months (May, June, July, August and September), showed comparatively higher enterococci concentrations in the swash zone. For example, with the current study, enterococci concentrations in the swash zone at Stirling, Cottesloe, Rockingham and Safety Bay, on average, all exceeded or were close to the secondary contact guideline. The remaining regions (Wanneroo, Cambridge and Shoalwater), on average, all exceeded the primary but not the secondary contact guideline. Only Joondalup and Scarborough remained below the guidelines. This information should be considered when managing stormwater, as the colder months do still attract many people to the beach, either to surf, swim or to recreate in the shallows (ie children).

A study of swash zone concentrations of enterococci in relation to a large stormwater drain (NST05) discharging to a Perth beach (Sorrento) was conducted recently (Green *et* *al*., 2006). The authors showed that in relation to primary contact guidelines, it wasn't safe to swim in the swash zone (255 m along the coast) until 27 to 43 hours after stormwater had ceased flowing from the local drain. This is the first study of its kind in Australia and will provide the DOH with locally relevant information to alert swimmers to the risks during the wet winter months.

High swash zone concentrations of enterococci were generally associated with high drain concentrations except in the case of Joondalup, Scarborough and Shoalwater. This may be due to several factors: the distance of the drain outfall from the swash zone; the higher wave energy of the swash zone thereby more rapid dilution and/or; the flow of stormwater at the time of sampling being insufficient to reach the swash zone.

Microbial quality — Sediment

Microbial quality of the sediments at recreational beaches is of concern as shown by studies overseas. In the United Kingdom, inter-tidal zone sediments appeared to serve as a substantial reservoir for enteric bacteria, which could contribute significantly to bacterial numbers in surface waters, especially in rough weather (Obiri-Danso and Jones, 1997). Enteric bacteria were recorded in both coastal waters and sand on a number of Israeli beaches, with the beach sand containing higher counts than adjacent shore waters (Ghinsberg et al., 1994). The Beach Health Program also assessed sediment enterococci concentrations beneath the stormwater drains, even though there are no guidelines for sediment and such samples are not collected by the DOH. In the Beach Health study, high sediment enterococci concentrations (>1,000 organisms/g) were associated with high stormwater concentrations in Cottesloe, Rockingham and Safety Bay. Other factors that could increase enterococci concentrations in the sediment besides stormwater include failing septic systems possibly contaminating shallow groundwater aquifers; fauna (eg seagulls on beaches, jetties or moored boats, or dog faeces from reserves and dog beaches); and decomposing seagrass or macroalgal wrack which provide a rich source of nutrients for bacteria to grow.

Several sites sampled in Cottesloe and Rockingham exhibited very high average levels of sediment bacteria (>10,000 organisms/g). These concentrations may be attributed, in some cases, to the same sources as described above such as build up of wrack or to pets at dog beaches. However, in most cases, it appears that neither a build up of wrack nor pet beach status is responsible, but that stormwater or possibly groundwater loads may be the greater source.

Contaminants in stormwater

Concentrations of nutrients and heavy metals in stormwater are comparable with a recent study by JDA Consultant Hydrologists in Perth (JDA, 2007). The study focused on the areas of the Cities of Nedlands and Subiaco and the Towns of Claremont, Cottesloe and Mosman Park, and the Shire of Peppermint Grove. These local governments form the Western Suburbs Regional Organisation of Councils (WESROC). JDA assessed stormwater contaminant concentrations at 23 sites and this was coupled with groundwater and receiving environment sampling. Of the 23 stormwater sites, two discharged to the coast and the remainder to the Swan River or regional wetlands. The WESROC survey provides data for TN, TP, TKN, FRP, copper, lead and zinc over the 2004 winter period.

The WESROC study also obtained first flush data for the stormwater drains, having sampled stormwater drains in May 2004. As a result, trend data is available showing a spiked decline in contaminant concentrations following these initial large rains. While the Beach Health Program officially missed the first flush during its winter 2005 sampling program, due to heavy rains that fell before May, other trends became evident and should not be discounted from a stormwater management perspective. These trends relate to significant spikes in stormwater nutrients and metals, and sediment metals over very short time frames (Figure A 11 and Figure A 12).In many cases, the spikes are more significant than the drop in concentration recorded following the first flush at most WESROC sites. Although trend data was presented for only six Beach Health sites, these spikes in concentration did occur at many of the 65 outfalls sampled.

A study in California also collected first flush data, to determine the impact of stormwater on the adjacent Monterey Bay Marine Sanctuary (Monterey Bay National Marine Sanctuary, 2000). The monitoring program occurred across three cities and ten sites and data was collected on concentrations of nitrate, orthophosphate, total coliforms and *Escherichia coli*. (*E. coli*), total dissolved and suspended solids, oil, grease, zinc copper, iron and lead. Both the average and the range of concentrations of zinc, copper, iron and lead were comparable to those obtained for the majority of Beach Health Program sites. However the Monterey Bay study reflects only the first flush concentrations, while those used for comparison from the Beach Health Program were averaged over a number of events in winter. This may suggest that metal concentrations reaching Perth beaches may indeed be significantly higher at first flush, and therefore also comparatively higher than those reaching Californian beaches around Monterey Bay.

Interestingly, while metal concentrations are comparable, nutrient concentrations at the Monterey Bay sites were higher than most sites in the Beach Health Program. This can be attributed in part to Australian soils being naturally low in phosphorus. However, some of the concentrations analysed in the current study would indicate high loads from external sources (such as landscaping at a domestic and possibly commercial scale).

Metals — Stormwater drain

Concentrations of heavy metals in stormwater appeared to show a regional trend with Joondalup, Stirling, Scarborough and Cottesloe exhibiting comparatively higher concentrations of heavy metals (aluminium, copper, iron and lead) than areas to the north and Rockingham to the south. These may be attributed to car parks and service stations (especially on West Coast Highway) and also urban and commercial landscaping. Copper, for example, is sourced from vehicle tyres and brake linings, and also from fungicides and pesticides; and lead from tyres, lead water pipes and plastic pipes and guttering.

Metals — Sediment

Concentrations of heavy metals in sediments adjacent to stormwater drains are comparable with a recent toxicant sediment survey conducted in Cockburn Sound and Owen Anchorage (DOW, 2006). Samples for this Cockburn Sound survey were collected from 21 shallow inter-tidal areas. Comparisons between the two surveys are possible as the Beach Health samples were also collected from shallow inter-tidal sediments within the stormwater channel beneath the drain. Sediment arsenic, chromium, copper, lead, nickel and zinc concentrations are comparable to those measured at the majority of sites in Cockburn Sound and Owen Anchorage (D0W, 2006). There are several sites sampled as part of the Beach Health Program where concentrations are similar to, or comparatively higher than, some of the Cockburn Sound sites (including the CBH and Kwinana bulk handling jetties). The Beach Health sites that exhibit comparatively higher concentrations of a suite of heavy metals are STG06, WAN04, COT05 and COT10, while those that exhibit comparatively higher concentrations of only a couple of metals are STG11, COT02, ROC01, ROC02, ROC10, SHL07 and SB03. Marine sediments are known to integrate contaminants in the long-term. Sediment re-suspension due to disturbance may provide an on-going source of contaminants to water and biota long after the cause of the initial contamination has ceased. With regard to the management of these contaminant fluxes and their potential impact on near-shore marine environments, it is possible that further sampling of these sites is required as part of on-going stormwater management practices (eg at STG06, WAN04, COT05 and COT10 and at the other sites listed above).

Total suspended solids

Total suspended solids were comparable across sites in the two studies mentioned above. Again, the Monterey Bay study reflects only the first flush concentrations of total suspended solids, while those used for comparison from the Beach Health study were averaged over a number of rain events. This suggests that the suspended solid concentrations reaching Perth beaches are higher than those reaching Monterey Bay as we would expect higher concentrations during the first flush than we recorded on average over the winter season.

The concentration of total suspended solids may simply provide a measure of the energy or size of the downfall: if rainfall intensity increases, more solids can be held in suspension (Duncan, 2003). However, there is an association between suspended solids and many other contaminants, including hydrocarbons, heavy metals and phosphorus (Duncan, 2003) and studies have shown that stormwater loads can be increased by a factor of 100 or more through construction activity or soil disturbance in catchments (Pisano, 1976; Barfield et al., 1978; and Konno and Nonomura, 1981). In this study, the increase in contaminant concentrations at Cottesloe drains over short time periods was most likely due to greater rainfall intensity in August 2005. However, it is not known whether there was also any construction activity occurring at the same time.

Loads of contaminants

The loads of contaminants flowing from stormwater drains to Perth beaches were estimated in a report by Doucette and Oswald (2006) using the 2005 average contaminant data from the current study (Appendix Z). These values were comparable to those found by JDA Consultant Hydrologists in 2004 at two sites (COT04 and COT05) that were common to both studies (JDA, 2007). There were also two contaminants that were common to both studies: total nitrogen and phosphorous. However, it should be noted that the average rainfall was greater in 2005 than 2004. The annual export rate for nitrogen at COT04 was about half of that estimated by JDA (2007): 1.3 kg/ha/yr compared with 2.1 kg/ha/yr. The same was observed for phosphorous with estimated values of 0.22 kg/ha/yr compared with 0.5 kg/ha/yr. In contrast the annual export rate for nitrogen at COT05 was nearly nine times greater than that estimated by JDA (2007) at 7.8 kg/ha/yr compared with 0.9 kg/ha/yr. Similarly phosphorous was estimated at four times greater with 0.45 kg/ha/yr compared with 0.1 kg/ha/yr. We do not know why the differences between the two studies vary between sites, since the differences in rainfall alone cannot explain the observed loads. However, again this data suggests that to manage stormwater effectively, best management practices should be tailored to the particular drain and its catchment.

At other sites in the Beach Health program, the loads of contaminants of Al, Fe, TN and TSS sometimes reached tens of kilograms/yr warranting further investigation (Appendix Z).

Recommendations

The water quality monitoring program has identified certain contaminants, their concentrations and also specific outfalls where further investigations may be required to determine sources and potential impacts on human health and/or on marine ecosystems. We recommend that local government also reduce or remove the sources of contaminants from stormwater drains and that they monitor and maintain whichever practice they implement or infrastructure that they install according to best practice methods described in the *Stormwater Management Manual for Western Australia* (DoW 2004-). Examples of ways of improving stormwater quality include reducing contaminants in stormwater by street sweeping and public education, as well as by preventing them from concentrating in the first place through water sensitive urban design techniques such as vegetated swales.

Diverting stormwater to groundwater, as a means to reduce the impacts of its contaminants on recreational activities and the environment, without controlling and treating the sources of contaminants, is not recommended. Some local governments are currently diverting stormwater this way and others are planning to implement this practice. This is not recommended because we do not know the degree of connection between stormwater, groundwater and near-shore coastal zones, nor what happens to the contaminants as they make their way through these different water bodies.

Part B — Impacts on near-shore marine habitats — a pilot study

Department of Water and Swan Catchment Council officers taking sediment cores in the inter-tidal zone of Sorrento Beach (near NST05), Perth Western Australia. ***Photograph by Suzanne Gattrell***.

1 Introduction

Microscopic algae inhabit the surface layer of marine sediments and are typically dominated by species of diatom, cyanobacteria or blue-green algae, euglenoids and some single-celled green algae. Many of these microphytobenthos communities have high primary productivity and play an important role in the marine ecosystem through processes of carbon fixation, oxygen production, nutrient cycling and as a food source for grazers. The microphytobenthos can dominate sandy habitats and therefore may be an indicator of the health of near-shore marine communities.

Chlorophyll *a* (chl *a*) concentrations in surface sediments provide information on community plant biomass. In the absence of macroscopic plant matter (eg seagrass and macroalgae), chl *a* is assumed to be attributed to the presence of microphytobenthos. Sediment samples were collected from the shallow, inter-tidal swash zone in Marmion Marine Park, along Perth’s northern beaches. The chl *a* concentrations were measured to assess the potential impact of stormwater flows on near-shore marine habitats. Two drain sites at sandy habitats within the City of Joondalup were selected, North Stirling 03 (NST03) and North Stirling 05 (NST05), with control sites, at least 100 m from each drain.

Inter-tidal sediments are often subjected to wave action and fluctuating gradients in light, temperature and nutrient concentrations, which could influence the overall biomass of microphytobenthos. To reduce some of this natural variability, attempts were made to select comparable sites for the drains and their controls.

In addition to chl *a*, phaeophytin concentrations were also recorded. Chlorophyll *a* can be easily transformed to phaeophytin (a yellow-green pigment) by the loss of the central magnesium ion, with acidification. Phaeophytin concentrations provide an indication of the amount of dead or dying plant matter in the sediment community. Low levels of phaeophytin may indicate a very active photosynthetic community. A crude measure of ‘health’ can be applied to this information, derived as the ratio of chlorophyll *a* to phaeophytin (Edmunds, *et al*., 2004). A low ratio of chlorophyll *a* to phaeophytin indicates a sample dominated by dead or decaying material or the deposition of detritus from another source. A high value for this ratio indicates a healthy, growing microalgal community with little seagrass or algal detritus.

The key contaminants in stormwater in the Swan Region were metals, nutrients and total suspended solids (Part A — Water and sediment quality sampling program). These contaminants can affect growth of microphytobenthos. In the case of nutrients, increased growth can occur with an increase in nutrients as long as the temperature and light conditions are appropriate. And in the case of metals, reduced growth and photosynthesis can occur when the metals (eg Cd, Cu, Hg, Pb and Zn) are in sufficient concentrations to behave as toxicants, (Jeffrey, 1981). With respect to total suspended solids, size can play an important role in delivering nutrients and/or metals as finer particles tend to bind these contaminants. The finer particles also provide a better habitat for microphytobenthos than the coarser ones.

Therefore besides chl *a* and phaeophytin, concentrations of nutrients (TN, TP, NOx, NH4, FRP) and metals (Al, Cr, Fe, Mn, Pb and Zn) and percentage composition of particle sizes of sediments were also measured.

If there was an impact of stormwater contaminants on the microphytobenthos, we would expect a higher health ratio of chl a to phaeophytin at the drain compared to control sites when nutrient levels are higher and a lower ratio when certain metal concentrations are higher. A higher health ratio would also be expected at sites with finer sediments, adequate nutrients and lower toxic metals than at a site with the opposite conditions.

2 Methods

2.1 Categorising sites in relation to stormwater threats and near-shore marine habitats

An analysis was undertaken to determine the potential threat posed by stormwater flows to marine habitats. This included an assessment of the type and extent of near-shore marine habitats, such as seagrass meadows, inter-tidal sand communities, inter-tidal reef platforms, rocky reefs and reef pavement with macrophyte communities. The assessment included evaluating their proximity to stormwater flows including distance from the source to the habitat and degree of impact, with direct discharge to marine waters potentially having the greatest impact. In selecting appropriate parameters and sites to evaluate the direct impacts of stormwater on near-shore coastal ecosystems all of these factors were taken into consideration. A conceptual model was developed to clarify these different scenarios in the Swan Region given the current arrangement of stormwater outlets along the coast (Part A — Water and sediment quality sampling program, Figure A 1).

The dominant habitats identified at sites adjacent to stormwater drains in the Swan region are shallow inter-tidal sand habitats, seagrass meadows, reef pavement and low relief rocky reef.

As a result of this threat analysis, the 65 drains sampled in Part A were further assessed to record the following information:

a) location of the outfall relative to the receiving waters (eg direct to dunes, beach or water) and total distance from the outfall to the ocean (eg including the distance though the dunes and across the beach);
b) habitat type immediately adjacent to (within 0 to 60 m) and surrounding the outfall (>60 m); and
c) seasonal changes and other variables (eg natural variability, sand scouring, other point source contamination, groundwater contamination etc).

2.2 Assessment of near-shore marine communities

Based on the site prioritisation, shallow sand communities in the inter-tidal zone were considered under greatest threat due to their proximity to stormwater flows. As such inter-tidal invertebrate infauna and microphytobenthos were identified as potential communities to assess as part of this pilot study. Given the patchy (both spatial and seasonal) distribution of invertebrate infauna in this inter-tidal zone and time and money constraints, a decision was made to focus only on the microphytobenthos for the pilot study.

The chlorophyll *a* concentrations within the surface sediments were used as a measure of productivity of microphytobenthos to detect any differences in these communities that could be a result of stormwater flows to these areas. Sites were selected based on high flow and volume outfalls located in sandy beach areas free of other immediately adjacent habitats and with a similar physical aspect (eg hydrodynamics and depth).

2.3 Study area

The study area occurs within the Marmion Marine Park, along Marmion Beach in Perth's northern coastal waters. The area is characterised by long stretches of sandy beach, broken by several groynes and some small bays. A broken limestone reef pavement occurs along much of this area, becoming exposed seasonally as sand sheet movement occurs across the inter-tidal zone. A low relief limestone reef system occurs in inter-tidal/sub-tidal waters, between 0 and 100 m from the coast and further off shore a parallel sub-tidal reef system extends along the coast. Macroalgae dominate these reef habitats and between the limestone pavement reef system and near-shore, sandy areas are colonised by various species of seagrass. These seagrass meadows are relatively patchy and generally occur as mixed species meadows.

Two impact areas were selected for the current study – North Stirling 03 (NST03) and North Stirling 05 (NST05) (Figure B 1). Both drains from these areas were sampled regularly as part of the water and sediment quality monitoring program, so data is available on a range of contaminants flowing from each over winter (Part A — Water and sediment quality sampling program, Appendix G and Appendix H). The control site for each impact area was located approximately 100 m north of the stormwater outfall. The location of the sites with respect to other features such as groins is depicted in the diagram (Figure B 1).

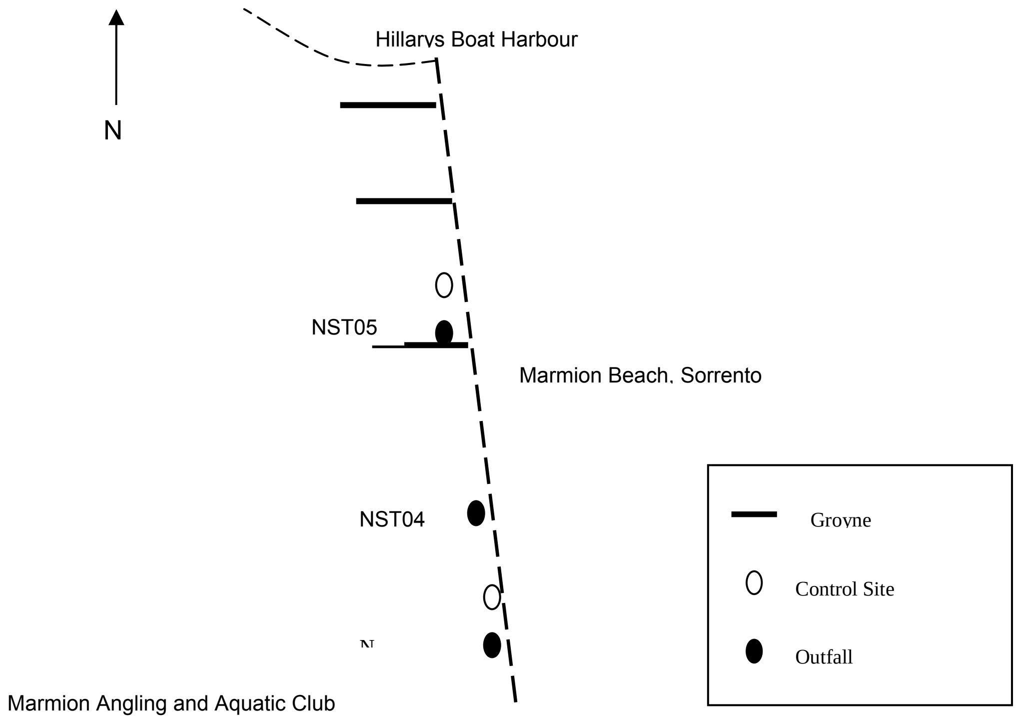


Figure B 1. Location of impact (stormwater outlets) NST03 and NST05 and their control sites.

2.4 Sampling program design

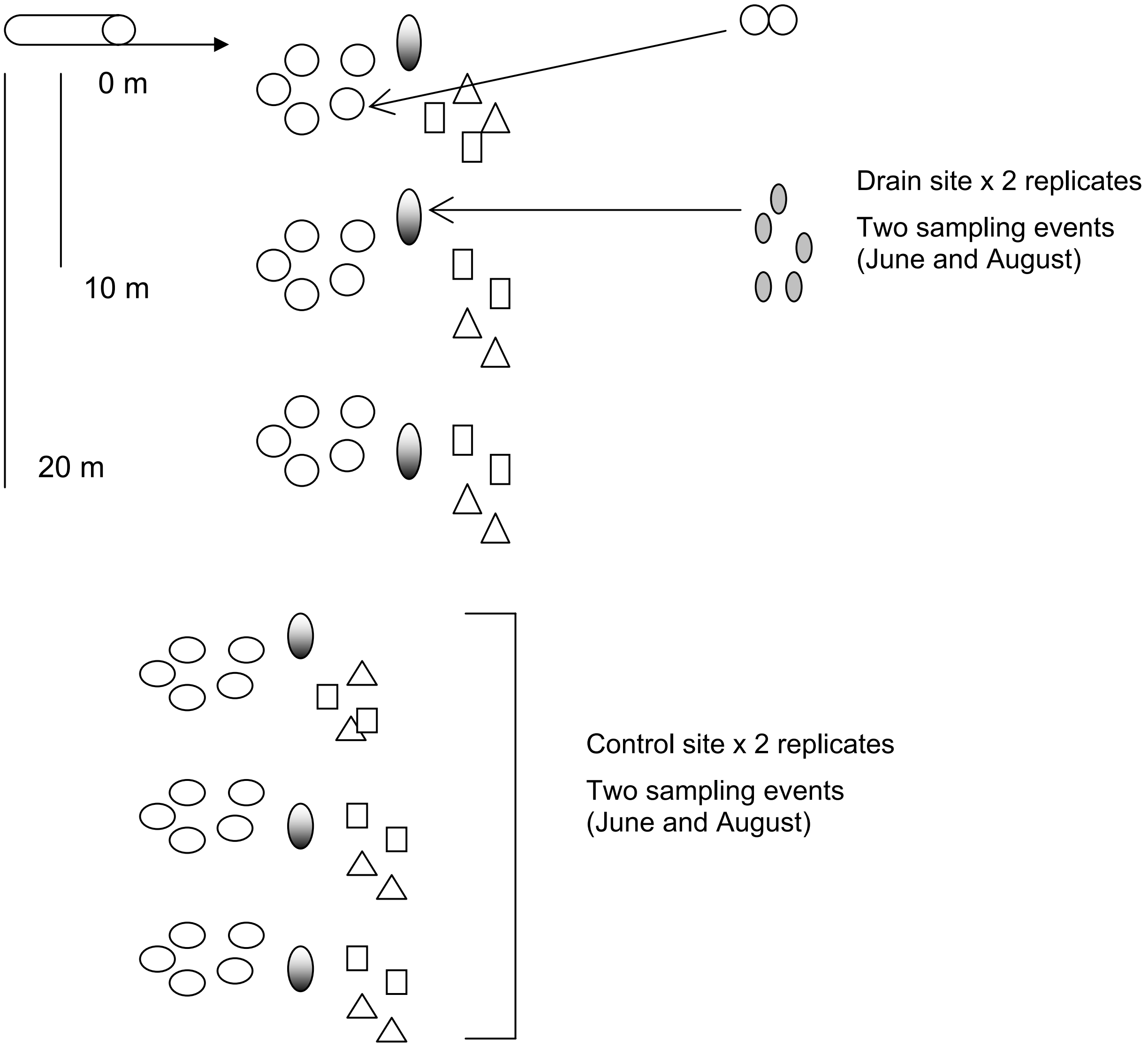
Across the two areas (NST03 and NST05), samples were collected at thee distances (0, 10 and 20 m) from each of the four sites made up of:

2 x stormwater drain outlets; and

2 x control sites.

The samples were collected in the swash zone at each site. The number of treatments was therefore three for each control and each drain site (Figure B 2). Sediment samples were collected twice (Time 1 and Time 2) through winter at each of the above sites (within one week of rainfall) (Figure B 3). For each treatment sediment samples were collected for chlorophyll *a*, nutrient, metals and particle size analysis.

Time 1 and Time 2: 2 drain and 2 control sites. At each site in the swash zone samples were collected at 0, 10 and 20 m apart, following a storm event.



Samples collected at each site

Sediment chlorophyll: 5 replicate samples (composite of 2 adjacent cores). At 3 spatial scales from outlet - 0, 10 and 20 m.

Sediment analysis:

Sediment Particle Size Analysis – 1 composite sample (5 cores);

THM – 2 samples;

TN/TP – 2 samples.

Total number samples for each sampling event:

Microphytobenthos: 60 samples

Sediment analysis:

a) particles size – 12 composite samples

b) THM – 24 samples

c) TN/TP – 24 samples.

Figure B 2. Experimental design: Sediment sample collection for chlorophyll *a*, nutrients, metals and particle size analysis.

2.4.1 Microphytobenthos (chlorophyll a and phaeophytin)

Sediments were sampled for chlorophyll *a* (including phaeophytin) following two significant storm events. Five replicate samples (each a composite of two adjacent cores) were collected for each treatment (0, 10 and 20 m from outlet or control) (Figure B 2). There were therefore 15 chlorophyll *a* samples per site. For details of analysis and limits of detection see Table A 3.

2.4.2 Nutrient, metal and particle size analysis

In addition, sediment samples were collected at each site during the Time 1 and Time 2 sampling. The cores were analysed for:

Phosphorus and Nitrogen (TN/TP). Two samples were collected per treatment, totalling 6 samples for analysis per site.

Total heavy metals (Al, As, Cr, Fe, Mn, Pb and Zn). Two samples were collected per treatment, totalling 6 samples for analysis per site.

Sediment particle size analysis using the Wentworth Scale:

- clay: 0 to 4μm
- silt: 4 to 62μm
- fine sand: 62 to 250μm
- medium sand: 250 to 500μm
- coarse sand: 500 to 2000μm
- gravel: 2000 to 10000μm.

Five sediment samples were collected for each treatment and combined. From this composite, a sub-sample was taken for analysis to determine particle size distributions, totalling three samples for analysis per site.

Details of the analysis for nutrients, metals and particle size are given in Table A 3.

2.5 Rainfall and sampling dates

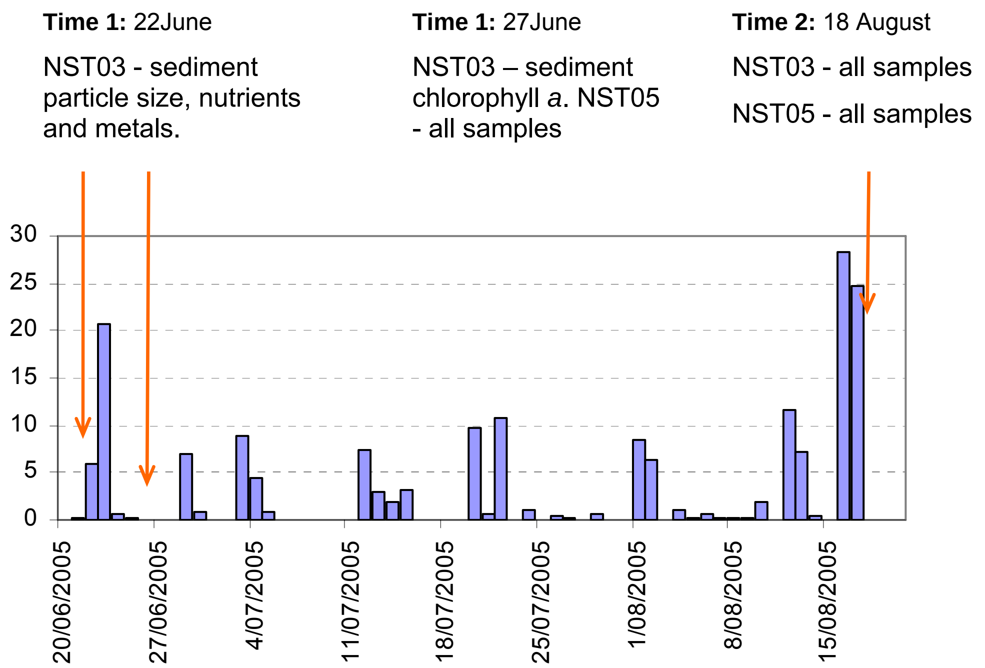


Figure B 3. Total daily rainfall (mm) at Swanbourne Station, dates of sampling, and types of samples collected.

Samples were collected at the NST03 and NSTG05 areas on three occasions. The first event was defined as the 22nd and 27th June (Time 1) and the second event as the 18th August (Time 2). Parameters collected on these dates are shown in Figure B 3.

2.6 Statistical analyses

The data for the four groups of variables (chlorophyll/phaeophytin, nutrients, metals and particle size) in relation to site and time was analysed using one way analysis of variance and presented graphically with vertical bars depicting standard deviations. Scheffé's test was applied to determine significant differences between sites and times.

As there were no consistent relationships with site or time, a correlation matrix between all variables (except for site and time) using Spearman's Rank Correlations was also created. The means were compared for each treatment (0, 10 and 20 m) at each of the four sites (2 outlets and 2 controls) at each sampling time (p > 0.05, n= 24). The correlations were created to see if there were in fact any relationships between the productivity of microphytobenthos and each of the potential drain contaminants present in the near-shore – nutrients, metals and suspended solids.

3 Results

3.1 Categorising sites in relation to stormwater threats and near-shore habitats

Following the initial appraisal (Part A — Water and sediment quality sampling program) to determine which drains were suitable for sampling, the remaining 65 drains (Appendix A) were further categorised in relation to the point of discharge and adjacent habitat type:

- Direct to beach – 39 stormwater drains discharge directly to the beach, at variable distances from the ocean. Stormwater enters marine waters via a channel cut down the beach.
- Direct to dunes – 20 stormwater drains discharge to the dunes/over rocks or onto grassed areas, at variable distances from the ocean. Stormwater may enter marine waters via groundwater as no channel evident to the beach. There is potential for some direct discharge when rainfall is extremely heavy and prolonged.
- Direct to ocean – Six stormwater drains discharge directly to the ocean (WAN08, STG11, CRMD, HMD, RMD and WMD).
- Adjacent habitat type – Immediate (<60 metres) and surrounding (>60 m).

The following summarises the dominant marine habitats located within 60 m of each drain. This distance includes the distance stormwater discharge must travel across the dunes and/or beach and also through the water column to the habitat:

1) Inter-tidal sand communities: dominant habitat adjacent to 37 drains. Seagrass, reef pavement and low relief reef may be present in the region, some distance from the outfall (80 and 200 m off shore).
2) seagrass: dominant habitat adjacent to 7 drains. Sites with near-shore seagrass meadows include: ROC 13, 16 and RMD, FRMD, SHL02, WAN05 and SB02;
3) reef pavement: dominant habitat adjacent to 10 drains, patchy distribution. At the time of the survey (April 2005), these platforms were not visible due to a layer of covering sand. Sites include: NST01, 04, 05, STG01, 03, 06, 07, 08, 09 and 10; and
4) low relief rocky reef: dominant habitat adjacent to 10 drains, patchy distribution. Sites include: WAN08, STG05, 08, 09 and 11, CMD and COT 05, 10, 11 and 12.

Habitat adjacent to direct discharge outlets include: inter-tidal sand habitat (CRMD); seagrass meadows within 50 m of discharge outlet (RMD); low relief rocky reef within 0-10 m of discharge outlet (WAN08 and STG11); low relief rocky reef over 120 m from the discharge outlet (HMD).

The purpose of the categorisation was to determine appropriate sites and potential marine habitats that may be under threat (eg seagrass meadows, inter-tidal sand communities, reef platforms and low relief rocky reef). The information from this process was summarised (Part A — Water and sediment quality sampling program, Figure A 1) and is discussed further in the following text.

Most drains (39 of 65) discharged directly to the beach, via channels cut to the waters edge and therefore could have a direct impact on localised inter-tidal sand communities. While other communities are present, they are at least 60 m further off shore (Part A — Water and sediment quality sampling program, Figure A 1).

When assessing the threat of stormwater to communities further off shore and therefore not directly exposed, other issues must be considered. For example:

stormwater dilution with seawater; and

existing and historical impacts such as the seagrass meadows adjacent to drains in Cockburn Sound (confounding water quality issues due to industry and urbanisation) or near-shore reef habitat adjacent to drains (wave action and seasonal sand scouring of macroalgal communities).

With these considerations, it was decided an assessment of near-shore sand communities would provide the best evidence of stormwater impacts, if any, through a preliminary study, with a focus on the productivity of microphytobenthos communities adjacent to outfalls.

3.2 Microphytobenthos (chlorophyll a and phaeophytin)

There were so significant differences in concentrations of chlorophyll *a* and phaeophytin between treatments within each of the four sites. Therefore, data for the 0, 10 and 20 m samples were pooled to obtain average chlorophyll *a* and phaeophytin concentrations for each site. At this level however, differences were observed – between control and drain sites and again at the next level between the NST03 and NST05 areas. The differences are discussed firstly within each sampling time and secondly they are compared across sampling times. The health of the microphytobenthos as defined by the ratio of chlorophyll *a* to phaeophytin was also compared.

3.2.1 Variation between sites within Time 1

Within the Time 1 sampling period, at NST03, chlorophyll *a* concentrations were significantly higher at the control than the drain site (p=0.02460, $F_{(1,28)}$) (Figure B 4). While at NST05 there were no significant differences.

Unlike the case of chlorophyll *a* at NST03, there were no significant differences in phaeophytin concentrations between the control and drain sites at either NST03 or NST05.

When the ratio of chlorophyll *a* to phaeophytin was examined at Time 1, there were significant differences between control and drain sites for NST03 but not NST05 (p=0.02978, $F_{(1,28)}$) (Figure B 5).

3.2.2 Variation between sites within Time 2

Similar to Time 1 observations, NST03 chlorophyll *a* concentrations were significantly higher at the control than the drain sites but in Time 2, this was also true for NST05 (p=0.00368, $F_{(1,28)}$ and p=0.00000 $F_{(1,28)}$), (Figure B 4).

In contrast to that observed in the Time 1 period, concentrations of phaeophytin were significantly higher at control than the drain sites in both areas – NST03 and NST05 (p=0.00021, $F_{(1,28)}$ and p=0.00000 $F_{(1,28)}$), (Figure B 4).

Unlike that observed for Time 1, when the ratio of chlorophyll *a* to phaeophytin was examined at Time 2, there were significant differences between control and drain sites for both NST05 (p=0.00000, $F_{(1,28)}$) and NST03 (p=0.01793, $F_{(1,28)}$). The difference in ratios was much greater at NST05. The ratio was 10:1 at NST05 drain compared to 6:1 at the control, while it was 5.8:1 at the NST03 drain compared to 4.7:1 at the control (Figure B 5).

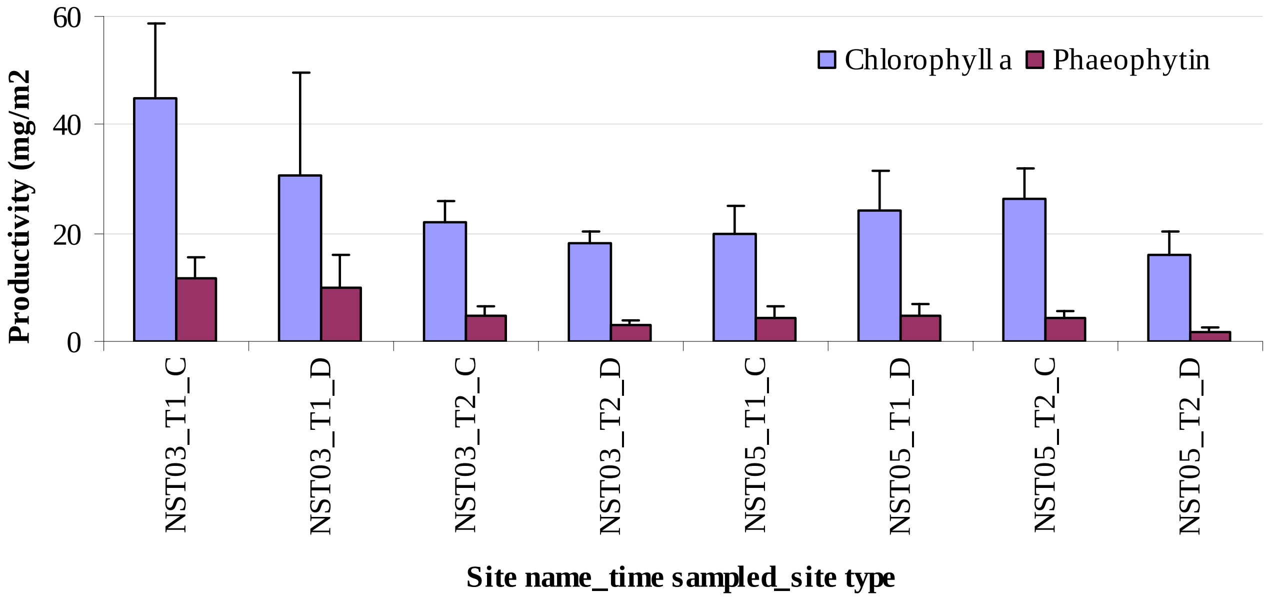


Figure B 4. Productivity (mg/m^2) (chlorophyll *a* and phaeophytin) at the four sites (NST03 and NST05, C = control, D = drain) and times (T1 = Time 1, T2 = Time 2). (mg/m^2). Error bars = standard deviation.

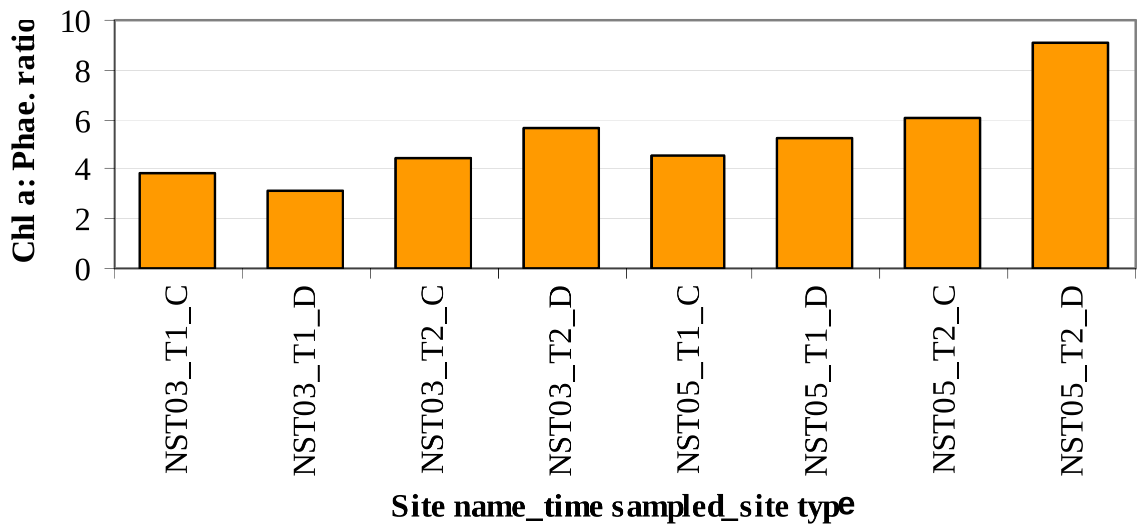


Figure B 5. Chlorophyll *a*:phaeophytin ratio in the sediment at the four sites (NST03 and NST05, C = control, D = drain) and times (T1 = Time 1, T2 = Time 2).

3.2.3 Variation between areas and times

The concentrations of chlorophyll *a* and phaeophytin were compared between the two areas, over the two sampling times (Figure B 4) and the health of the microphytobenthos as defined by the ratio of chlorophyll *a* to phaeophytin was also compared (Figure B 5).

The NST03 area had significantly higher concentrations of chlorophyll *a* than the NST05 area, at Time 1 (p=0.00003, $F_{(1,58)}$) (Figure B 4). When sampled the second time they were comparable across sites. A similar trend occurred with the phaeophytin, although a more significant difference was observed at Time 1 (p=0.00000, $F_{(1,58)}$) than Time 2 (p=0.01541, $F_{(1,58)}$) (Figure B 4).

At Time 1, the NST03 area had a significantly lower ratio of less than 4:1 (chlorophyll *a*: phaeophytin), than other areas where the ratio was between 5 to 8:1 at both Times 1 and 2 (p=0.00000, $F_{(3,116)}$) (Figure B 5).

Notably, at Time 2, the drain site at NST05 had a significantly higher ratio of around 10:1 than all other sites at either time (p=0.00000, $F_{(3,116)}$) (Figure B 5).

3.3 Nutrient and metal analysis

As with the chlorophyll *a* analysis, there were no significant differences in concentrations of nutrients and metals between treatments within each of the four sites. Therefore, data for the 0, 10 and 20 m samples were pooled to obtain average concentrations of nutrients and metals for each site. At this level however, differences were observed – between control and drain sites and again at the next level between the NST03 and NST05 areas. The differences are discussed, firstly within each sampling time, and secondly they are compared across sampling times.

3.3.1 Variation between sites within Time 1

At NST03 there were no significant differences between control and drain sites, but there were at NST05 (Figure B 6 a to c). The concentrations of TN, TP, Al, Cr, Pb and Mn were all significantly higher at the NST05 control than the drain site. This trend was different to that observed for chlorophyll a where the concentrations were greater at the control of NST03 rather than that of NST05 (Figure B 4).

It is noteworthy that in the case of Pb, higher concentrations appear to be associated with lower chlorophyll a productivity (Figure B 6 a and Figure B 4). Given the link between depressed growth and photosynthesis and increased metal concentrations (Jeffrey, 1981), this might explain why chlorophyll a (productivity) was higher at the NST03 control site. A similar argument could be made for higher chlorophyll concentrations (even though not significant) at the NST05 drain site compared to the control.

3.3.2 Variation between sites within Time 2

The converse occurred at Time 2 with respect to nutrient and metal concentrations with no significant differences at NST05 control and drain sites but differences at NST03. At the NST03 drain site there were significantly higher concentrations of Al, Cr, Fe and Mn than at the control, but no significant differences between sites for TN, TP, Pb and Zn (Figure B 6 a to c). This trend was accompanied by increased concentrations of chlorophyll a/phaeophytin at the NST03 control over the drain site.

At NST05 there were no significant differences between control and drain sites, except for TN which was higher at the control (Figure B 6 a to c).

Again, although not significant, higher concentrations of Pb appear to be associated with lower chlorophyll productivity in each area.

3.3.3 Variation between areas and times

The concentrations of nutrients and metals were compared between the two areas, over the two sampling times.

Generally concentrations of nutrients and metals were comparable between the two areas, with the exception of NST03 at Time 1 where concentrations of TN, TP, Al, Cr, Mn and Zn were higher than at Time 2 and also much higher than both times at NST05 (Figure B 6 a to c). This trend is similar to that observed for chlorophyll *a* where NST03 was significantly higher than NST05 at Time 1.

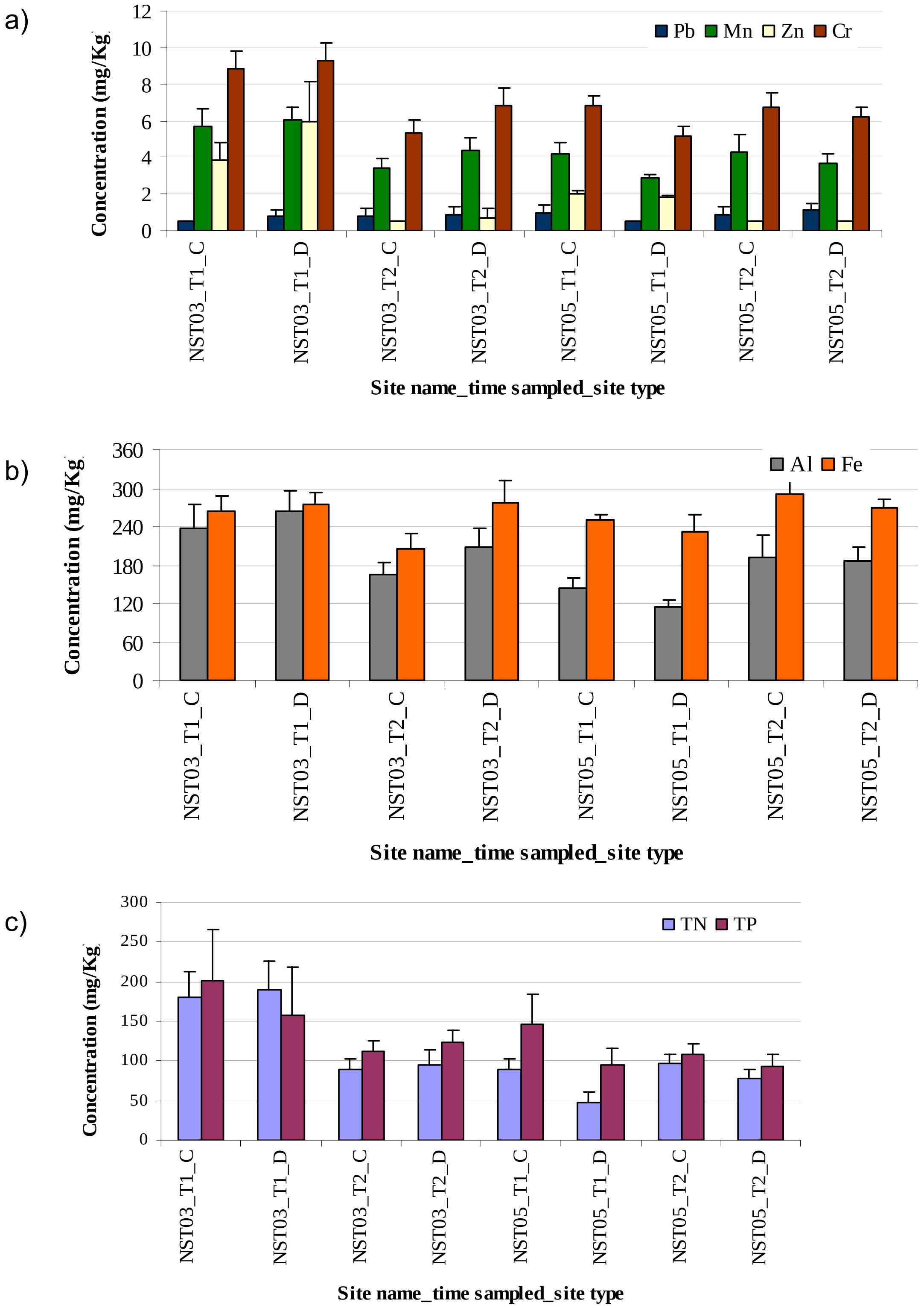


Figure B 6 (a to c). Concentrations (mg/kg) of metals and nutrients in the sediment at the four sites. (C = control, D = drain, T1 = Time 1 and T2 = Time 2). Error bars = standard deviation.

3.4 Variation in particle sizes between sites

The fine sand (62 to 250µm) appeared to be associated with higher concentrations of nutrients and metals (cf Figure B 6 a, b with Figure B 7). The greater proportion of fine sand was found at NST03 at Time 1 when higher concentrations of TN, TP and some of the metals (Al, Cr, Mn and Zn) also occurred.

The greater proportion of coarse sand (500 to 2000µm) occurred at NST03 and at NST05 at Time 2 after a higher rainfall (55 mm over the previous two days) than at Time 1 (25 mm over the previous two days) (Figure B 3 and Figure B 7).

There were no significant differences in the proportion of clay (0 to 4µm), silt (4 to 62µm), medium sand (250 to 500µm) or gravel (2 to 10 mm) across the sites or times.

The final two categories of the sediment particle size analysis (clay and silt) have been excluded from the Figure because the sediments sampled and analysed contained very small quantities – generally less than one per cent contribution to the total sample.

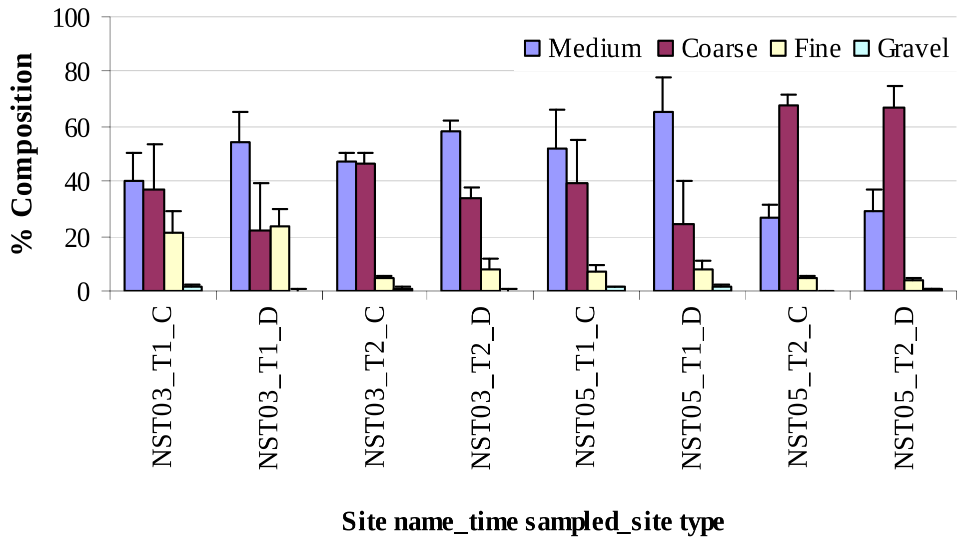


Figure B 7. Percent composition of sediment particle sizes at the four sites (C = control, D = drain, T1 = Time 1 and T2 = Time 2). Error bars = standard deviation.

3.5 Relationship between microphytobenthos, nutrients, metals and particle size

In the previous section, there were no consistent trends in productivity of microphytobenthos or potential contaminants from drains in relation to the location of drain outlets. To determine whether or not there was any relationship between microphytobenthos and any of the potential contaminants, a correlation analysis was performed (Table B 1).

Table B 1. Spearman's Rank Correlations between chlorophyll (Chla), phaeophytin (Phae); nutrients (TN, TP); metals (Al, Cr, Fe, Pb, Mn, Zn) and sediment particle size (Fine, Medium, Coarse). Significant correlations are highlighted in red (*p*>0.05; n= 24).

	Chla	Phae	TN	TP	Al	Cr	Fe	Pb	Mn	Zn	Fine	Medium	Coarse
Chla	1.000000	0.904762	0.642857	0.571429	0.452381	0.404762	0.047619	-0.754505	0.476190	0.561143	0.238095	0.261905	-0.142857
Phae	0.904762	1.000000	0.500000	0.619048	0.357143	0.309524	-0.285714	-0.850315	0.333333	0.561143	0.190476	0.404762	-0.238095
TN	0.642857	0.500000	1.000000	0.785714	0.880952	0.904762	0.571429	-0.119763	0.952381	0.536745	0.023810	0.285714	0.023810
TP	0.571429	0.619048	0.785714	1.000000	0.595238	0.833333	0.047619	-0.287430	0.761905	0.780720	0.309524	0.476190	-0.285714
Al	0.452381	0.357143	0.880952	0.595238	1.000000	0.857143	0.642857	-0.047905	0.928571	0.390360	-0.214286	0.380952	0.047619
Cr	0.404762	0.309524	0.904762	0.833333	0.857143	1.000000	0.523810	0.071858	0.976190	0.683130	0.142857	0.428571	-0.166667
Fe	0.047619	-0.285714	0.571429	0.047619	0.642857	0.523810	1.000000	0.407193	0.642857	-0.048795	-0.166667	-0.047619	0.238095
Pb	-0.754505	-0.850315	-0.119763	-0.287430	-0.047905	0.071858	0.407193	1.000000	0.023953	-0.343616	-0.287430	-0.419169	0.359288
Mn	0.476190	0.333333	0.952381	0.761905	0.928571	0.976190	0.642857	0.023953	1.000000	0.585540	0.047619	0.380952	-0.071429
Zn	0.561143	0.561143	0.536745	0.780720	0.390360	0.683130	-0.048795	-0.343616	0.585540	1.000000	0.683130	0.658733	-0.683130
Fine	0.238095	0.190476	0.023810	0.309524	-0.214286	0.142857	-0.166667	-0.287430	0.047619	0.683130	1.000000	0.547619	-0.857143
Medium	0.261905	0.404762	0.285714	0.476190	0.380952	0.428571	-0.047619	-0.419169	0.380952	0.658733	0.547619	1.000000	-0.857143
Coarse	-0.142857	-0.238095	0.023810	-0.285714	0.047619	-0.166667	0.238095	0.359288	-0.071429	-0.683130	-0.857143	-0.857143	1.000000

The most striking correlation was found between lead and chlorophyll *a* (-0.75) and phaeophytin (-0.85). In fact, chlorophyll *a* and phaeophytin were not significantly correlated with any other potential drain contaminant (nutrients, metals or sediment particle size).

As expected, a high positive correlation was also found between chlorophyll a and phaeophytin (0.90) – since one is the break down product of the other. In other words, where actively growing microphytobenthos are observed, dead or dying cells are also found.

Other significant correlations were found between TN and TP (0.79), Al (0.88), Cr (0.90) and Mn (0.95). Total phosphorous (TP), like TN, was also correlated with Cr (0.83) and Mn (0.76) but unlike TN, was also correlated with Zn (0.78). Aluminium was correlated with Cr (0.86) and Mn (0.93).

There were no correlations between sediment particle size and nutrients or metals. However, coarse sediments were negatively correlated with medium (-0.86) and fine sediments (-0.86).

The high negative correlation between lead and chlorophyll *a* is shown graphically (Figure B 8). The figure shows that when lead is below detection limits(<1 mg/kg), the microphytobenthos can reach productivity levels of up to ~60 mg/m^2 (Figure B 8). However when lead is detectable (>1 mg/kg), the productivity is limited to ~20 mg/m^2. This suggests that the lead is having an inhibitory effect on the biomass of microphytobenthos.

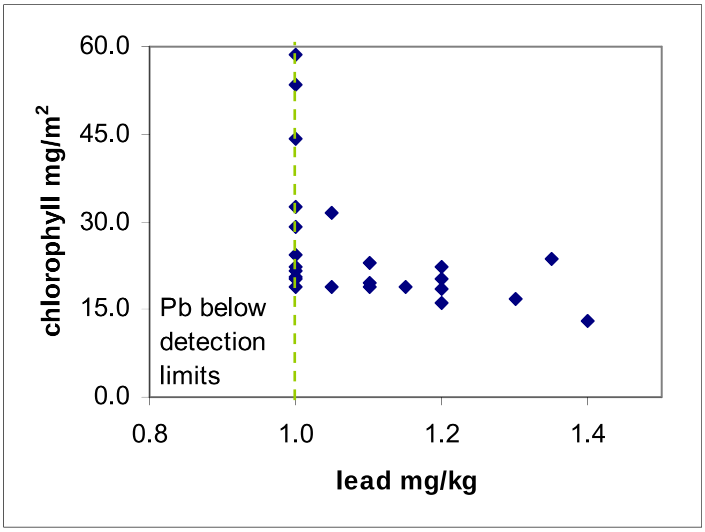


Figure B 8. Productivity of microphytobenthos (chlorophyll a mg/m^2) in relation to sediment lead (Pb) concentrations (mg/kg). Green dotted line shows limit of detection for Pb analysis (<1 mg/kg).

4 Discussion

This study provides strong evidence that lead concentrations in sediment affect the productivity of microphytobenthos. However, we could not find a direct relationship between drain location and these two variables. Despite this, the source of lead in near-shore sediments is most likely to be from stormwater that flows over heavily used coastal roads and car parks. At the location of the study, it could also be from runoff associated with a service station located nearby. This hypothesis is supported by the fact that lead was found in concentrations above guideline levels in the drains that flow into this region. The high turnover of sediments in the swash zone of this area also suggests that the lead is most likely from a recent rather than historical source.

Regardless of the source of lead, it is important to investigate this contamination further. Microphytobenthos form the basis of the marine food chain and can therefore pass on toxicants to invertebrates and other organisms that rely on them as a food source.

Although, overall the pilot study did not show a consistent link between stormwater inputs and microphytobenthos productivity, on one occasion this did occur. An event-driven increase in stormwater contaminant concentrations did result in greater concentrations of chlorophyll *a/*phaeophytin within surface sediments, with this increase coinciding with significantly higher levels of TN, TP, Al, Cr, Fe, Mn and Zn and fine sediments. Specifically, concentrations were significantly higher at one of the drain sites (NST03) at Time 1 than Time 2 and also significantly higher than at the other drain site (NST05) at either time. Sediment type may have had an influence, with silty fine sediments providing a favourable binding surface not only for nutrients and metal compounds but also as a substrate for microphytobenthos to thrive over coarser sediments.

This spike in contaminant concentrations is comparable to the significant increases in concentrations experienced at a number of sites during the Part A sampling program, where a peak in concentrations was evident between 12 and 16 August at some of the Cottesloe sites (Variation in contaminant concentrations over time, Part A — Water and sediment quality sampling program). These sporadic events may be as important as a first flush event and a greater understanding of these spike events and their effect on sediment contaminants is needed to manage stormwater effectively.

The increases in contaminant concentrations on this sampling day at NST03 were reflected in the microphytobenthos where chlorophyll a/phaeophytin concentrations were also significantly higher when sampled 5 days later. This suggests a possible link between stormwater contaminant concentrations and productivity of microphytobenthos, particularly with regards to nutrients such as nitrogen. However, the productivity of microphytobenthos can also be stimulated by particular metals at low concentrations (Jeffrey, 1981). It is possible that such an effect was not detected at either NST05 or at NST03 at the second sampling because contaminant concentrations were too low. Alternatively, other variables such as the location of groynes, wind-driven currents and/or longshore drift may have overshadowed the impact of this stormwater by dispersing the contaminants and masking the effect. Thus, contaminants in drains may affect the growth of microphytobenthos but the effect depends on flow of contaminants, exposure and concentration.

Another confounding influence may have been the build up of wrack (mainly decaying *Ecklonia* sp.) at the NST05 control site on the second sampling event. This observation was unexpected given one would assume the wrack to collect in the pit of the groyne immediately adjacent to the NST05 outfall (Figure B 1). However, consistent with the results, the analysis confirms that this control site also had a lower chlorophyll *a*/phaeophytin ratio (ie health) than the drain site where there was no wrack build-up. This is to be expected as a low ratio indicates a sample dominated by dead or decaying material (in this case decaying *Ecklonia*), while a high ratio would indicate a healthy growing microphytobenthos community.

Changes in the sediment particle size over time may influence the concentration of chlorophyll and the other measured parameters, especially with respect to the ratio of fine to coarse sand. The sediment analysis showed that at NST03 there was a 60 per cent reduction in the percent composition of fine sand between the first and second sampling events and a concomitant decrease in concentrations of chlorophyll *a*/phaeophytin, nutrients and some metals at this time. The other notable change in the sediment composition between the two sampling events was at NST05 where there was a 50 per cent reduction in fine sand and a corresponding increase in coarse sand. However, this does not equate to a similar trend in productivity, nutrient or metal concentrations.

This pilot study was not able to identify a definitive link between microphytobenthos productivity and stormwater inputs. In retrospect, this may have been because the project design was too ambitious in trying to detect change at small spatial scales (0, 10 and 20 m site distances from outfalls) and also at medium scales (between control and impact sites 100 m apart), when other confounding variables are evident at these coastal sites. For example, groynes, longshore drift and wind-driven currents affect water circulation and mixing and therefore the extent of stormwater mixing and the resulting impact of any contaminants. In addition, some of the sites did not fall into clear categories eg the control site for NST03 was close to (~80 m south of) another stormwater outlet (NST04).

Another aspect of the experimental design that could be improved would be to measure the dissolved nutrients and metals in pore water rather than just the totals in sediment. This is because microphytobenthos derive their nutrition from dissolved nutrients in pore water and similarly, dissolved metals are more readily available and assimilated than the other forms of these compounds.

Recommendations

Since stormwater is currently diverted to groundwater by some local governments on the coast and because others are considering implementing the same practice, we recommend that funding be provided to research the degree of connection between stormwater, groundwater and near-shore coastal zones. Research should also focus on what happens to the contaminants as they make their way through these different water bodies. With this knowledge available, it will be easier to predict the effects of stormwater contaminants on near shore coastal environments.

Appendices (A-Z)

Appendix A (Part 1 and Part 2). Description, location and photographs of sampled stormwater drains discharging to the Perth metropolitan coastline.

Site ID	Description of drains	Pipe diameter (mm)	Easting	Northing
WAN03	Roberts Rd Back of car park.	NA	0375915	6495258
WAN04	20 m south of Roberts Rd car park area.	N/A	0375921	6495133
WAN05	Beach outfall by car park at end of Ocean drive	~375	0376314	6494449
WAN06	Beach outfall	225	0376384	6494398
WAN08	Ocean outfall in limestone outcrop	900	0376714	6493675
WAN13	Rock wall ocean outlet	~1000	0376987	6492630
JND01a	Rocky outcrop at northern end of Burns Beach car park	N/A	0378571	6488790
JND01b	South end Burns Beach car park. Outlet opposite café.	NA	0378661	6488670
NST05 (JND02)	Beach outfall	450	0381473	6477385
NST04 (JND03)	Beach outfall	300	0381581	6477197
NST03 (JND04)	Beach outfall	450	0381632	6477006
NST01 (JND05)	Beach outfall, Marmion Angling & Aquatic Club car park	375	0381717	6476712
STG01	Beach outfall southern end of Watermans Beach	580	0381906	6475715
STG03	Beach outfall, 200 m south of Fisheries labs.	300	0381900	6475069
STG05	Beach outfall, end of North Beach Road	500	0381970	6474281
STG06	South of end of Hamersley Street, high up on bank	300	0381963	6473973
CMD	Carine Main Drain. Flows out onto limestone outcrop	750	0381921	6474054
STG07	Beach outfall, S of Saunders St	375	0381958	6473777
STG08	Beach outfall, S of Giles St	600	0381987	6473563
STG09ab	Twin outlets on limestone outcrop	300+300	0381968	6473392
STG10	Vertical bubble-up grate just N of Trigg SLSC, flows to beach	225	0381983	6472468
STG11	Hidden in limestone rocks	450	0381917	6472733
SCB01	Top of beach, northern end of Esplanade car park	450	0382229	6471113
SCB02	Top of beach under wire fence with channel cut to beach	525	0382260	6470826

Site ID	Description of drains	Pipe diameter (mm)	Easting	Northing
SCB03	Retrofitted steel beach outlet: “Stirling C.C. Site SCBC1”	450	0382261	6470628
CRMD	Colin Road Main Drain. South of SLSC. Recently changed to a large bubble up outlet (2004)	600	0382307	6470328
HMD	Herdsman Main Drain. Discharges into ocean	1000	0382294	6467330
COT02	Beach outfall, northern end of North Cottesloe SLSC	750	0382131	6460141
COT03	Small black pipe, half buried	N/A	0382131	6460131
COT04	Outfall at top of beach, large channel to beach	400	0382039	6459594
COT05	Drain at bottom of bank, top of beach	230	0382096	6458997
COT06	Outfall at top of beach	300	0382093	6458786
COT07	Outfall at top of beach	300	0382074	6458642
COT08	Outfall at top of beach	300	0382076	6458612
COT10	Beach St groyne outfall, at top of beach, behind large bush.	300	0382071	6458091
ROC01	South of Grain Silo. Governor Rd	700	0382075	6430223
ROC02	North of Grain Silo. Walk along beach.	700	0382258	6430422
ROC03	Beach outfall, end of beach access, bottom of Victoria St	550	0381232	6429121
ROC04	Eroded channel to beach. Previously buried.	425	0380731	6428683
ROC05A	Beach outfall, Northern side of new lookout / monument	525	0380495	6428504
ROC06	Outfall at top of beach	750	0380337	6428411
ROC07	Large channel and basin and no drain. Backfilled by Council	240	0380260	6428357
ROC08	Small beach outlet, on corner by the jetty	285	0380108	6428276
ROC10	Grassy swale near road verge	225	0379951	6428149
ROC11	Drain just North of beach access near the road	375	0379653	6428132
ROC12	Drain buried in debris and bushes, end of Fisher St	300	0379490	6428162
ROC13ab	Two plastic outfalls, buried mid beach	250+250	0379203	6428251
ROC14	Beach outlet near boat ramp	375	0379064	6428302
ROC16	Outlet high up near the road draining onto rocks	225	0378624	6428322

Site ID	Description of drains	Pipe diameter (mm)	Easting	Northing
RMD	Rockingham Main Drain. Open drain with outlet at Mangles Bay Angling & Aquatic Club	N/A	0377800	6428395
SHL01	Outlet at top of beach	750	0377858	6426790
SHL02	Drain high in bank	225	0377814	6426605
SHL03	Outlet drains into dunes	550	0377873	6426219
SHL04	Large eroded basin and channel but outlet buried	N/A	0377912	6425556
SHL07	Into dunes, but flow may reach beach	450	0378543	6425009
FRMD	Forrester Road Main Drain. Mixing chamber with bubble up grate & 225 mm outlet to beach	325	0379242	6424959
SB01	Beach Outfall ~150M north of Bent St	225	0379387	6424865
SB02	Outfall some where in a rock wall couldn’t be located	N/A	0379465	6424800
SB03	Beach outfall at end of June Rd	500	0380018	6424688
SB04	Beach outfall south of car park	700	0380228	6424632
SB05	Beach outfall south of Malibu Rd	300	0380686	6424328
SB06	Beach outfall at end of Malibu Rd	500	0380580	6424445
SB07	Beach outfall at end of Ernest St	500	0380397	6424555
WK01	View Rd car park, off Warnbro Road	NA	0381088	6423872
WKMD	End of View Rd.	225	0379242	6424959
WK02	Opposite No 80 Warnbro Beach Rd.	NA	0381214	6423673

Appendix A (Part 2) Photographs of stormwater drains discharging to the Perth metropolitan coastline.

City of Wanneroo stormwater drains


WAN03


WAN04

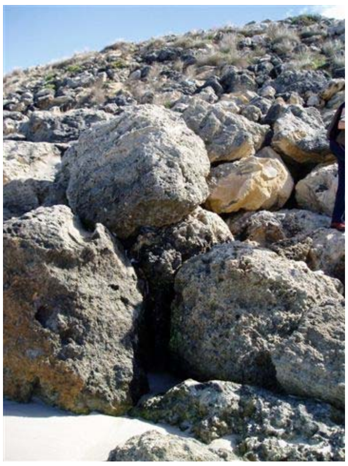

WAN05


WAN06


WAN07


WAN08(1)

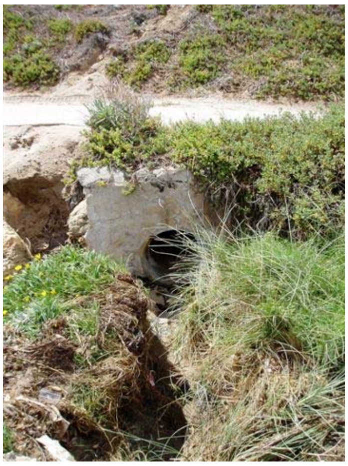

WAN08(2)


WAN13

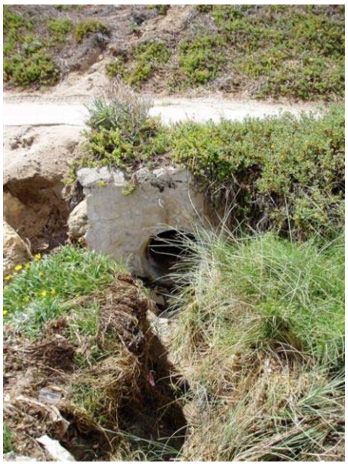
City of Joondalup stormwater drains

JND01_a

JND01_b



NST01



NST01

NST02

NST03(1)

NST03(2)

NST04

NST05

City of Stirling stormwater drains


STG01


STG02


STG03


STG04


STG05


STG06


STG07


STG08


STG09

City of Stirling stormwater drains continued

STG10

STG11

SCB02

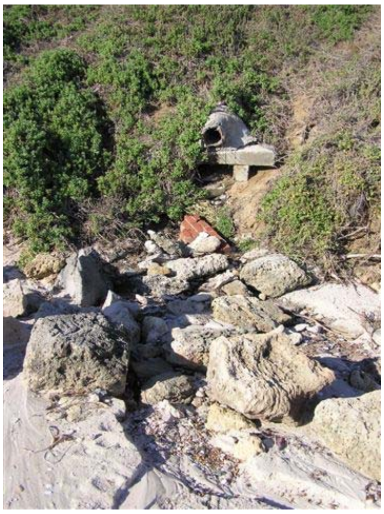
SCB03

CMD – Carine Main Drain

Town of Cottesloe stormwater drains

COT02

COT04



COT05

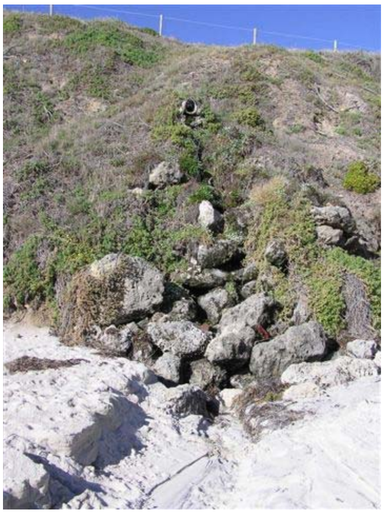
COT06

COT07

COT08

COT09

COT10



COT11

Town of Cottesloe stormwater drains continued

COT12

COT13

Town of Cambridge stormwater drain (Herdsman Main Drain)

HMD - Herdsman Main Drain

City of Rockingham stormwater drains

ROC02(1)

ROC02(2)

ROC03

ROC04

ROC05

ROC07

ROC08

ROC09

City of Rockingham stormwater drains continued

ROC10

ROC11

ROC12

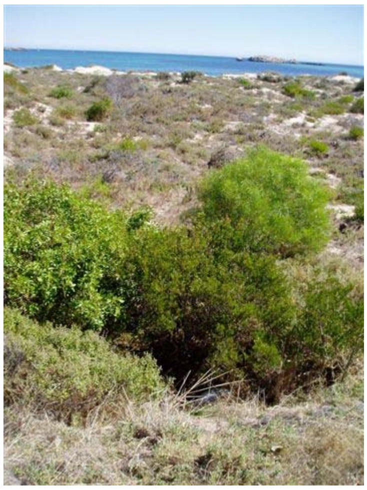
ROC13

ROC14

ROC16

SHL01

SHL02



SHL03

City of Rockingham stormwater drains continued

SHL04(1)

SHL04(2)

SHL07

FRMD - Forrester Road Main Drain

SB01

SB02

SB03

SB04

SB05

City of Rockingham stormwater drains continued

SB06

SB07

RMD - Rockingham Main Drain

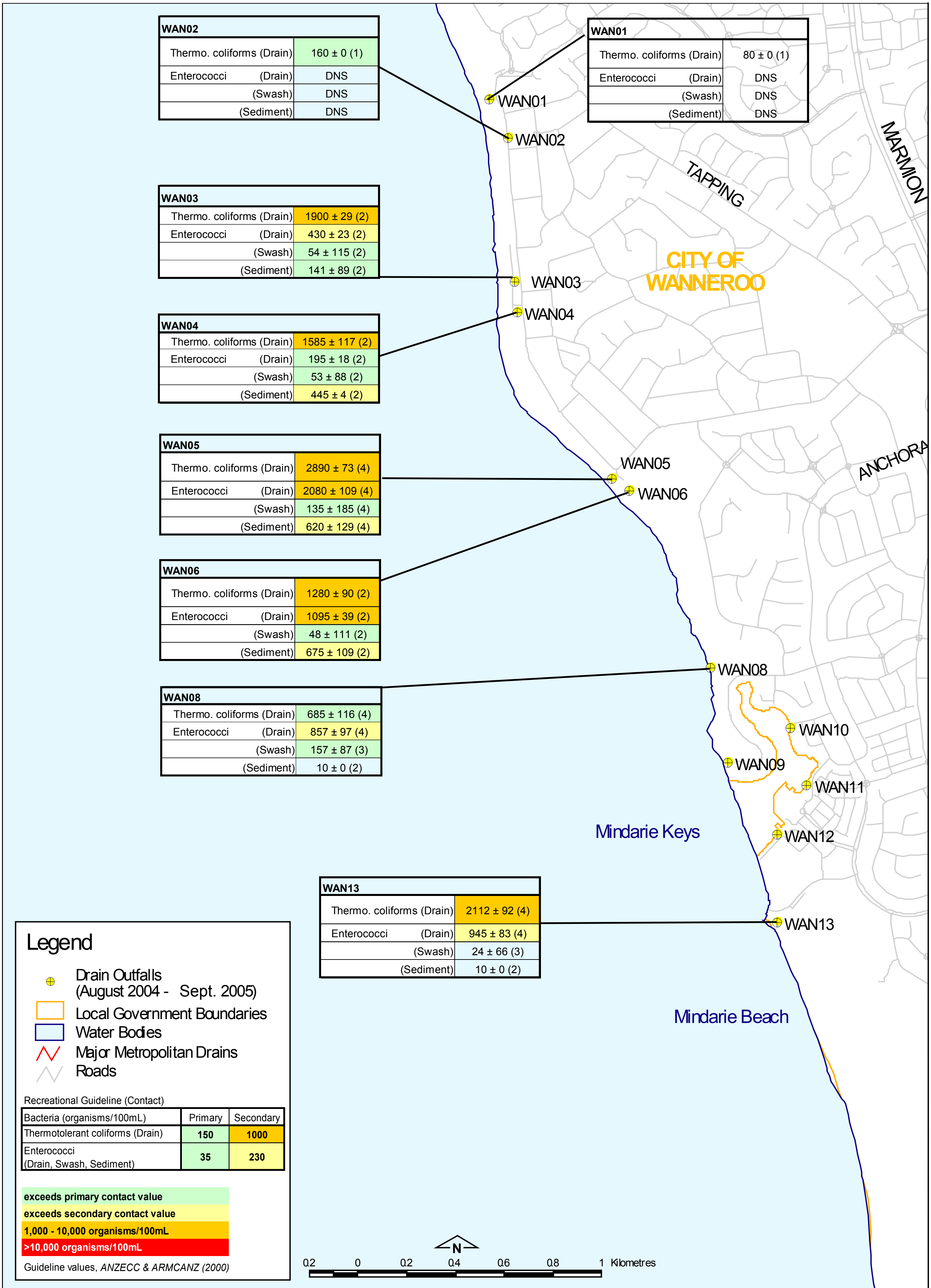
WMD - Waikiki Main Drain

WK01

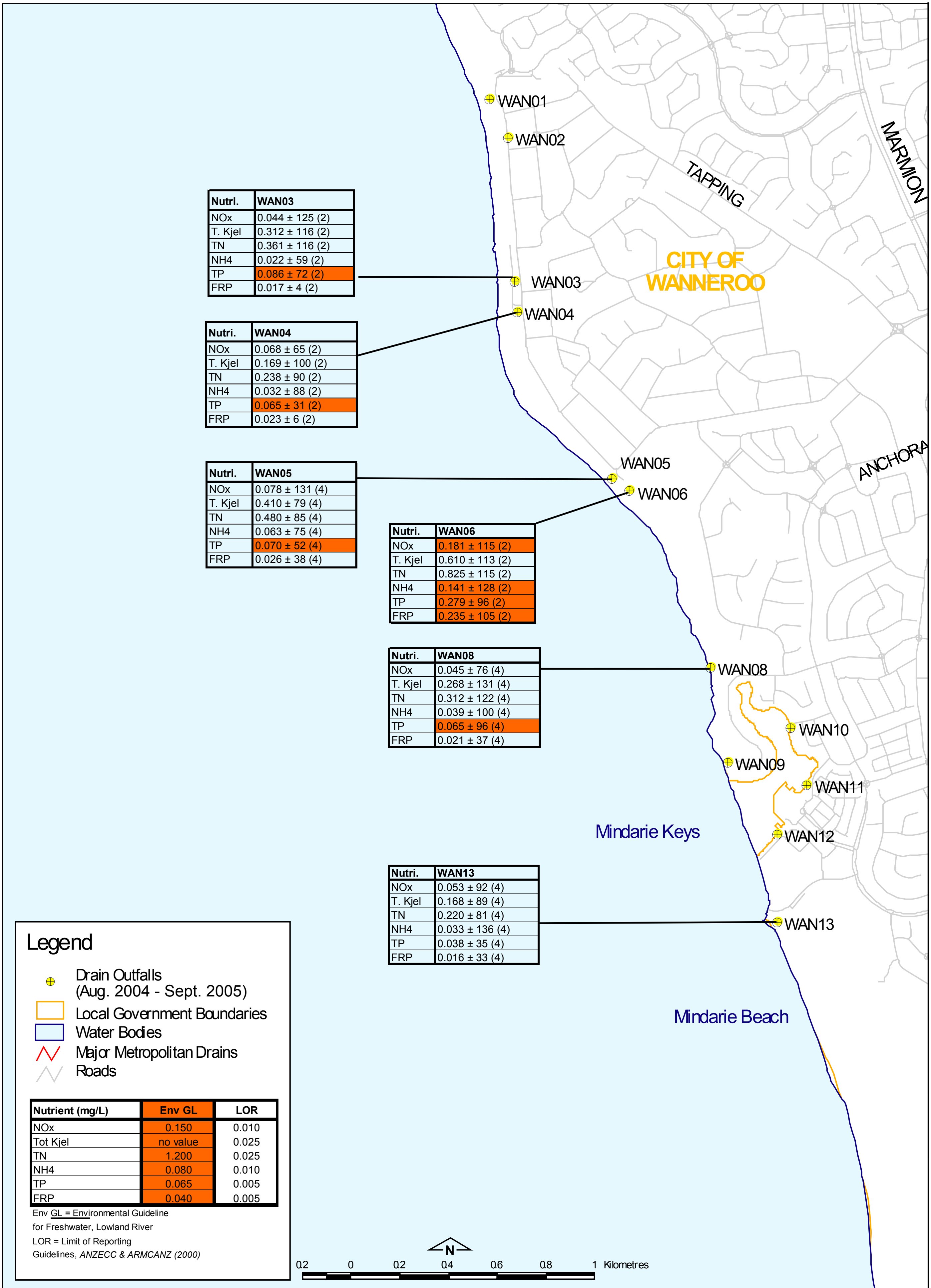
WK02

Appendix B. Stormwater drains and justification for excluding from sampling. Description of outfall and location, available on request.

Site Name	Reason not sampled
WAN01	Lge distance from beach/in dunes
WAN02	not located
WAN07	Lge distance from beach/in dunes
WAN09	Bubble up grate hidden, no way to sample. In marina.
WAN10 – WAN12	In marina. Not natural environment.
NST02	overgrown
STG02	bubble up grill, no access to sample.
STG04	no access to sample
STG12	Lge distance from beach/in dunes
STG13	Lge distance from beach/in dunes
STG14	Lge distance from beach/in dunes
STG15	Lge distance from beach/in dunes
STG16	Lge distance from beach/in dunes
STG17	Lge distance from beach/in dunes
SCB04	grass
COT01	Not located
COT09	No pipe
COT11	Council removed, replaced with sumps/soaks
COT12	Council removed, replaced with sumps/soaks
COT13	Council removed, replaced with sumps/soaks
ROC01 (old)	Not located
ROC02 (old)	Not located
ROC09	Lge distance from beach/in dunes
ROC11	Lge distance from beach/in dunes
ROC15	Not located
SHL03	Lge distance from beach/in dunes
SHL05	Not located
SHL06	Not located
SHL08	Not located
SB08	Not located
Subiaco MD	Not accessible (underwater)
Essex/Howard St MD	Into harbour. Not natural environment.



Appendix C Average bacterial concentrations (organisms/100mL ± coefficient of variation (n)) for each drain, swash and sediment site in Wanneroo.



Nutri.	WAN03
NOx	0.044 ± 125 (2)
T. Kjel	0.312 ± 116 (2)
TN	0.361 ± 116 (2)
NH4	0.022 ± 59 (2)
TP	0.086 ± 72 (2)
FRP	0.017 ± 4 (2)

Nutri.	WAN04
NOx	0.068 ± 65 (2)
T. Kjel	0.169 ± 100 (2)
TN	0.238 ± 90 (2)
NH4	0.032 ± 88 (2)
TP	0.065 ± 31 (2)
FRP	0.023 ± 6 (2)

Nutri.	WAN05
NOx	0.078 ± 131 (4)
T. Kjel	0.410 ± 79 (4)
TN	0.480 ± 85 (4)
NH4	0.063 ± 75 (4)
TP	0.070 ± 52 (4)
FRP	0.026 ± 38 (4)

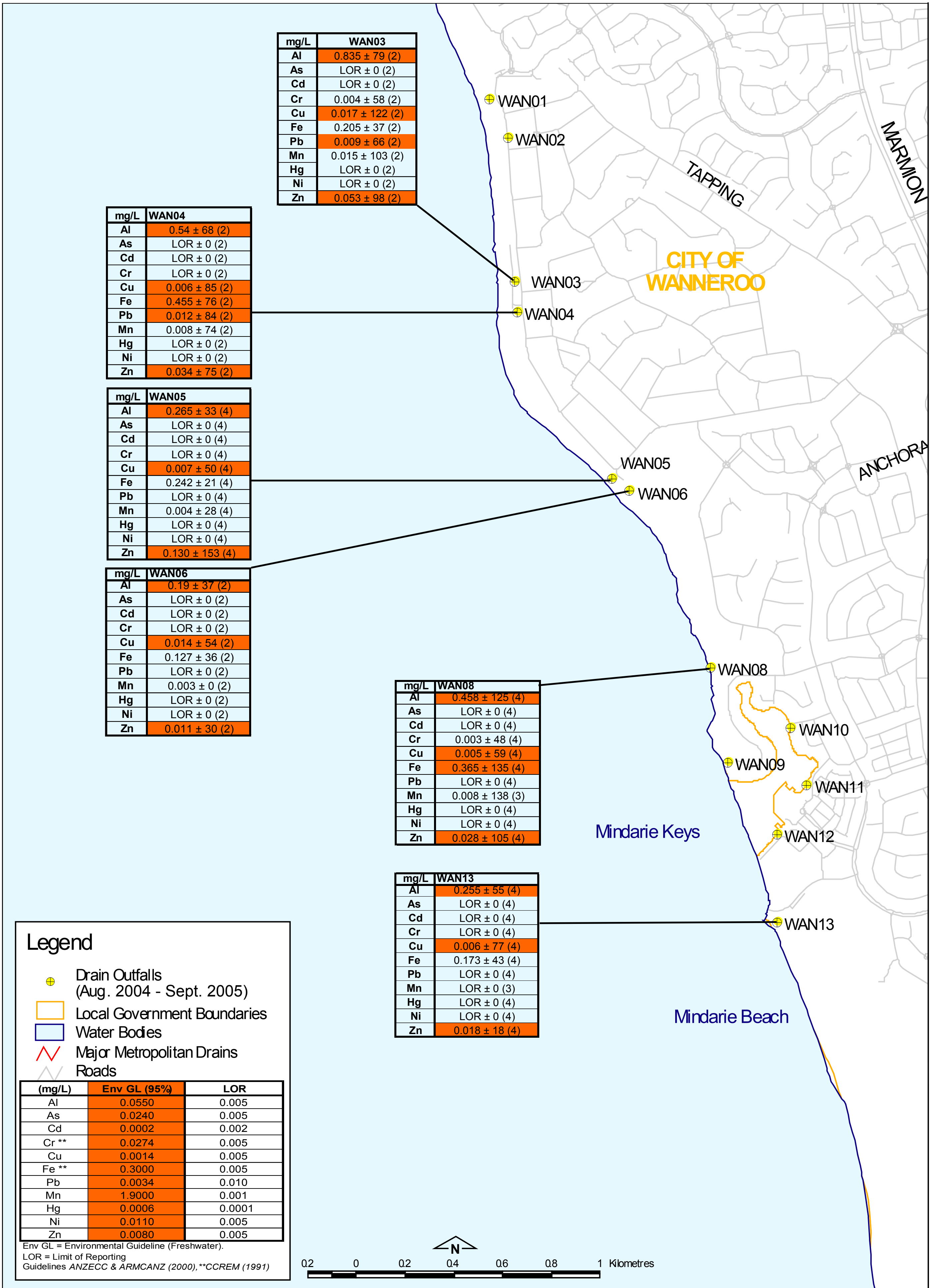
Nutri.	WAN06
NOx	0.181 ± 115 (2)
T. Kjel	0.610 ± 113 (2)
TN	0.825 ± 115 (2)
NH4	0.141 ± 128 (2)
TP	0.279 ± 96 (2)
FRP	0.235 ± 105 (2)

Nutri.	WAN08
NOx	0.045 ± 76 (4)
T. Kjel	0.268 ± 131 (4)
TN	0.312 ± 122 (4)
NH4	0.039 ± 100 (4)
TP	0.065 ± 96 (4)
FRP	0.021 ± 37 (4)

Nutri.	WAN13
NOx	0.053 ± 92 (4)
T. Kjel	0.168 ± 89 (4)
TN	0.220 ± 81 (4)
NH4	0.033 ± 136 (4)
TP	0.038 ± 35 (4)
FRP	0.016 ± 33 (4)

Nutrient (mg/L)	Env GL	LOR
NOx	0.150	0.010
Tot Kjel	no value	0.025
TN	1.200	0.025
NH4	0.080	0.010
TP	0.065	0.005
FRP	0.040	0.005

Appendix D Average nutrient concentrations (mg/L ± coefficient of variation (n)) for each Wanneroo drain site.



mg/L	WAN03
Al	0.835 ± 79 (2)
As	LOR ± 0 (2)
Cd	LOR ± 0 (2)
Cr	0.004 ± 58 (2)
Cu	0.017 ± 122 (2)
Fe	0.205 ± 37 (2)
Pb	0.009 ± 66 (2)
Mn	0.015 ± 103 (2)
Hg	LOR ± 0 (2)
Ni	LOR ± 0 (2)
Zn	0.053 ± 98 (2)

mg/L	WAN04
Al	0.54 ± 68 (2)
As	LOR ± 0 (2)
Cd	LOR ± 0 (2)
Cr	LOR ± 0 (2)
Cu	0.006 ± 85 (2)
Fe	0.455 ± 76 (2)
Pb	0.012 ± 84 (2)
Mn	0.008 ± 74 (2)
Hg	LOR ± 0 (2)
Ni	LOR ± 0 (2)
Zn	0.034 ± 75 (2)

mg/L	WAN05
Al	0.265 ± 33 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	LOR ± 0 (4)
Cu	0.007 ± 50 (4)
Fe	0.242 ± 21 (4)
Pb	LOR ± 0 (4)
Mn	0.004 ± 28 (4)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.130 ± 153 (4)

mg/L	WAN06
Al	0.19 ± 37 (2)
As	LOR ± 0 (2)
Cd	LOR ± 0 (2)
Cr	LOR ± 0 (2)
Cu	0.014 ± 54 (2)
Fe	0.127 ± 36 (2)
Pb	LOR ± 0 (2)
Mn	0.003 ± 0 (2)
Hg	LOR ± 0 (2)
Ni	LOR ± 0 (2)
Zn	0.011 ± 30 (2)

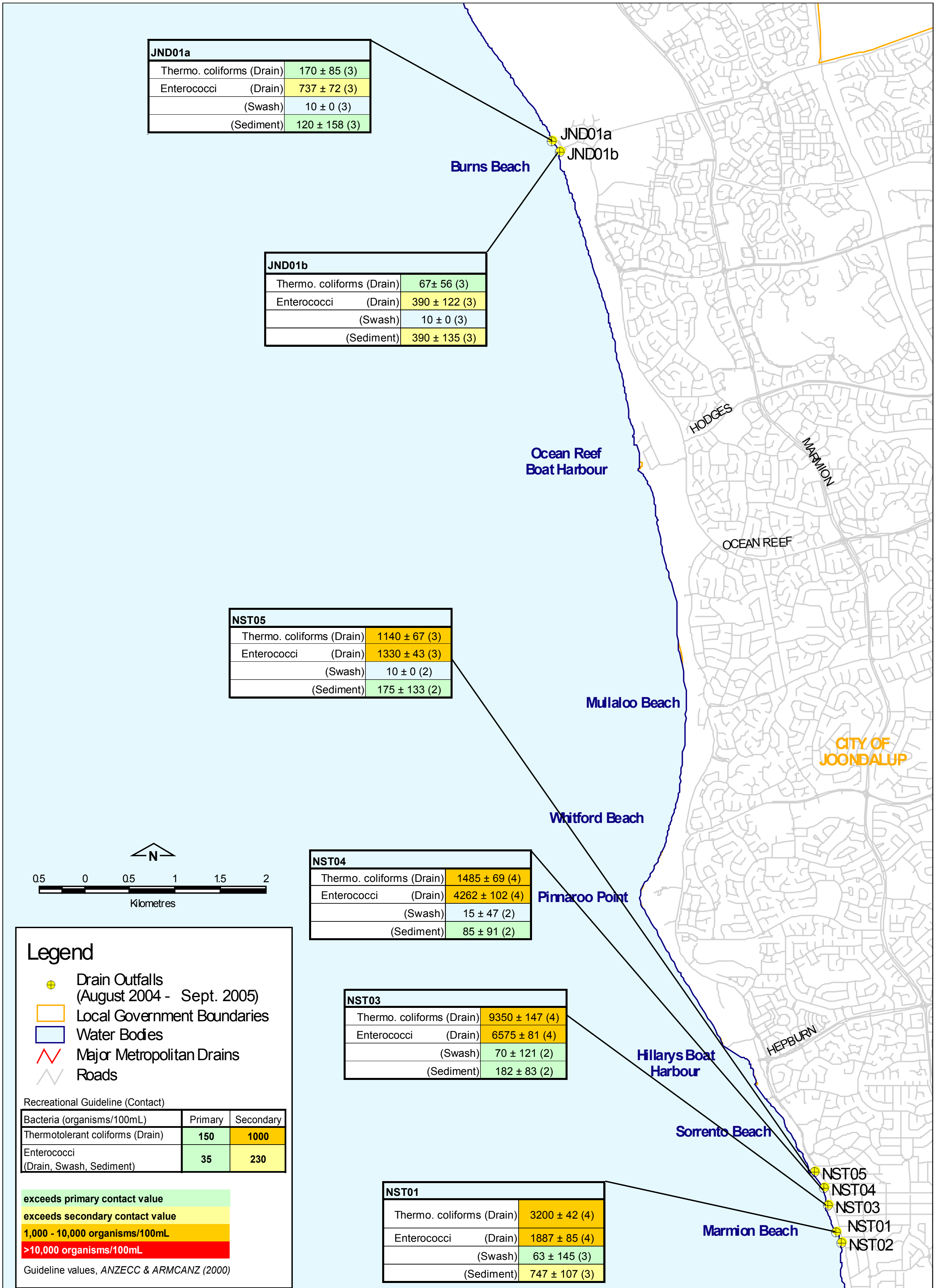
mg/L	WAN08
Al	0.458 ± 125 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	0.003 ± 48 (4)
Cu	0.005 ± 59 (4)
Fe	0.365 ± 135 (4)
Pb	LOR ± 0 (4)
Mn	0.008 ± 138 (3)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.028 ± 105 (4)

mg/L	WAN13
Al	0.255 ± 55 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	LOR ± 0 (4)
Cu	0.006 ± 77 (4)
Fe	0.173 ± 43 (4)
Pb	LOR ± 0 (4)
Mn	LOR ± 0 (3)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.018 ± 18 (4)

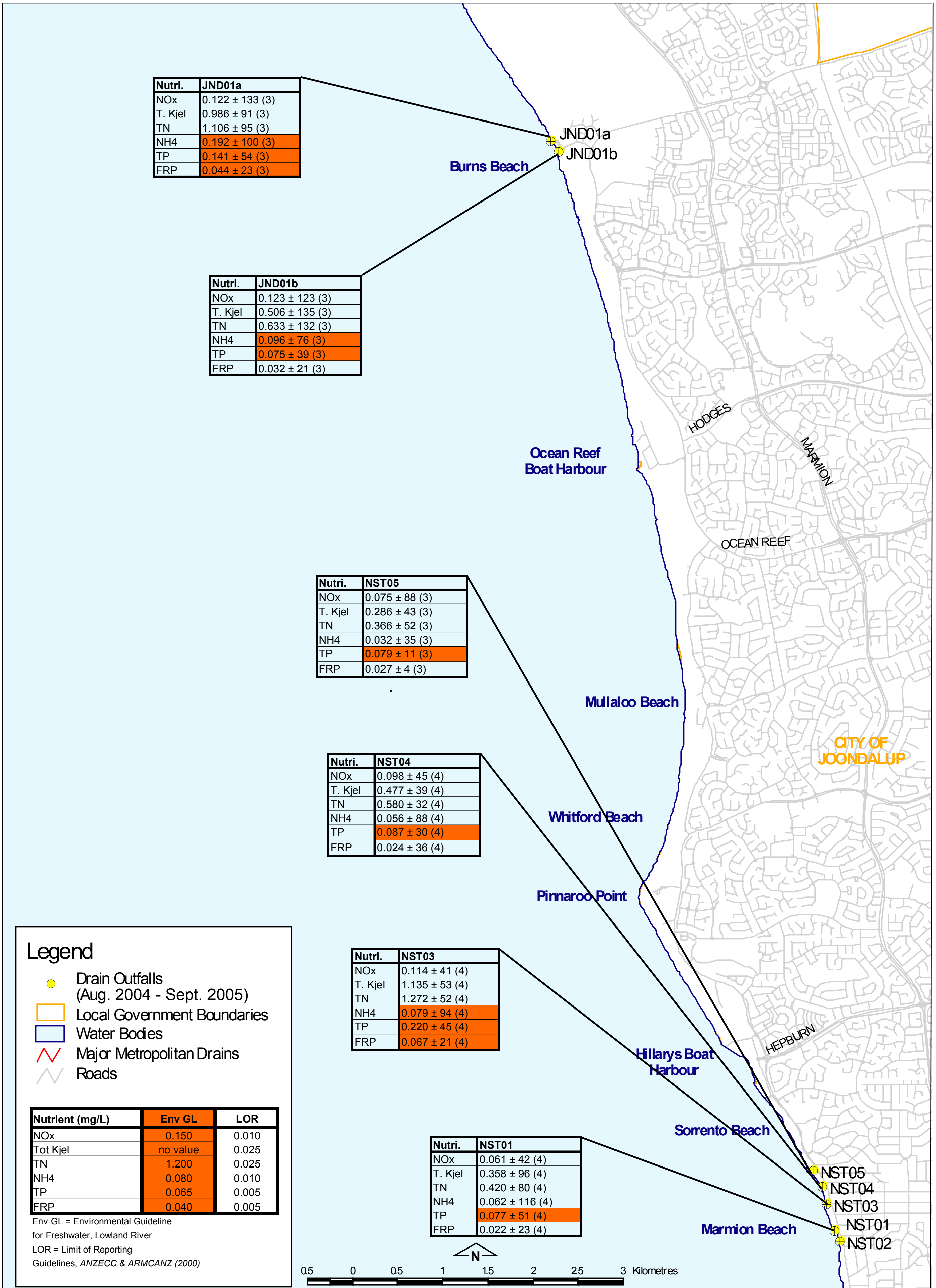
(mg/L)	Env GL (95%)	LOR
Al	0.0550	0.005
As	0.0240	0.005
Cd	0.0002	0.002
Cr **	0.0274	0.005
Cu	0.0014	0.005
Fe **	0.3000	0.005
Pb	0.0034	0.010
Mn	1.9000	0.001
Hg	0.0006	0.0001
Ni	0.0110	0.005
Zn	0.0080	0.005

Env GL = Environmental Guideline (Freshwater).
LOR = Limit of Reporting
Guidelines *ANZECC & ARMCANZ (2000)*, ***CCREM (1991)*

Appendix E Average total metal concentrations (mg/L ± coefficient of variation (n)) for each Wanneroo drain site.



Appendix F Average bacterial concentrations (organisms/100mL ± coefficient of variation (n)) for each drain, swash and sediment site in Joondalup.



Nutri.	JND01a
NOx	0.122 ± 133 (3)
T. Kjel	0.986 ± 91 (3)
TN	1.106 ± 95 (3)
NH4	0.192 ± 100 (3)
TP	0.141 ± 54 (3)
FRP	0.044 ± 23 (3)

Nutri.	JND01b
NOx	0.123 ± 123 (3)
T. Kjel	0.506 ± 135 (3)
TN	0.633 ± 132 (3)
NH4	0.096 ± 76 (3)
TP	0.075 ± 39 (3)
FRP	0.032 ± 21 (3)

Nutri.	NST05
NOx	0.075 ± 88 (3)
T. Kjel	0.286 ± 43 (3)
TN	0.366 ± 52 (3)
NH4	0.032 ± 35 (3)
TP	0.079 ± 11 (3)
FRP	0.027 ± 4 (3)

Nutri.	NST04
NOx	0.098 ± 45 (4)
T. Kjel	0.477 ± 39 (4)
TN	0.580 ± 32 (4)
NH4	0.056 ± 88 (4)
TP	0.087 ± 30 (4)
FRP	0.024 ± 36 (4)

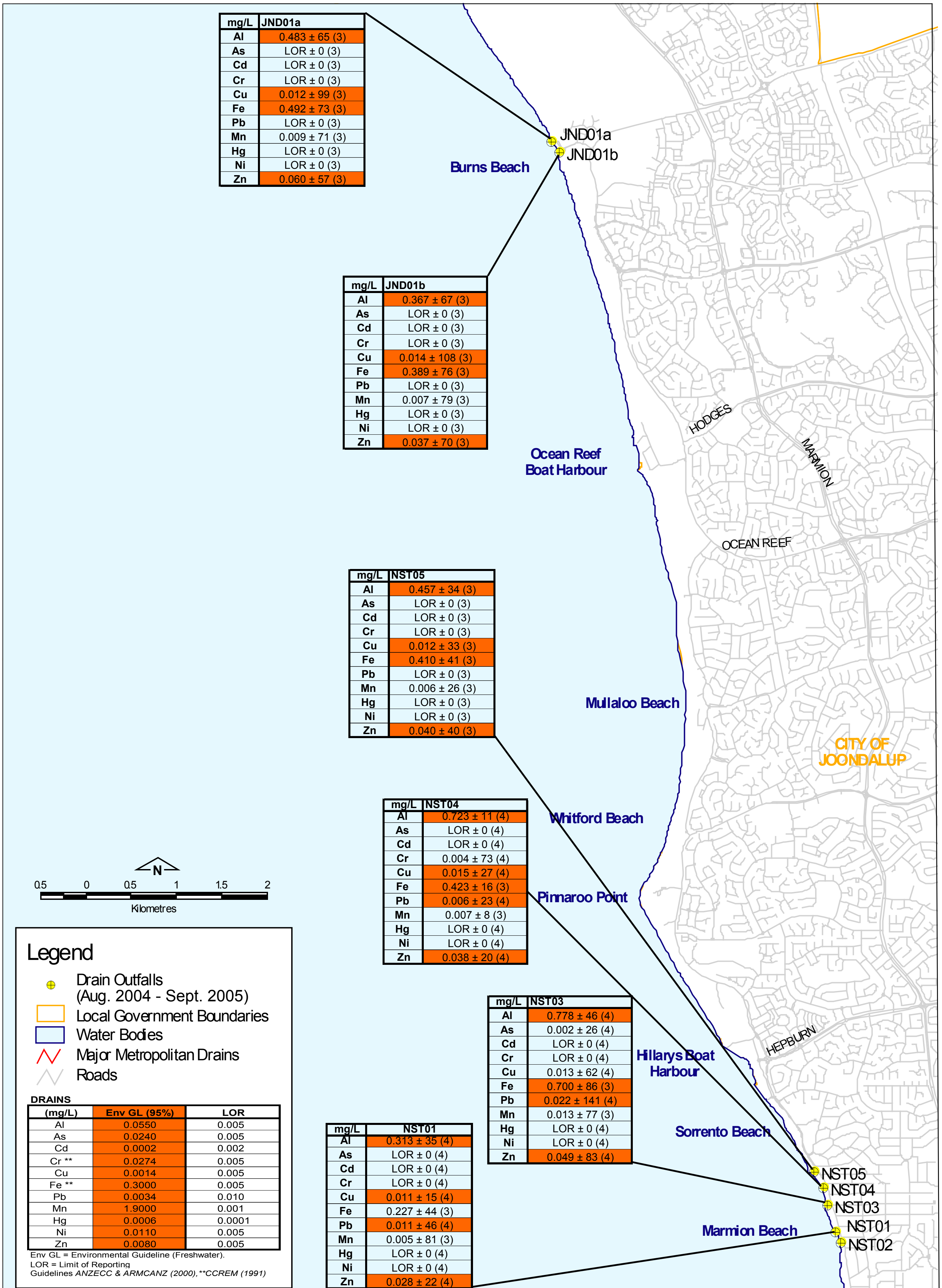
Nutri.	NST03
NOx	0.114 ± 41 (4)
T. Kjel	1.135 ± 53 (4)
TN	1.272 ± 52 (4)
NH4	0.079 ± 94 (4)
TP	0.220 ± 45 (4)
FRP	0.067 ± 21 (4)

Nutri.	NST01
NOx	0.061 ± 42 (4)
T. Kjel	0.358 ± 96 (4)
TN	0.420 ± 80 (4)
NH4	0.062 ± 116 (4)
TP	0.077 ± 51 (4)
FRP	0.022 ± 23 (4)

Nutrient (mg/L)	Env GL	LOR
NOx	0.150	0.010
Tot Kjel	no value	0.025
TN	1.200	0.025
NH4	0.080	0.010
TP	0.065	0.005
FRP	0.040	0.005

Env GL = Environmental Guideline
for Freshwater, Lowland River
LOR = Limit of Reporting
Guidelines, *ANZECC & ARMCANZ (2000)*

Appendix G Average nutrient concentrations (mg/L ± coefficient of variation (n)) for each Joondalup drain site.



mg/L	JND01a
Al	0.483 ± 65 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.012 ± 99 (3)
Fe	0.492 ± 73 (3)
Pb	LOR ± 0 (3)
Mn	0.009 ± 71 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.060 ± 57 (3)

mg/L	JND01b
Al	0.367 ± 67 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.014 ± 108 (3)
Fe	0.389 ± 76 (3)
Pb	LOR ± 0 (3)
Mn	0.007 ± 79 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.037 ± 70 (3)

mg/L	NST05
Al	0.457 ± 34 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.012 ± 33 (3)
Fe	0.410 ± 41 (3)
Pb	LOR ± 0 (3)
Mn	0.006 ± 26 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.040 ± 40 (3)

mg/L	NST04
Al	0.723 ± 11 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	0.004 ± 73 (4)
Cu	0.015 ± 27 (4)
Fe	0.423 ± 16 (3)
Pb	0.006 ± 23 (4)
Mn	0.007 ± 8 (3)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.038 ± 20 (4)

mg/L	NST03
Al	0.778 ± 46 (4)
As	0.002 ± 26 (4)
Cd	LOR ± 0 (4)
Cr	LOR ± 0 (4)
Cu	0.013 ± 62 (4)
Fe	0.700 ± 86 (3)
Pb	0.022 ± 141 (4)
Mn	0.013 ± 77 (3)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.049 ± 83 (4)

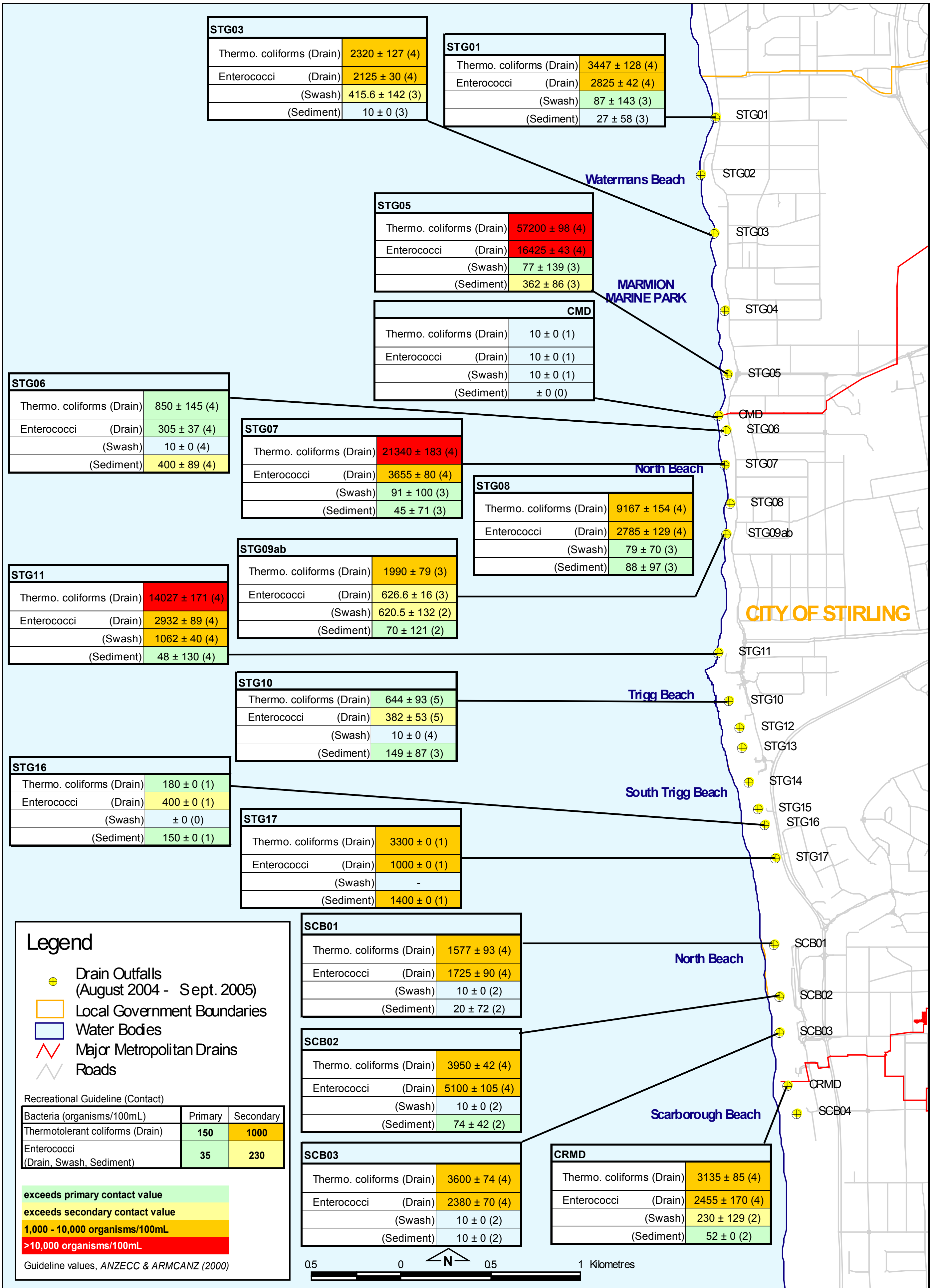
mg/L	NST01
Al	0.313 ± 35 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	LOR ± 0 (4)
Cu	0.011 ± 15 (4)
Fe	0.227 ± 44 (3)
Pb	0.011 ± 46 (4)
Mn	0.005 ± 81 (3)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.028 ± 22 (4)

DRAINS

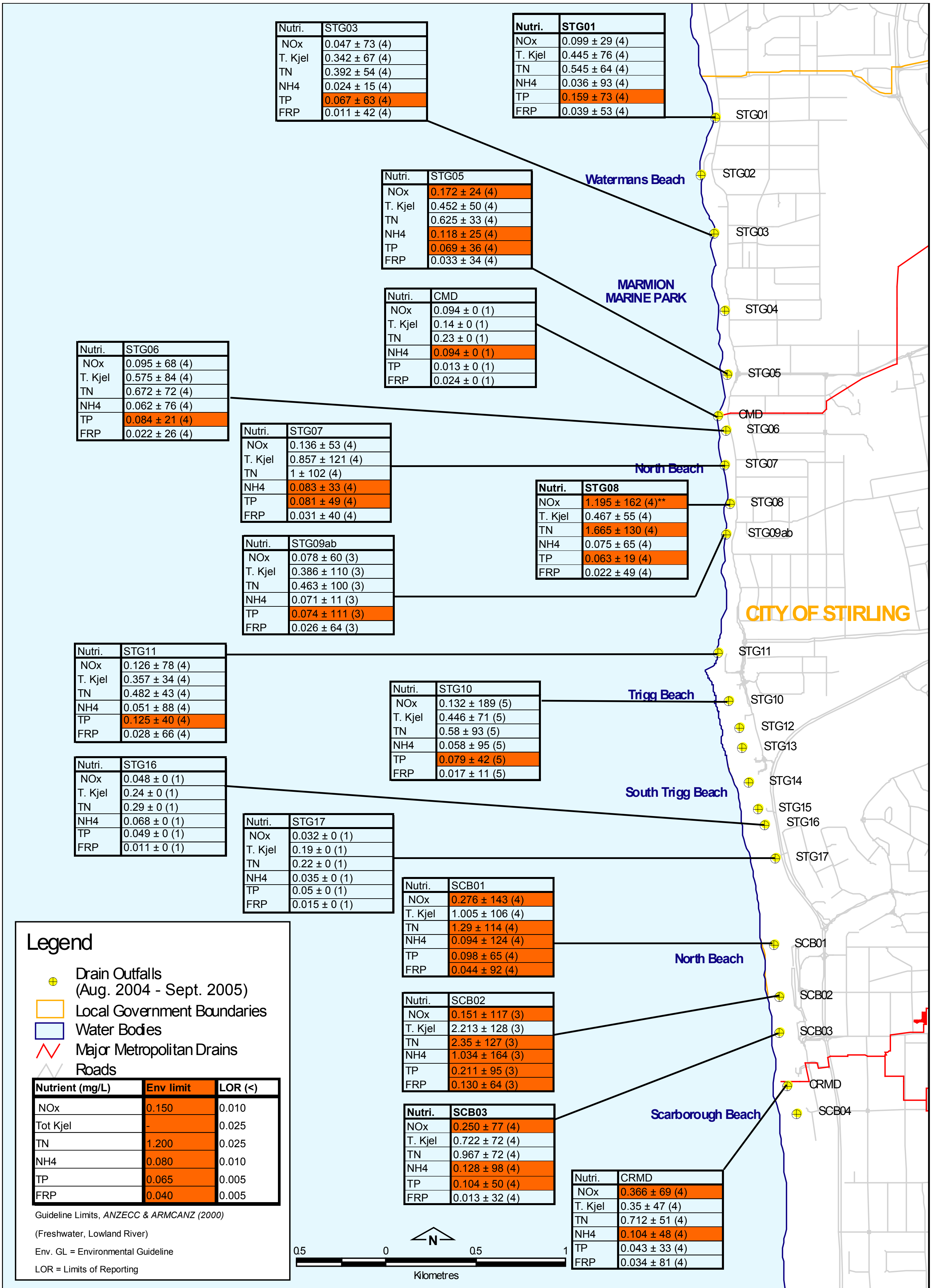
(mg/L)	Env GL (95%)	LOR
Al	0.0550	0.005
As	0.0240	0.005
Cd	0.0002	0.002
Cr **	0.0274	0.005
Cu	0.0014	0.005
Fe **	0.3000	0.005
Pb	0.0034	0.010
Mn	1.9000	0.001
Hg	0.0006	0.0001
Ni	0.0110	0.005
Zn	0.0080	0.005

Env GL = Environmental Guideline (Freshwater).
LOR = Limit of Reporting
Guidelines *ANZECC & ARMCANZ (2000),**CCREM (1991)*

Appendix H Average total metal concentrations (mg/L ± coefficient of variation (n)) for each Joondalup drain site.



Appendix I Average bacterial concentrations (organisms/100mL ± coefficient of variation (n)) for each drain, swash and sediment site in Stirling.



Nutri.	STG03
NOx	0.047 ± 73 (4)
T. Kjel	0.342 ± 67 (4)
TN	0.392 ± 54 (4)
NH4	0.024 ± 15 (4)
TP	0.067 ± 63 (4)
FRP	0.011 ± 42 (4)

Nutri.	**STG01**
NOx	0.099 ± 29 (4)
T. Kjel	0.445 ± 76 (4)
TN	0.545 ± 64 (4)
NH4	0.036 ± 93 (4)
TP	0.159 ± 73 (4)
FRP	0.039 ± 53 (4)

Nutri.	STG05
NOx	0.172 ± 24 (4)
T. Kjel	0.452 ± 50 (4)
TN	0.625 ± 33 (4)
NH4	0.118 ± 25 (4)
TP	0.069 ± 36 (4)
FRP	0.033 ± 34 (4)

Nutri.	CMD
NOx	0.094 ± 0 (1)
T. Kjel	0.14 ± 0 (1)
TN	0.23 ± 0 (1)
NH4	0.094 ± 0 (1)
TP	0.013 ± 0 (1)
FRP	0.024 ± 0 (1)

Nutri.	STG06
NOx	0.095 ± 68 (4)
T. Kjel	0.575 ± 84 (4)
TN	0.672 ± 72 (4)
NH4	0.062 ± 76 (4)
TP	0.084 ± 21 (4)
FRP	0.022 ± 26 (4)

Nutri.	STG07
NOx	0.136 ± 53 (4)
T. Kjel	0.857 ± 121 (4)
TN	1 ± 102 (4)
NH4	0.083 ± 33 (4)
TP	0.081 ± 49 (4)
FRP	0.031 ± 40 (4)

Nutri.	**STG08**
NOx	1.195 ± 162 (4)**
T. Kjel	0.467 ± 55 (4)
TN	1.665 ± 130 (4)
NH4	0.075 ± 65 (4)
TP	0.063 ± 19 (4)
FRP	0.022 ± 49 (4)

Nutri.	STG09ab
NOx	0.078 ± 60 (3)
T. Kjel	0.386 ± 110 (3)
TN	0.463 ± 100 (3)
NH4	0.071 ± 11 (3)
TP	0.074 ± 111 (3)
FRP	0.026 ± 64 (3)

Nutri.	STG11
NOx	0.126 ± 78 (4)
T. Kjel	0.357 ± 34 (4)
TN	0.482 ± 43 (4)
NH4	0.051 ± 88 (4)
TP	0.125 ± 40 (4)
FRP	0.028 ± 66 (4)

Nutri.	STG10
NOx	0.132 ± 189 (5)
T. Kjel	0.446 ± 71 (5)
TN	0.58 ± 93 (5)
NH4	0.058 ± 95 (5)
TP	0.079 ± 42 (5)
FRP	0.017 ± 11 (5)

Nutri.	STG16
NOx	0.048 ± 0 (1)
T. Kjel	0.24 ± 0 (1)
TN	0.29 ± 0 (1)
NH4	0.068 ± 0 (1)
TP	0.049 ± 0 (1)
FRP	0.011 ± 0 (1)

Nutri.	STG17
NOx	0.032 ± 0 (1)
T. Kjel	0.19 ± 0 (1)
TN	0.22 ± 0 (1)
NH4	0.035 ± 0 (1)
TP	0.05 ± 0 (1)
FRP	0.015 ± 0 (1)

Nutri.	SCB01
NOx	0.276 ± 143 (4)
T. Kjel	1.005 ± 106 (4)
TN	1.29 ± 114 (4)
NH4	0.094 ± 124 (4)
TP	0.098 ± 65 (4)
FRP	0.044 ± 92 (4)

Nutri.	SCB02
NOx	0.151 ± 117 (3)
T. Kjel	2.213 ± 128 (3)
TN	2.35 ± 127 (3)
NH4	1.034 ± 164 (3)
TP	0.211 ± 95 (3)
FRP	0.130 ± 64 (3)

Nutri.	**SCB03**
NOx	0.250 ± 77 (4)
T. Kjel	0.722 ± 72 (4)
TN	0.967 ± 72 (4)
NH4	0.128 ± 98 (4)
TP	0.104 ± 50 (4)
FRP	0.013 ± 32 (4)

Nutri.	CRMD
NOx	0.366 ± 69 (4)
T. Kjel	0.35 ± 47 (4)
TN	0.712 ± 51 (4)
NH4	0.104 ± 48 (4)
TP	0.043 ± 33 (4)
FRP	0.034 ± 81 (4)

Nutrient (mg/L)	**Env limit**	**LOR (<)**
NOx	0.150	0.010
Tot Kjel	-	0.025
TN	1.200	0.025
NH4	0.080	0.010
TP	0.065	0.005
FRP	0.040	0.005

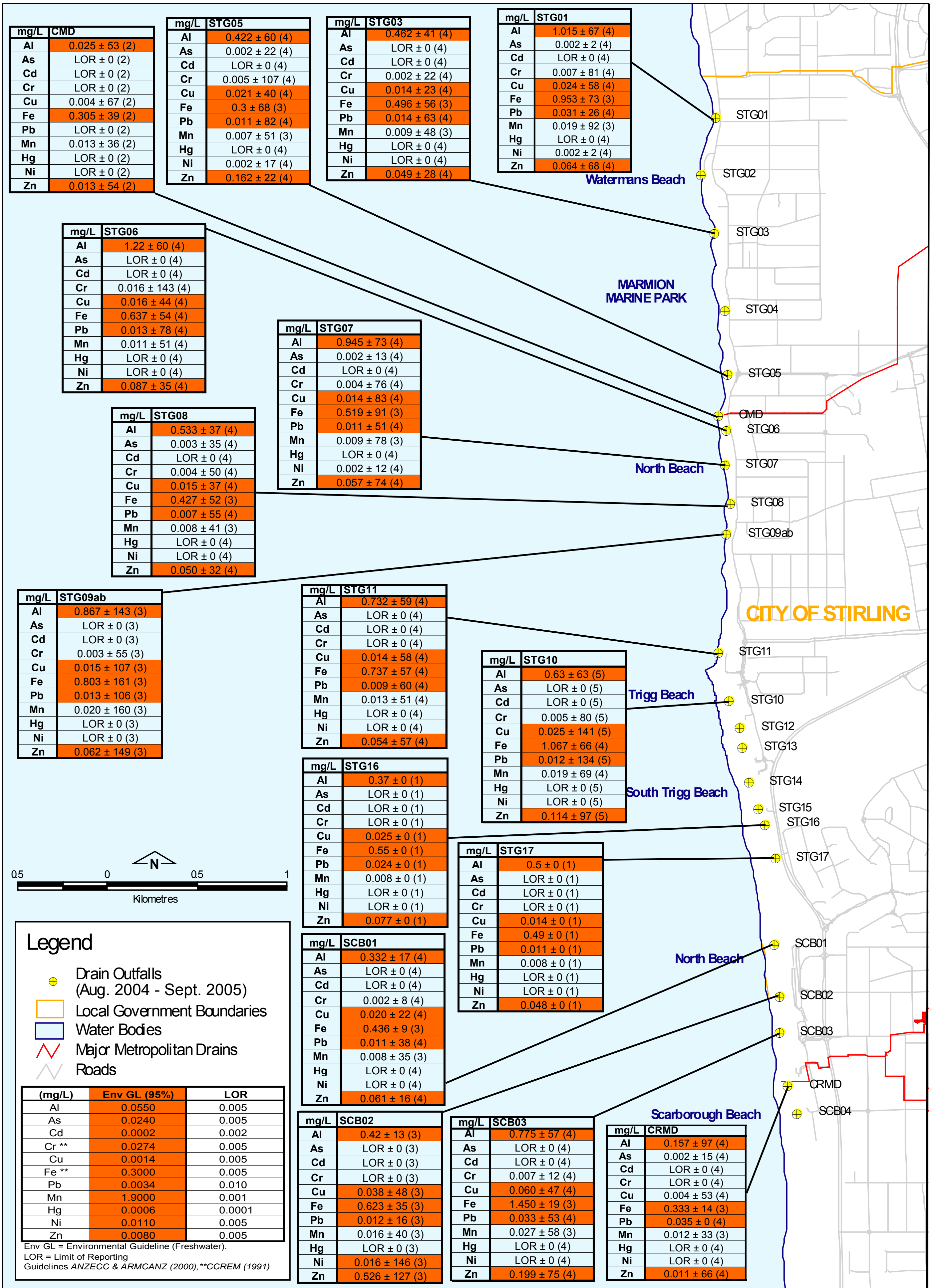
Guideline Limits, *ANZECC & ARMCANZ (2000)*

(Freshwater, Lowland River)

Env. GL = Environmental Guideline

LOR = Limits of Reporting

Appendix J Average nutrient concentrations (mg/L ± coefficient of variation (n)) for each Stirling drain site.



mg/L	CMD
Al	0.025 ± 53 (2)
As	LOR ± 0 (2)
Cd	LOR ± 0 (2)
Cr	LOR ± 0 (2)
Cu	0.004 ± 67 (2)
Fe	0.305 ± 39 (2)
Pb	LOR ± 0 (2)
Mn	0.013 ± 36 (2)
Hg	LOR ± 0 (2)
Ni	LOR ± 0 (2)
Zn	0.013 ± 54 (2)

mg/L	STG05
Al	0.422 ± 60 (4)
As	0.002 ± 22 (4)
Cd	LOR ± 0 (4)
Cr	0.005 ± 107 (4)
Cu	0.021 ± 40 (4)
Fe	0.3 ± 68 (3)
Pb	0.011 ± 82 (4)
Mn	0.007 ± 51 (3)
Hg	LOR ± 0 (4)
Ni	0.002 ± 17 (4)
Zn	0.162 ± 22 (4)

mg/L	STG03
Al	0.462 ± 41 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	0.002 ± 22 (4)
Cu	0.014 ± 23 (4)
Fe	0.496 ± 56 (3)
Pb	0.014 ± 63 (4)
Mn	0.009 ± 48 (3)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.049 ± 28 (4)

mg/L	STG01
Al	1.015 ± 67 (4)
As	0.002 ± 2 (4)
Cd	LOR ± 0 (4)
Cr	0.007 ± 81 (4)
Cu	0.024 ± 58 (4)
Fe	0.953 ± 73 (3)
Pb	0.031 ± 26 (4)
Mn	0.019 ± 92 (3)
Hg	LOR ± 0 (4)
Ni	0.002 ± 2 (4)
Zn	0.064 ± 68 (4)

mg/L	STG06
Al	1.22 ± 60 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	0.016 ± 143 (4)
Cu	0.016 ± 44 (4)
Fe	0.637 ± 54 (4)
Pb	0.013 ± 78 (4)
Mn	0.011 ± 51 (4)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.087 ± 35 (4)

mg/L	STG07
Al	0.945 ± 73 (4)
As	0.002 ± 13 (4)
Cd	LOR ± 0 (4)
Cr	0.004 ± 76 (4)
Cu	0.014 ± 83 (4)
Fe	0.519 ± 91 (3)
Pb	0.011 ± 51 (4)
Mn	0.009 ± 78 (3)
Hg	LOR ± 0 (4)
Ni	0.002 ± 12 (4)
Zn	0.057 ± 74 (4)

mg/L	STG08
Al	0.533 ± 37 (4)
As	0.003 ± 35 (4)
Cd	LOR ± 0 (4)
Cr	0.004 ± 50 (4)
Cu	0.015 ± 37 (4)
Fe	0.427 ± 52 (3)
Pb	0.007 ± 55 (4)
Mn	0.008 ± 41 (3)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.050 ± 32 (4)

mg/L	STG09ab
Al	0.867 ± 143 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	0.003 ± 55 (3)
Cu	0.015 ± 107 (3)
Fe	0.803 ± 161 (3)
Pb	0.013 ± 106 (3)
Mn	0.020 ± 160 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.062 ± 149 (3)

mg/L	STG11
Al	0.732 ± 59 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	LOR ± 0 (4)
Cu	0.014 ± 58 (4)
Fe	0.737 ± 57 (4)
Pb	0.009 ± 60 (4)
Mn	0.013 ± 51 (4)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.054 ± 57 (4)

mg/L	STG10
Al	0.63 ± 63 (5)
As	LOR ± 0 (5)
Cd	LOR ± 0 (5)
Cr	0.005 ± 80 (5)
Cu	0.025 ± 141 (5)
Fe	1.067 ± 66 (4)
Pb	0.012 ± 134 (5)
Mn	0.019 ± 69 (4)
Hg	LOR ± 0 (5)
Ni	LOR ± 0 (5)
Zn	0.114 ± 97 (5)

mg/L	STG16
Al	0.37 ± 0 (1)
As	LOR ± 0 (1)
Cd	LOR ± 0 (1)
Cr	LOR ± 0 (1)
Cu	0.025 ± 0 (1)
Fe	0.55 ± 0 (1)
Pb	0.024 ± 0 (1)
Mn	0.008 ± 0 (1)
Hg	LOR ± 0 (1)
Ni	LOR ± 0 (1)
Zn	0.077 ± 0 (1)

mg/L	STG17
Al	0.5 ± 0 (1)
As	LOR ± 0 (1)
Cd	LOR ± 0 (1)
Cr	LOR ± 0 (1)
Cu	0.014 ± 0 (1)
Fe	0.49 ± 0 (1)
Pb	0.011 ± 0 (1)
Mn	0.008 ± 0 (1)
Hg	LOR ± 0 (1)
Ni	LOR ± 0 (1)
Zn	0.048 ± 0 (1)

mg/L	SCB01
Al	0.332 ± 17 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	0.002 ± 8 (4)
Cu	0.020 ± 22 (4)
Fe	0.436 ± 9 (3)
Pb	0.011 ± 38 (4)
Mn	0.008 ± 35 (3)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.061 ± 16 (4)

mg/L	SCB02
Al	0.42 ± 13 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.038 ± 48 (3)
Fe	0.623 ± 35 (3)
Pb	0.012 ± 16 (3)
Mn	0.016 ± 40 (3)
Hg	LOR ± 0 (3)
Ni	0.016 ± 146 (3)
Zn	0.526 ± 127 (3)

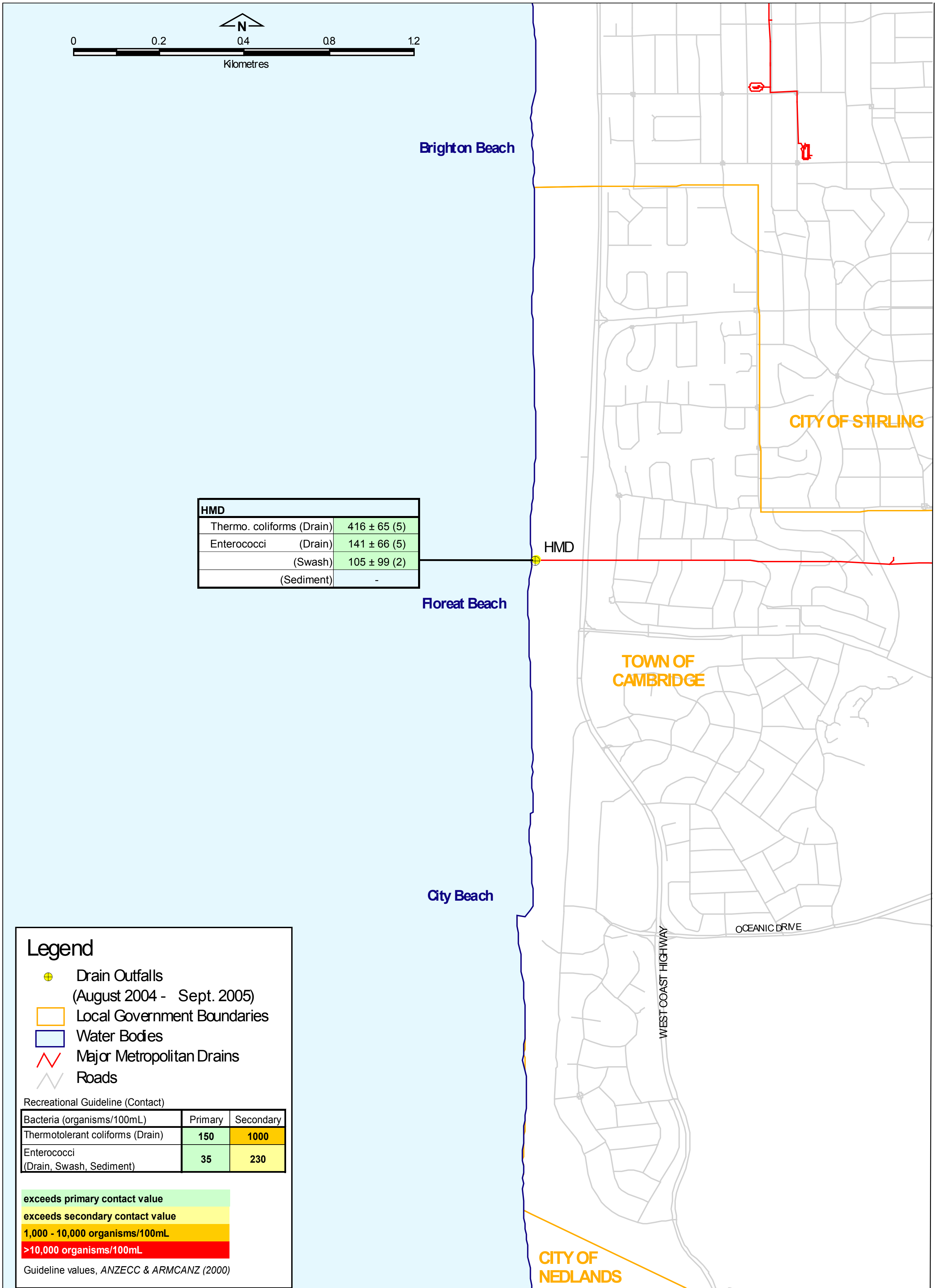
mg/L	SCB03
Al	0.775 ± 57 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	0.007 ± 12 (4)
Cu	0.060 ± 47 (4)
Fe	1.450 ± 19 (3)
Pb	0.033 ± 53 (4)
Mn	0.027 ± 58 (3)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.199 ± 75 (4)

mg/L	CRMD
Al	0.157 ± 97 (4)
As	0.002 ± 15 (4)
Cd	LOR ± 0 (4)
Cr	LOR ± 0 (4)
Cu	0.004 ± 53 (4)
Fe	0.333 ± 14 (3)
Pb	0.035 ± 0 (4)
Mn	0.012 ± 33 (3)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.011 ± 66 (4)

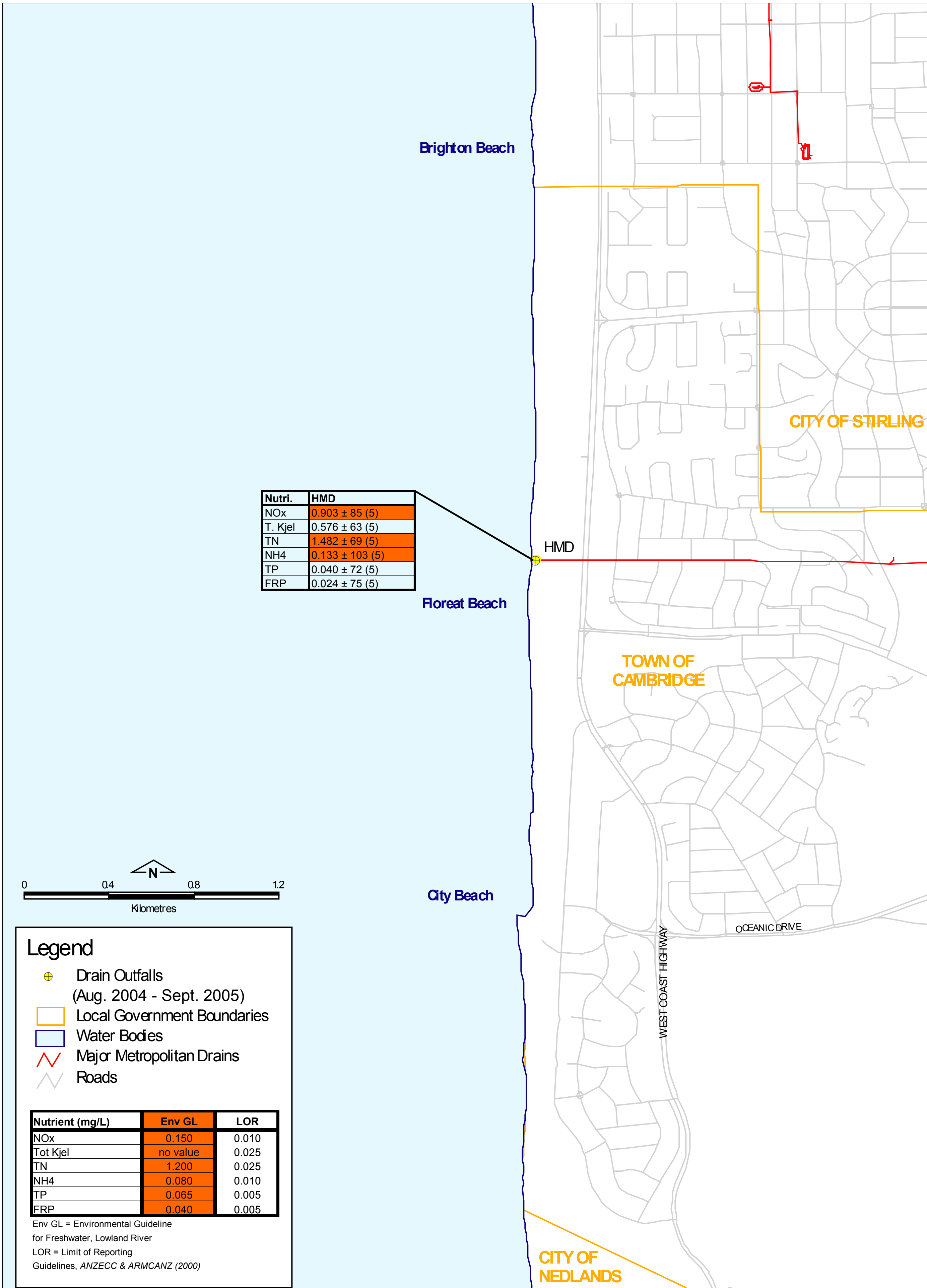
(mg/L)	Env GL (95%)	LOR
Al	0.0550	0.005
As	0.0240	0.005
Cd	0.0002	0.002
Cr **	0.0274	0.005
Cu	0.0014	0.005
Fe **	0.3000	0.005
Pb	0.0034	0.010
Mn	1.9000	0.001
Hg	0.0006	0.0001
Ni	0.0110	0.005
Zn	0.0080	0.005

Env GL = Environmental Guideline (Freshwater).
LOR = Limit of Reporting
Guidelines *ANZECC & ARMCANZ (2000),**CCREM (1991)*

Appendix K Average total metal concentrations (mg/L ± coefficient of variation (n)) for each Stirling drain site.



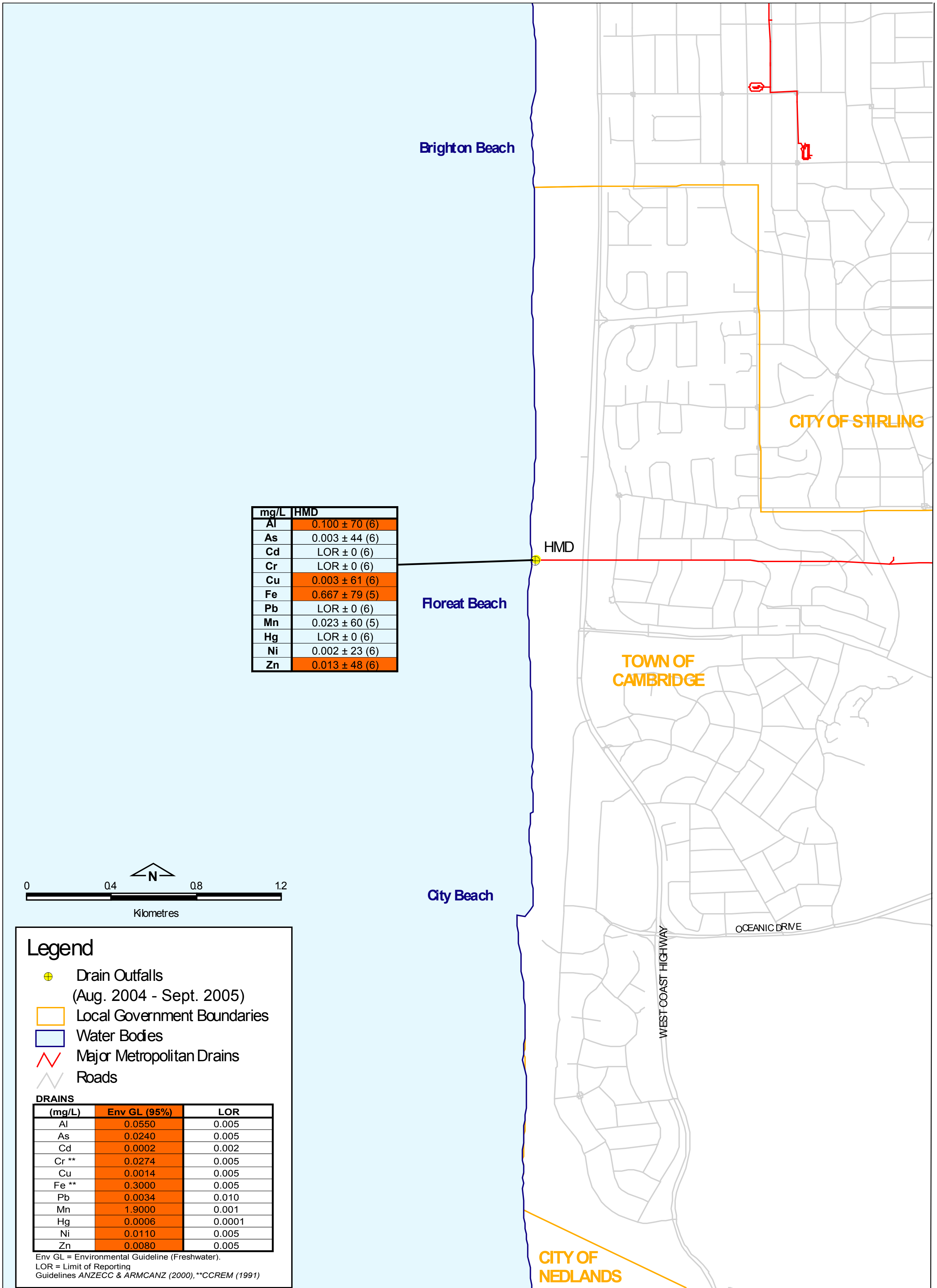
Appendix L Average bacterial concentrations (organisms/100mL ± coefficient of variation (n)) for each drain, swash and sediment site in Cambridge.



Nutri.	HMD
NOx	0.903 ± 85 (5)
T. Kjel	0.576 ± 63 (5)
TN	1.482 ± 69 (5)
NH4	0.133 ± 103 (5)
TP	0.040 ± 72 (5)
FRP	0.024 ± 75 (5)

Nutrient (mg/L)	Env GL	LOR
NOx	0.150	0.010
Tot Kjel	no value	0.025
TN	1.200	0.025
NH4	0.080	0.010
TP	0.065	0.005
FRP	0.040	0.005

Appendix M Average nutrient concentrations (mg/L ± coefficient of variation (n)) for the Cambridge drain site.



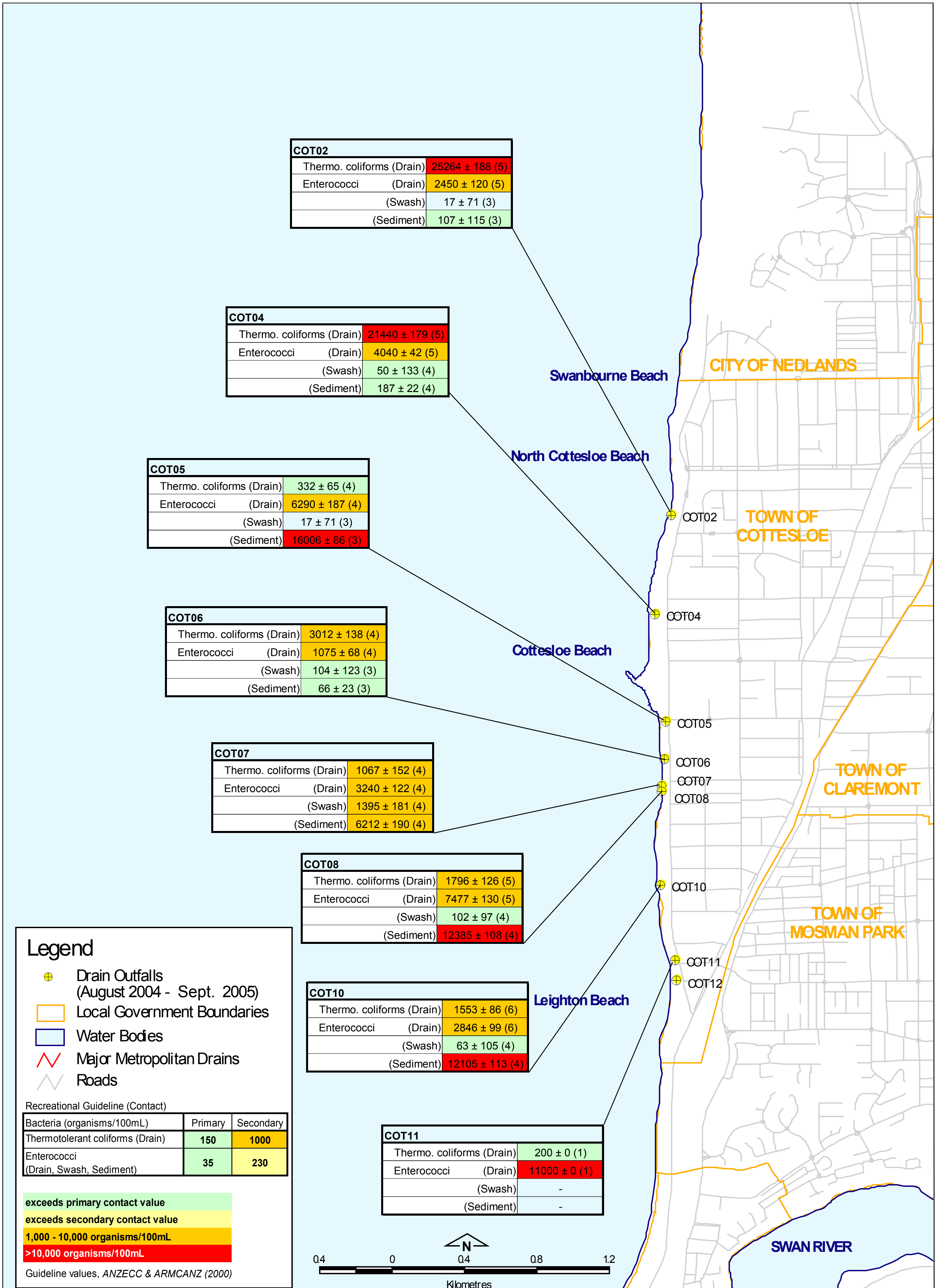
mg/L	HMD
Al	0.100 ± 70 (6)
As	0.003 ± 44 (6)
Cd	LOR ± 0 (6)
Cr	LOR ± 0 (6)
Cu	0.003 ± 61 (6)
Fe	0.667 ± 79 (5)
Pb	LOR ± 0 (6)
Mn	0.023 ± 60 (5)
Hg	LOR ± 0 (6)
Ni	0.002 ± 23 (6)
Zn	0.013 ± 48 (6)

DRAINS

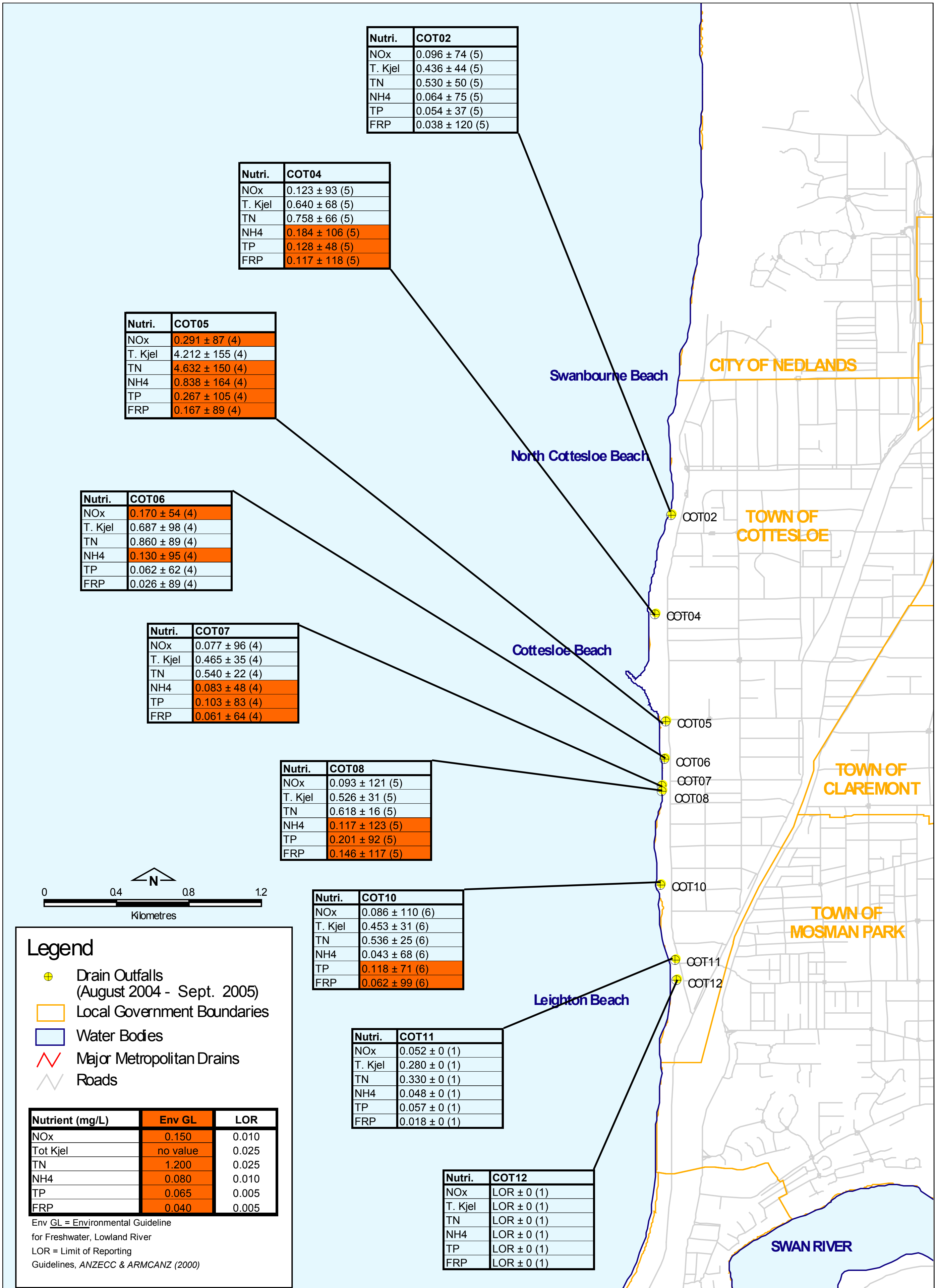
(mg/L)	Env GL (95%)	LOR
Al	0.0550	0.005
As	0.0240	0.005
Cd	0.0002	0.002
Cr **	0.0274	0.005
Cu	0.0014	0.005
Fe **	0.3000	0.005
Pb	0.0034	0.010
Mn	1.9000	0.001
Hg	0.0006	0.0001
Ni	0.0110	0.005
Zn	0.0080	0.005

Env GL = Environmental Guideline (Freshwater).
LOR = Limit of Reporting
Guidelines *ANZECC & ARMCANZ (2000),**CCREM (1991)*

Appendix N Average total metal concentrations (mg/L ± coefficient of variation (n)) for the Cambridge site.



Appendix O Average bacterial concentrations (organisms/100mL ± coefficient of variation (n)) for each drain, swash and sediment site in Cottesloe.



Nutri.	COT02
NOx	0.096 ± 74 (5)
T. Kjel	0.436 ± 44 (5)
TN	0.530 ± 50 (5)
NH4	0.064 ± 75 (5)
TP	0.054 ± 37 (5)
FRP	0.038 ± 120 (5)

Nutri.	COT04
NOx	0.123 ± 93 (5)
T. Kjel	0.640 ± 68 (5)
TN	0.758 ± 66 (5)
NH4	0.184 ± 106 (5)
TP	0.128 ± 48 (5)
FRP	0.117 ± 118 (5)

Nutri.	COT05
NOx	0.291 ± 87 (4)
T. Kjel	4.212 ± 155 (4)
TN	4.632 ± 150 (4)
NH4	0.838 ± 164 (4)
TP	0.267 ± 105 (4)
FRP	0.167 ± 89 (4)

Nutri.	COT06
NOx	0.170 ± 54 (4)
T. Kjel	0.687 ± 98 (4)
TN	0.860 ± 89 (4)
NH4	0.130 ± 95 (4)
TP	0.062 ± 62 (4)
FRP	0.026 ± 89 (4)

Nutri.	COT07
NOx	0.077 ± 96 (4)
T. Kjel	0.465 ± 35 (4)
TN	0.540 ± 22 (4)
NH4	0.083 ± 48 (4)
TP	0.103 ± 83 (4)
FRP	0.061 ± 64 (4)

Nutri.	COT08
NOx	0.093 ± 121 (5)
T. Kjel	0.526 ± 31 (5)
TN	0.618 ± 16 (5)
NH4	0.117 ± 123 (5)
TP	0.201 ± 92 (5)
FRP	0.146 ± 117 (5)

Nutri.	COT10
NOx	0.086 ± 110 (6)
T. Kjel	0.453 ± 31 (6)
TN	0.536 ± 25 (6)
NH4	0.043 ± 68 (6)
TP	0.118 ± 71 (6)
FRP	0.062 ± 99 (6)

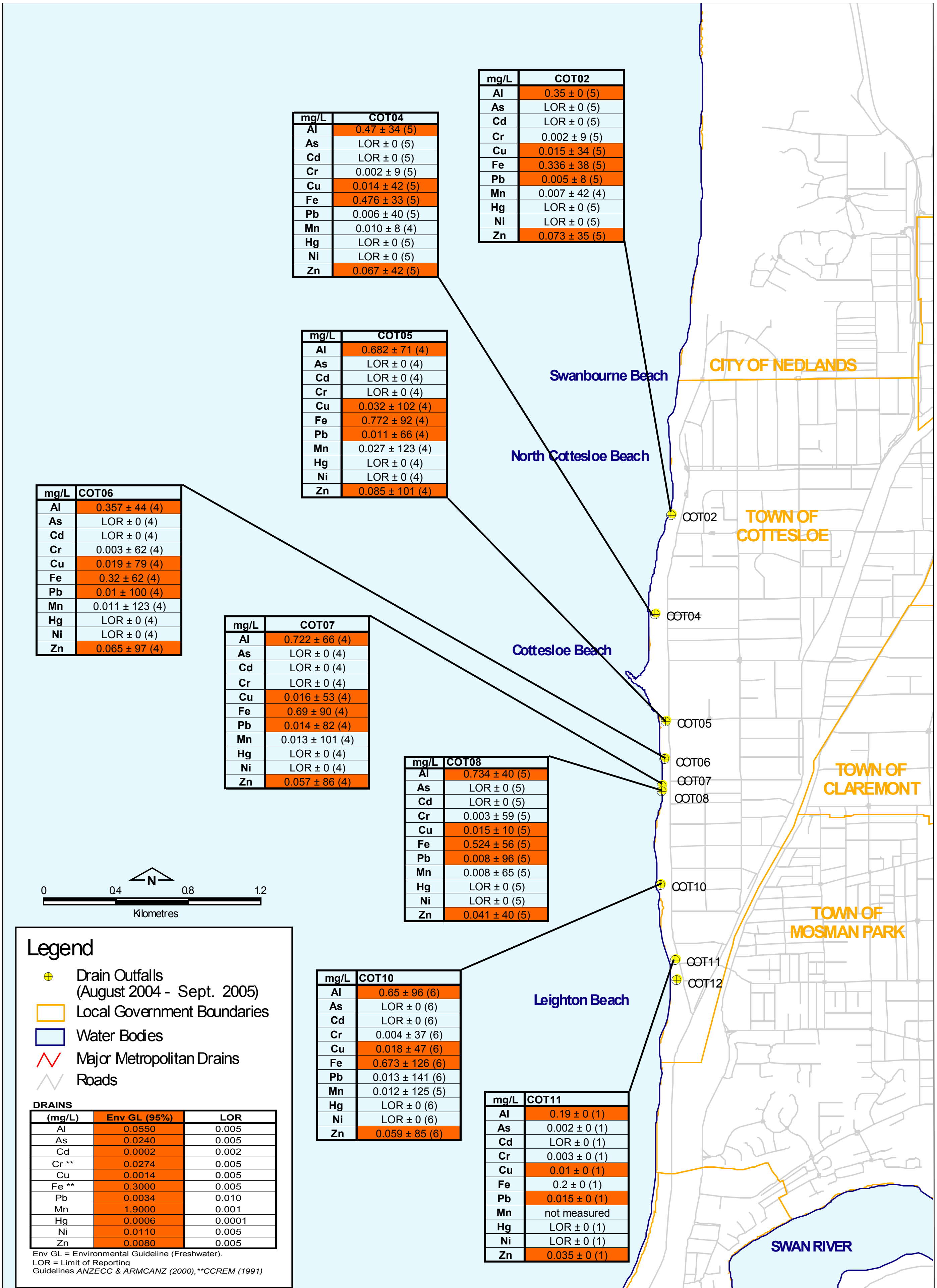
Nutri.	COT11
NOx	0.052 ± 0 (1)
T. Kjel	0.280 ± 0 (1)
TN	0.330 ± 0 (1)
NH4	0.048 ± 0 (1)
TP	0.057 ± 0 (1)
FRP	0.018 ± 0 (1)

Nutri.	COT12
NOx	LOR ± 0 (1)
T. Kjel	LOR ± 0 (1)
TN	LOR ± 0 (1)
NH4	LOR ± 0 (1)
TP	LOR ± 0 (1)
FRP	LOR ± 0 (1)

Nutrient (mg/L)	Env GL	LOR
NOx	0.150	0.010
Tot Kjel	no value	0.025
TN	1.200	0.025
NH4	0.080	0.010
TP	0.065	0.005
FRP	0.040	0.005

Env GL = Environmental Guideline for Freshwater, Lowland River
LOR = Limit of Reporting
Guidelines, *ANZECC & ARMCANZ (2000)*

Appendix P Average nutrient concentrations (mg/L ± coefficient of variation (n)) for each Cottesloe drain site.



mg/L	COT02
Al	0.35 ± 0 (5)
As	LOR ± 0 (5)
Cd	LOR ± 0 (5)
Cr	0.002 ± 9 (5)
Cu	0.015 ± 34 (5)
Fe	0.336 ± 38 (5)
Pb	0.005 ± 8 (5)
Mn	0.007 ± 42 (4)
Hg	LOR ± 0 (5)
Ni	LOR ± 0 (5)
Zn	0.073 ± 35 (5)

mg/L	COT04
Al	0.47 ± 34 (5)
As	LOR ± 0 (5)
Cd	LOR ± 0 (5)
Cr	0.002 ± 9 (5)
Cu	0.014 ± 42 (5)
Fe	0.476 ± 33 (5)
Pb	0.006 ± 40 (5)
Mn	0.010 ± 8 (4)
Hg	LOR ± 0 (5)
Ni	LOR ± 0 (5)
Zn	0.067 ± 42 (5)

mg/L	COT05
Al	0.682 ± 71 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	LOR ± 0 (4)
Cu	0.032 ± 102 (4)
Fe	0.772 ± 92 (4)
Pb	0.011 ± 66 (4)
Mn	0.027 ± 123 (4)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.085 ± 101 (4)

mg/L	COT06
Al	0.357 ± 44 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	0.003 ± 62 (4)
Cu	0.019 ± 79 (4)
Fe	0.32 ± 62 (4)
Pb	0.01 ± 100 (4)
Mn	0.011 ± 123 (4)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.065 ± 97 (4)

mg/L	COT07
Al	0.722 ± 66 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	LOR ± 0 (4)
Cu	0.016 ± 53 (4)
Fe	0.69 ± 90 (4)
Pb	0.014 ± 82 (4)
Mn	0.013 ± 101 (4)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.057 ± 86 (4)

mg/L	COT08
Al	0.734 ± 40 (5)
As	LOR ± 0 (5)
Cd	LOR ± 0 (5)
Cr	0.003 ± 59 (5)
Cu	0.015 ± 10 (5)
Fe	0.524 ± 56 (5)
Pb	0.008 ± 96 (5)
Mn	0.008 ± 65 (5)
Hg	LOR ± 0 (5)
Ni	LOR ± 0 (5)
Zn	0.041 ± 40 (5)

mg/L	COT10
Al	0.65 ± 96 (6)
As	LOR ± 0 (6)
Cd	LOR ± 0 (6)
Cr	0.004 ± 37 (6)
Cu	0.018 ± 47 (6)
Fe	0.673 ± 126 (6)
Pb	0.013 ± 141 (6)
Mn	0.012 ± 125 (5)
Hg	LOR ± 0 (6)
Ni	LOR ± 0 (6)
Zn	0.059 ± 85 (6)

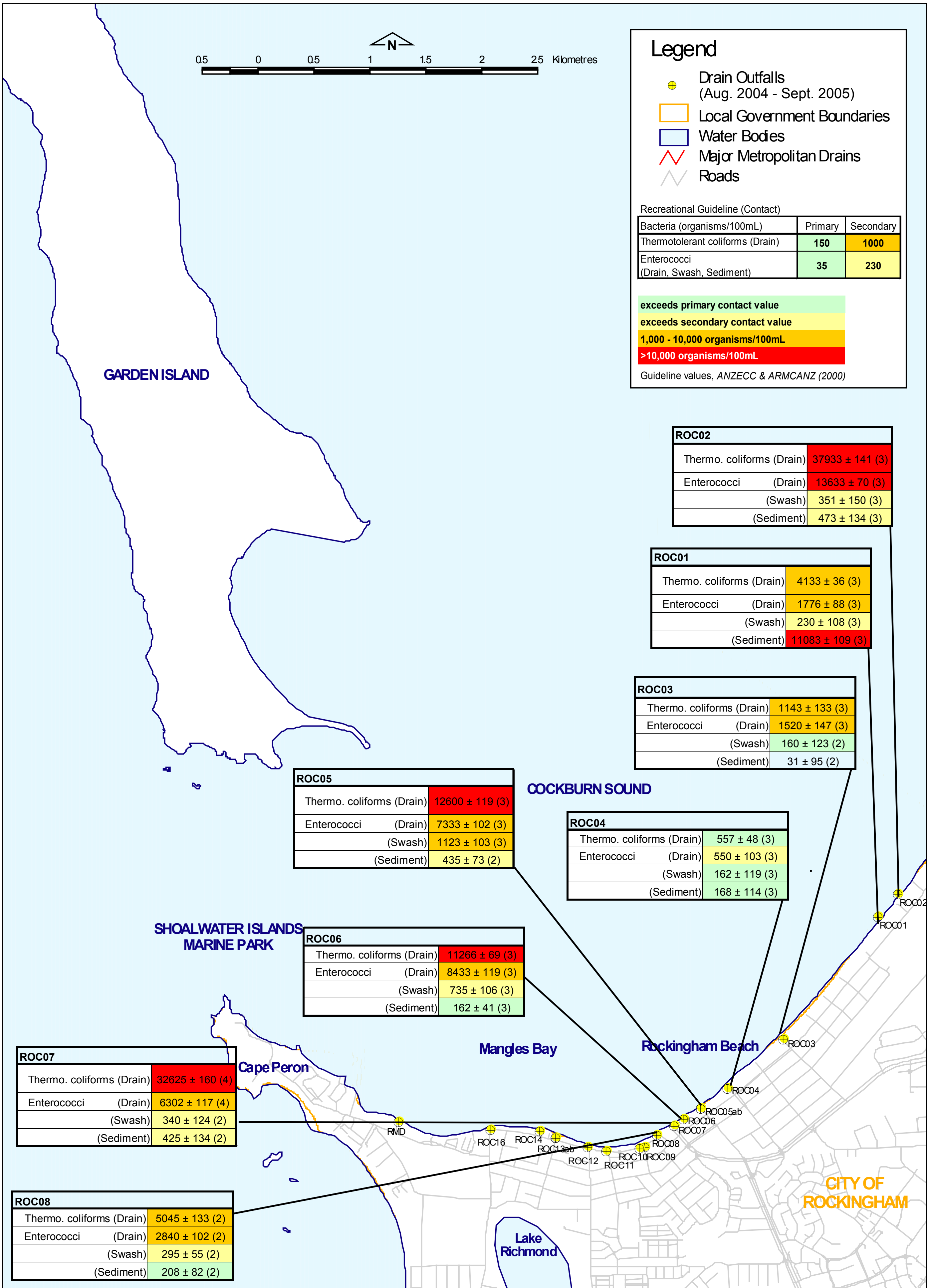
mg/L	COT11
Al	0.19 ± 0 (1)
As	0.002 ± 0 (1)
Cd	LOR ± 0 (1)
Cr	0.003 ± 0 (1)
Cu	0.01 ± 0 (1)
Fe	0.2 ± 0 (1)
Pb	0.015 ± 0 (1)
Mn	not measured
Hg	LOR ± 0 (1)
Ni	LOR ± 0 (1)
Zn	0.035 ± 0 (1)

DRAINS

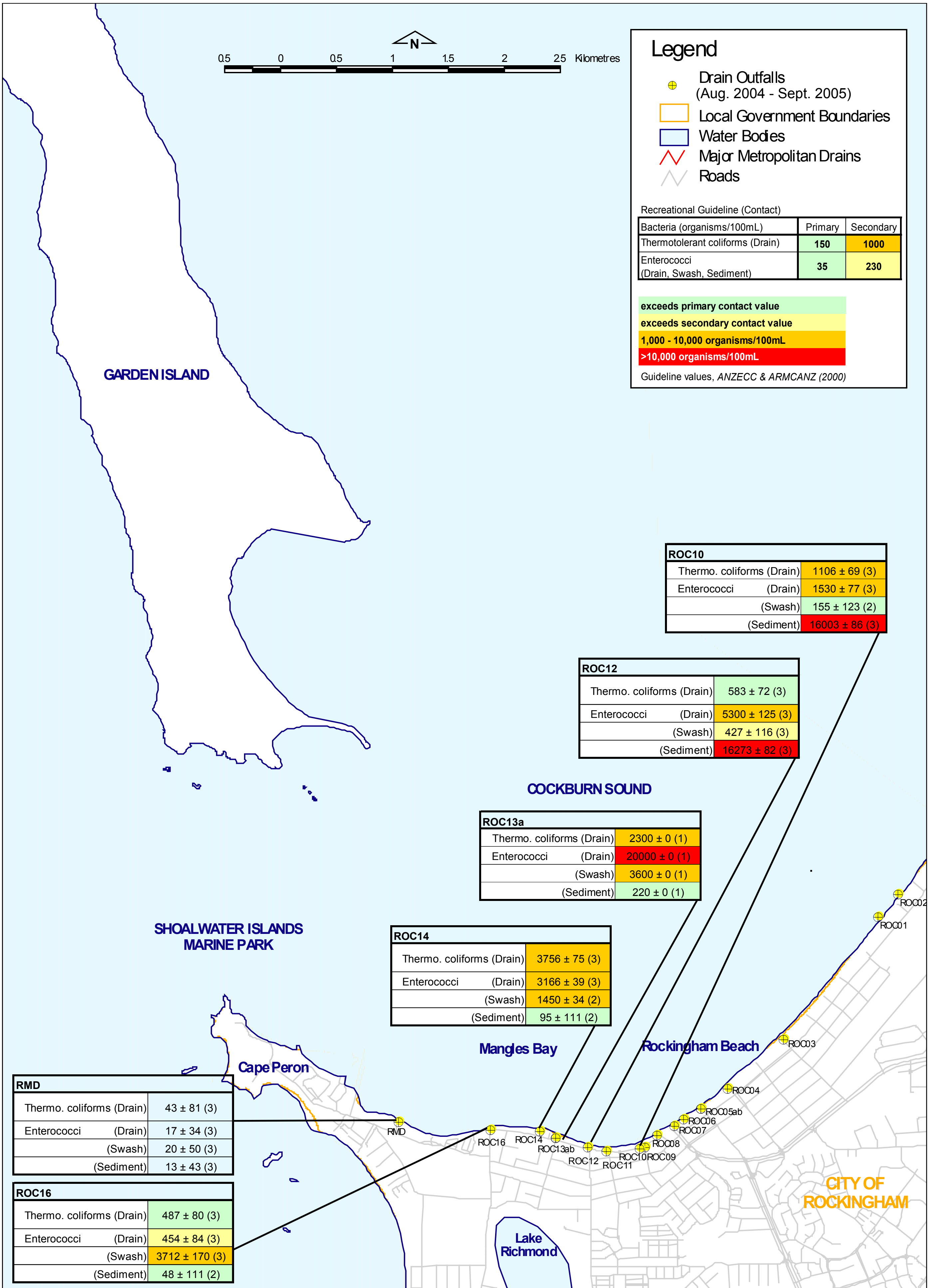
(mg/L)	Env GL (95%)	LOR
Al	0.0550	0.005
As	0.0240	0.005
Cd	0.0002	0.002
Cr **	0.0274	0.005
Cu	0.0014	0.005
Fe **	0.3000	0.005
Pb	0.0034	0.010
Mn	1.9000	0.001
Hg	0.0006	0.0001
Ni	0.0110	0.005
Zn	0.0080	0.005

Env GL = Environmental Guideline (Freshwater).
LOR = Limit of Reporting
Guidelines *ANZECC & ARMCANZ (2000),**CCREM (1991)*

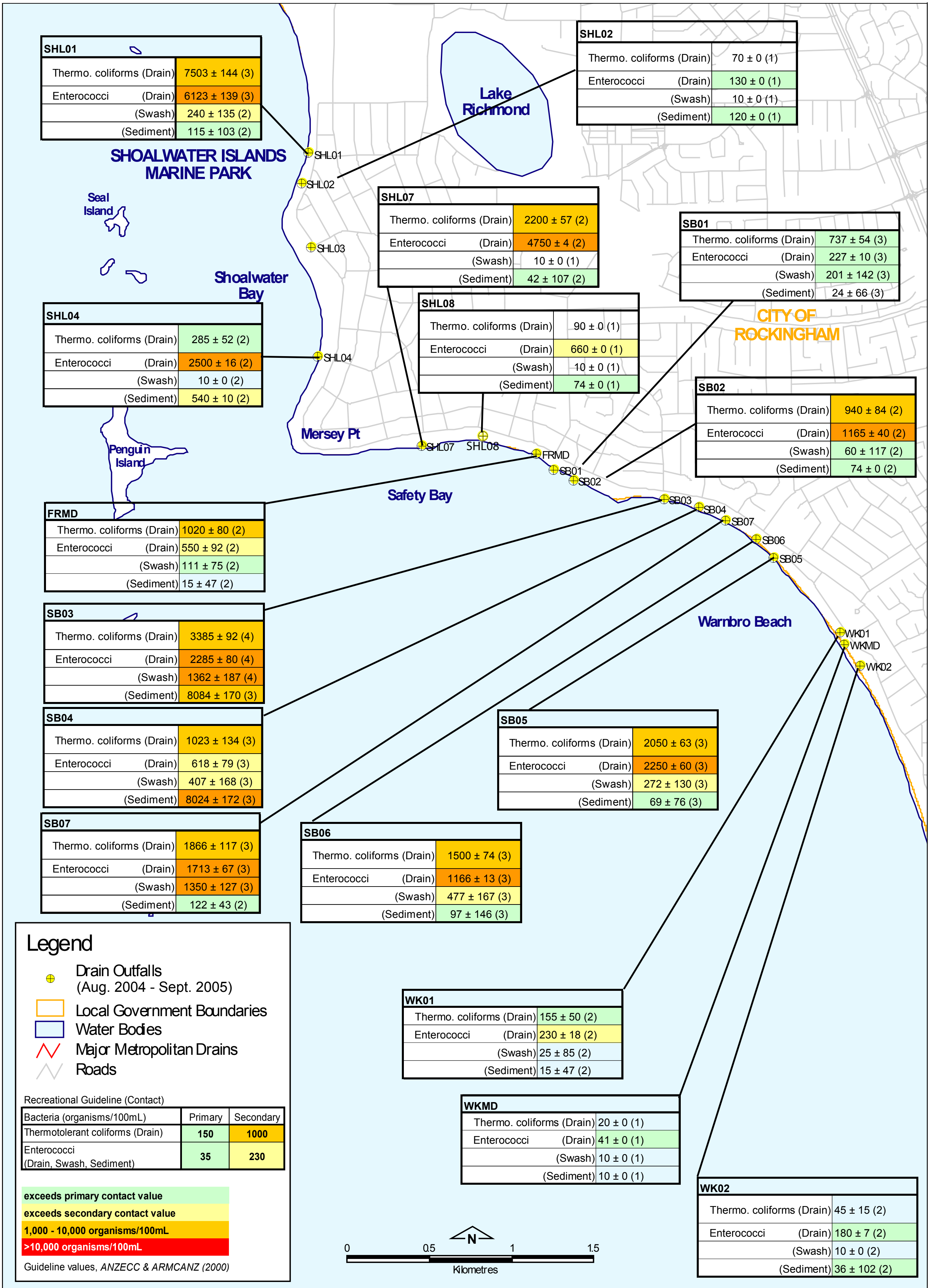
Appendix Q Average total metal concentrations (mg/L ± coefficient of variation (n)) for each Cottesloe drain site.



Appendix R Average bacterial concentrations (organisms/100mL ± coefficient of variation (n)) for each drain, swash and sediment site in Rockingham (1of 3).



Appendix S Average bacterial concentrations (organisms/100mL ± coefficient of variation (n)) for each drain, swash and sediment site in Rockingham (2 of 3).



SHL01

Thermo. coliforms (Drain)	7503 ± 144 (3)
Enterococci (Drain)	6123 ± 139 (3)
(Swash)	240 ± 135 (2)
(Sediment)	115 ± 103 (2)

SHL02

Thermo. coliforms (Drain)	70 ± 0 (1)
Enterococci (Drain)	130 ± 0 (1)
(Swash)	10 ± 0 (1)
(Sediment)	120 ± 0 (1)

SHL07

Thermo. coliforms (Drain)	2200 ± 57 (2)
Enterococci (Drain)	4750 ± 4 (2)
(Swash)	10 ± 0 (1)
(Sediment)	42 ± 107 (2)

SB01

Thermo. coliforms (Drain)	737 ± 54 (3)
Enterococci (Drain)	227 ± 10 (3)
(Swash)	201 ± 142 (3)
(Sediment)	24 ± 66 (3)

SHL04

Thermo. coliforms (Drain)	285 ± 52 (2)
Enterococci (Drain)	2500 ± 16 (2)
(Swash)	10 ± 0 (2)
(Sediment)	540 ± 10 (2)

SHL08

Thermo. coliforms (Drain)	90 ± 0 (1)
Enterococci (Drain)	660 ± 0 (1)
(Swash)	10 ± 0 (1)
(Sediment)	74 ± 0 (1)

SB02

Thermo. coliforms (Drain)	940 ± 84 (2)
Enterococci (Drain)	1165 ± 40 (2)
(Swash)	60 ± 117 (2)
(Sediment)	74 ± 0 (2)

FRMD

Thermo. coliforms (Drain)	1020 ± 80 (2)
Enterococci (Drain)	550 ± 92 (2)
(Swash)	111 ± 75 (2)
(Sediment)	15 ± 47 (2)

SB03

Thermo. coliforms (Drain)	3385 ± 92 (4)
Enterococci (Drain)	2285 ± 80 (4)
(Swash)	1362 ± 187 (4)
(Sediment)	8084 ± 170 (3)

SB04

Thermo. coliforms (Drain)	1023 ± 134 (3)
Enterococci (Drain)	618 ± 79 (3)
(Swash)	407 ± 168 (3)
(Sediment)	8024 ± 172 (3)

SB05

Thermo. coliforms (Drain)	2050 ± 63 (3)
Enterococci (Drain)	2250 ± 60 (3)
(Swash)	272 ± 130 (3)
(Sediment)	69 ± 76 (3)

SB07

Thermo. coliforms (Drain)	1866 ± 117 (3)
Enterococci (Drain)	1713 ± 67 (3)
(Swash)	1350 ± 127 (3)
(Sediment)	122 ± 43 (2)

SB06

Thermo. coliforms (Drain)	1500 ± 74 (3)
Enterococci (Drain)	1166 ± 13 (3)
(Swash)	477 ± 167 (3)
(Sediment)	97 ± 146 (3)

WK01

Thermo. coliforms (Drain)	155 ± 50 (2)
Enterococci (Drain)	230 ± 18 (2)
(Swash)	25 ± 85 (2)
(Sediment)	15 ± 47 (2)

WKMD

Thermo. coliforms (Drain)	20 ± 0 (1)
Enterococci (Drain)	41 ± 0 (1)
(Swash)	10 ± 0 (1)
(Sediment)	10 ± 0 (1)

WK02

Thermo. coliforms (Drain)	45 ± 15 (2)
Enterococci (Drain)	180 ± 7 (2)
(Swash)	10 ± 0 (2)
(Sediment)	36 ± 102 (2)

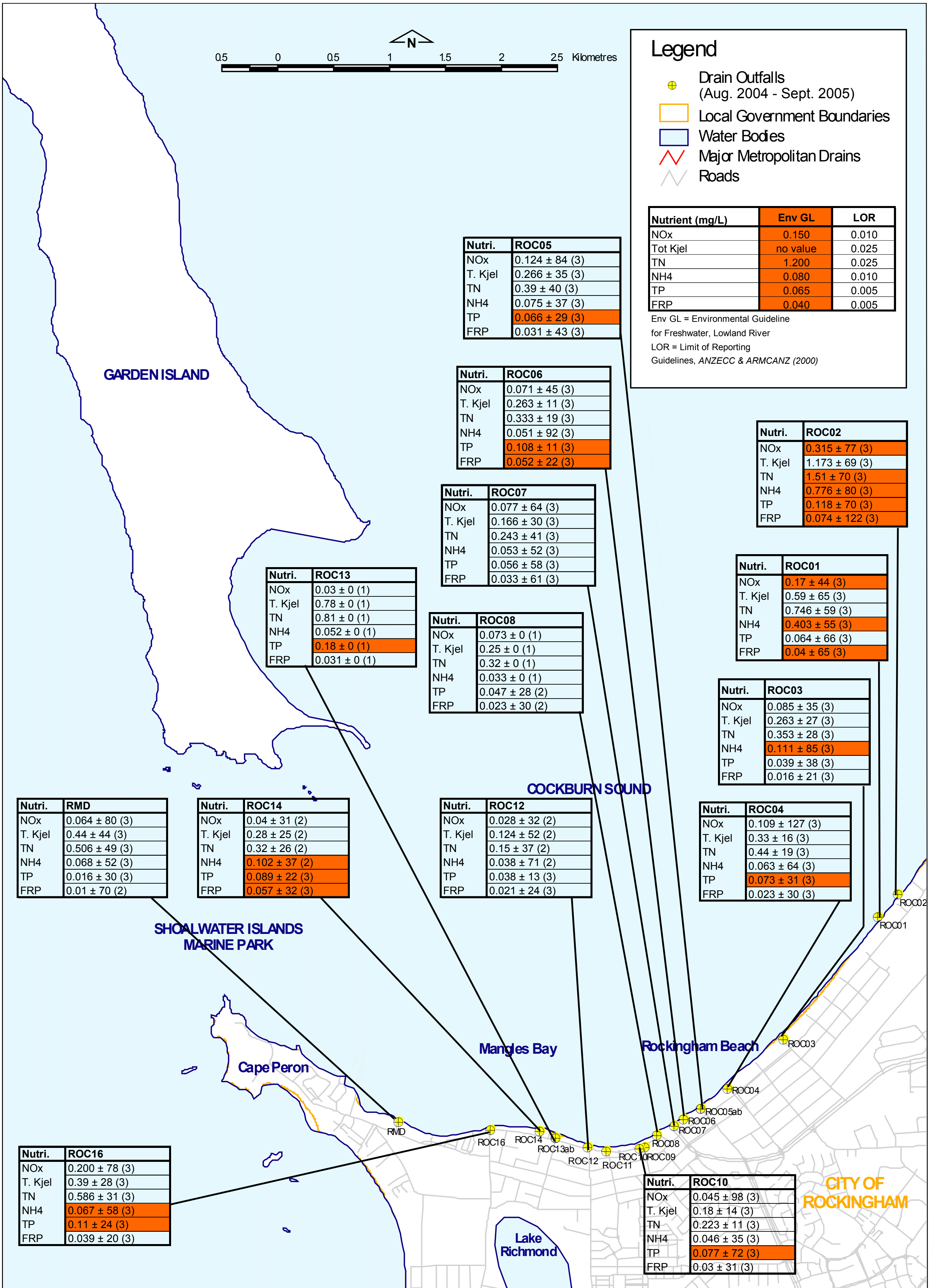
Recreational Guideline (Contact)

Bacteria (organisms/100mL)	Primary	Secondary
Thermotolerant coliforms (Drain)	150	1000
Enterococci (Drain, Swash, Sediment)	35	230

exceeds primary contact value
exceeds secondary contact value
1,000 - 10,000 organisms/100mL
>10,000 organisms/100mL

Guideline values, *ANZECC & ARMCANZ (2000)*

Appendix T Average bacterial concentrations (organisms/100mL ± coefficient of variation (n)) for each drain, swash and sediment site in Rockingham (3 of 3).



Nutrient (mg/L)	Env GL	LOR
NOx	0.150	0.010
Tot Kjel	no value	0.025
TN	1.200	0.025
NH4	0.080	0.010
TP	0.065	0.005
FRP	0.040	0.005

Nutri.	ROC05
NOx	0.124 ± 84 (3)
T. Kjel	0.266 ± 35 (3)
TN	0.39 ± 40 (3)
NH4	0.075 ± 37 (3)
TP	0.066 ± 29 (3)
FRP	0.031 ± 43 (3)

Nutri.	ROC06
NOx	0.071 ± 45 (3)
T. Kjel	0.263 ± 11 (3)
TN	0.333 ± 19 (3)
NH4	0.051 ± 92 (3)
TP	0.108 ± 11 (3)
FRP	0.052 ± 22 (3)

Nutri.	ROC02
NOx	0.315 ± 77 (3)
T. Kjel	1.173 ± 69 (3)
TN	1.51 ± 70 (3)
NH4	0.776 ± 80 (3)
TP	0.118 ± 70 (3)
FRP	0.074 ± 122 (3)

Nutri.	ROC07
NOx	0.077 ± 64 (3)
T. Kjel	0.166 ± 30 (3)
TN	0.243 ± 41 (3)
NH4	0.053 ± 52 (3)
TP	0.056 ± 58 (3)
FRP	0.033 ± 61 (3)

Nutri.	ROC13
NOx	0.03 ± 0 (1)
T. Kjel	0.78 ± 0 (1)
TN	0.81 ± 0 (1)
NH4	0.052 ± 0 (1)
TP	0.18 ± 0 (1)
FRP	0.031 ± 0 (1)

Nutri.	ROC01
NOx	0.17 ± 44 (3)
T. Kjel	0.59 ± 65 (3)
TN	0.746 ± 59 (3)
NH4	0.403 ± 55 (3)
TP	0.064 ± 66 (3)
FRP	0.04 ± 65 (3)

Nutri.	ROC08
NOx	0.073 ± 0 (1)
T. Kjel	0.25 ± 0 (1)
TN	0.32 ± 0 (1)
NH4	0.033 ± 0 (1)
TP	0.047 ± 28 (2)
FRP	0.023 ± 30 (2)

Nutri.	ROC03
NOx	0.085 ± 35 (3)
T. Kjel	0.263 ± 27 (3)
TN	0.353 ± 28 (3)
NH4	0.111 ± 85 (3)
TP	0.039 ± 38 (3)
FRP	0.016 ± 21 (3)

Nutri.	RMD
NOx	0.064 ± 80 (3)
T. Kjel	0.44 ± 44 (3)
TN	0.506 ± 49 (3)
NH4	0.068 ± 52 (3)
TP	0.016 ± 30 (3)
FRP	0.01 ± 70 (2)

Nutri.	ROC14
NOx	0.04 ± 31 (2)
T. Kjel	0.28 ± 25 (2)
TN	0.32 ± 26 (2)
NH4	0.102 ± 37 (2)
TP	0.089 ± 22 (3)
FRP	0.057 ± 32 (3)

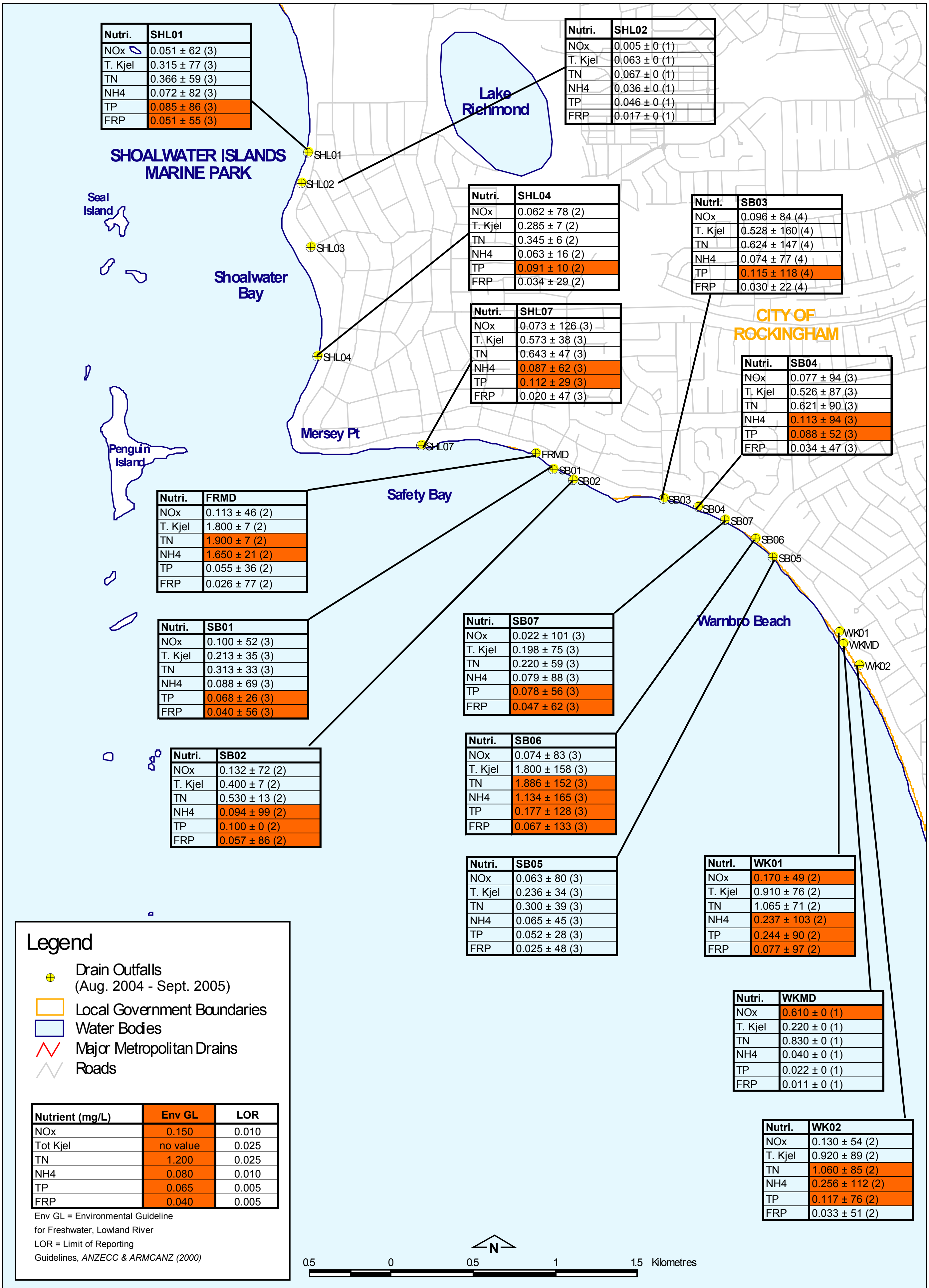
Nutri.	ROC12
NOx	0.028 ± 32 (2)
T. Kjel	0.124 ± 52 (2)
TN	0.15 ± 37 (2)
NH4	0.038 ± 71 (2)
TP	0.038 ± 13 (2)
FRP	0.021 ± 24 (3)

Nutri.	ROC04
NOx	0.109 ± 127 (3)
T. Kjel	0.33 ± 16 (3)
TN	0.44 ± 19 (3)
NH4	0.063 ± 64 (3)
TP	0.073 ± 31 (3)
FRP	0.023 ± 30 (3)

Nutri.	ROC16
NOx	0.200 ± 78 (3)
T. Kjel	0.39 ± 28 (3)
TN	0.586 ± 31 (3)
NH4	0.067 ± 58 (3)
TP	0.11 ± 24 (3)
FRP	0.039 ± 20 (3)

Nutri.	ROC10
NOx	0.045 ± 98 (3)
T. Kjel	0.18 ± 14 (3)
TN	0.223 ± 11 (3)
NH4	0.046 ± 35 (3)
TP	0.077 ± 72 (3)
FRP	0.03 ± 31 (3)

Appendix U Average nutrient concentrations (mg/L ± coefficient of variation (n)) for each Rockingham drain site (1 of 2).



Nutri.	SHL01
NOx	0.051 ± 62 (3)
T. Kjel	0.315 ± 77 (3)
TN	0.366 ± 59 (3)
NH4	0.072 ± 82 (3)
TP	0.085 ± 86 (3)
FRP	0.051 ± 55 (3)

Nutri.	SHL02
NOx	0.005 ± 0 (1)
T. Kjel	0.063 ± 0 (1)
TN	0.067 ± 0 (1)
NH4	0.036 ± 0 (1)
TP	0.046 ± 0 (1)
FRP	0.017 ± 0 (1)

Nutri.	SHL04
NOx	0.062 ± 78 (2)
T. Kjel	0.285 ± 7 (2)
TN	0.345 ± 6 (2)
NH4	0.063 ± 16 (2)
TP	0.091 ± 10 (2)
FRP	0.034 ± 29 (2)

Nutri.	SB03
NOx	0.096 ± 84 (4)
T. Kjel	0.528 ± 160 (4)
TN	0.624 ± 147 (4)
NH4	0.074 ± 77 (4)
TP	0.115 ± 118 (4)
FRP	0.030 ± 22 (4)

Nutri.	SHL07
NOx	0.073 ± 126 (3)
T. Kjel	0.573 ± 38 (3)
TN	0.643 ± 47 (3)
NH4	0.087 ± 62 (3)
TP	0.112 ± 29 (3)
FRP	0.020 ± 47 (3)

Nutri.	SB04
NOx	0.077 ± 94 (3)
T. Kjel	0.526 ± 87 (3)
TN	0.621 ± 90 (3)
NH4	0.113 ± 94 (3)
TP	0.088 ± 52 (3)
FRP	0.034 ± 47 (3)

Nutri.	FRMD
NOx	0.113 ± 46 (2)
T. Kjel	1.800 ± 7 (2)
TN	1.900 ± 7 (2)
NH4	1.650 ± 21 (2)
TP	0.055 ± 36 (2)
FRP	0.026 ± 77 (2)

Nutri.	SB01
NOx	0.100 ± 52 (3)
T. Kjel	0.213 ± 35 (3)
TN	0.313 ± 33 (3)
NH4	0.088 ± 69 (3)
TP	0.068 ± 26 (3)
FRP	0.040 ± 56 (3)

Nutri.	SB07
NOx	0.022 ± 101 (3)
T. Kjel	0.198 ± 75 (3)
TN	0.220 ± 59 (3)
NH4	0.079 ± 88 (3)
TP	0.078 ± 56 (3)
FRP	0.047 ± 62 (3)

Nutri.	SB02
NOx	0.132 ± 72 (2)
T. Kjel	0.400 ± 7 (2)
TN	0.530 ± 13 (2)
NH4	0.094 ± 99 (2)
TP	0.100 ± 0 (2)
FRP	0.057 ± 86 (2)

Nutri.	SB06
NOx	0.074 ± 83 (3)
T. Kjel	1.800 ± 158 (3)
TN	1.886 ± 152 (3)
NH4	1.134 ± 165 (3)
TP	0.177 ± 128 (3)
FRP	0.067 ± 133 (3)

Nutri.	SB05
NOx	0.063 ± 80 (3)
T. Kjel	0.236 ± 34 (3)
TN	0.300 ± 39 (3)
NH4	0.065 ± 45 (3)
TP	0.052 ± 28 (3)
FRP	0.025 ± 48 (3)

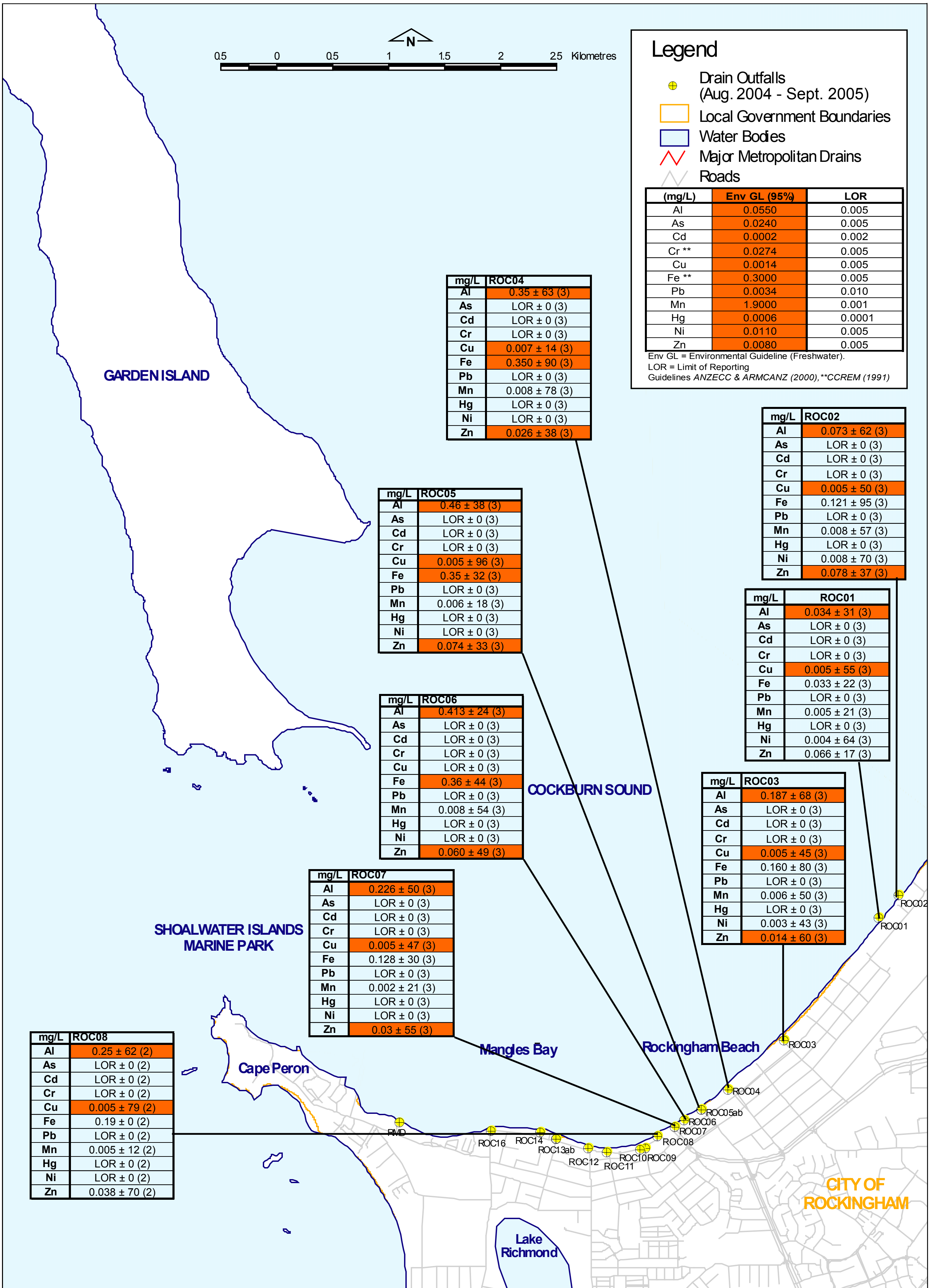
Nutri.	WK01
NOx	0.170 ± 49 (2)
T. Kjel	0.910 ± 76 (2)
TN	1.065 ± 71 (2)
NH4	0.237 ± 103 (2)
TP	0.244 ± 90 (2)
FRP	0.077 ± 97 (2)

Nutri.	WKMD
NOx	0.610 ± 0 (1)
T. Kjel	0.220 ± 0 (1)
TN	0.830 ± 0 (1)
NH4	0.040 ± 0 (1)
TP	0.022 ± 0 (1)
FRP	0.011 ± 0 (1)

Nutri.	WK02
NOx	0.130 ± 54 (2)
T. Kjel	0.920 ± 89 (2)
TN	1.060 ± 85 (2)
NH4	0.256 ± 112 (2)
TP	0.117 ± 76 (2)
FRP	0.033 ± 51 (2)

Nutrient (mg/L)	Env GL	LOR
NOx	0.150	0.010
Tot Kjel	no value	0.025
TN	1.200	0.025
NH4	0.080	0.010
TP	0.065	0.005
FRP	0.040	0.005

Appendix V Average nutrient concentrations (mg/L ± coefficient of variation (n)) for each Rockingham drain site (2 of 2).



(mg/L)	Env GL (95%)	LOR
Al	0.0550	0.005
As	0.0240	0.005
Cd	0.0002	0.002
Cr **	0.0274	0.005
Cu	0.0014	0.005
Fe **	0.3000	0.005
Pb	0.0034	0.010
Mn	1.9000	0.001
Hg	0.0006	0.0001
Ni	0.0110	0.005
Zn	0.0080	0.005

mg/L	ROC04
Al	0.35 ± 63 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.007 ± 14 (3)
Fe	0.350 ± 90 (3)
Pb	LOR ± 0 (3)
Mn	0.008 ± 78 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.026 ± 38 (3)

mg/L	ROC02
Al	0.073 ± 62 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.005 ± 50 (3)
Fe	0.121 ± 95 (3)
Pb	LOR ± 0 (3)
Mn	0.008 ± 57 (3)
Hg	LOR ± 0 (3)
Ni	0.008 ± 70 (3)
Zn	0.078 ± 37 (3)

mg/L	ROC05
Al	0.46 ± 38 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.005 ± 96 (3)
Fe	0.35 ± 32 (3)
Pb	LOR ± 0 (3)
Mn	0.006 ± 18 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.074 ± 33 (3)

mg/L	ROC01
Al	0.034 ± 31 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.005 ± 55 (3)
Fe	0.033 ± 22 (3)
Pb	LOR ± 0 (3)
Mn	0.005 ± 21 (3)
Hg	LOR ± 0 (3)
Ni	0.004 ± 64 (3)
Zn	0.066 ± 17 (3)

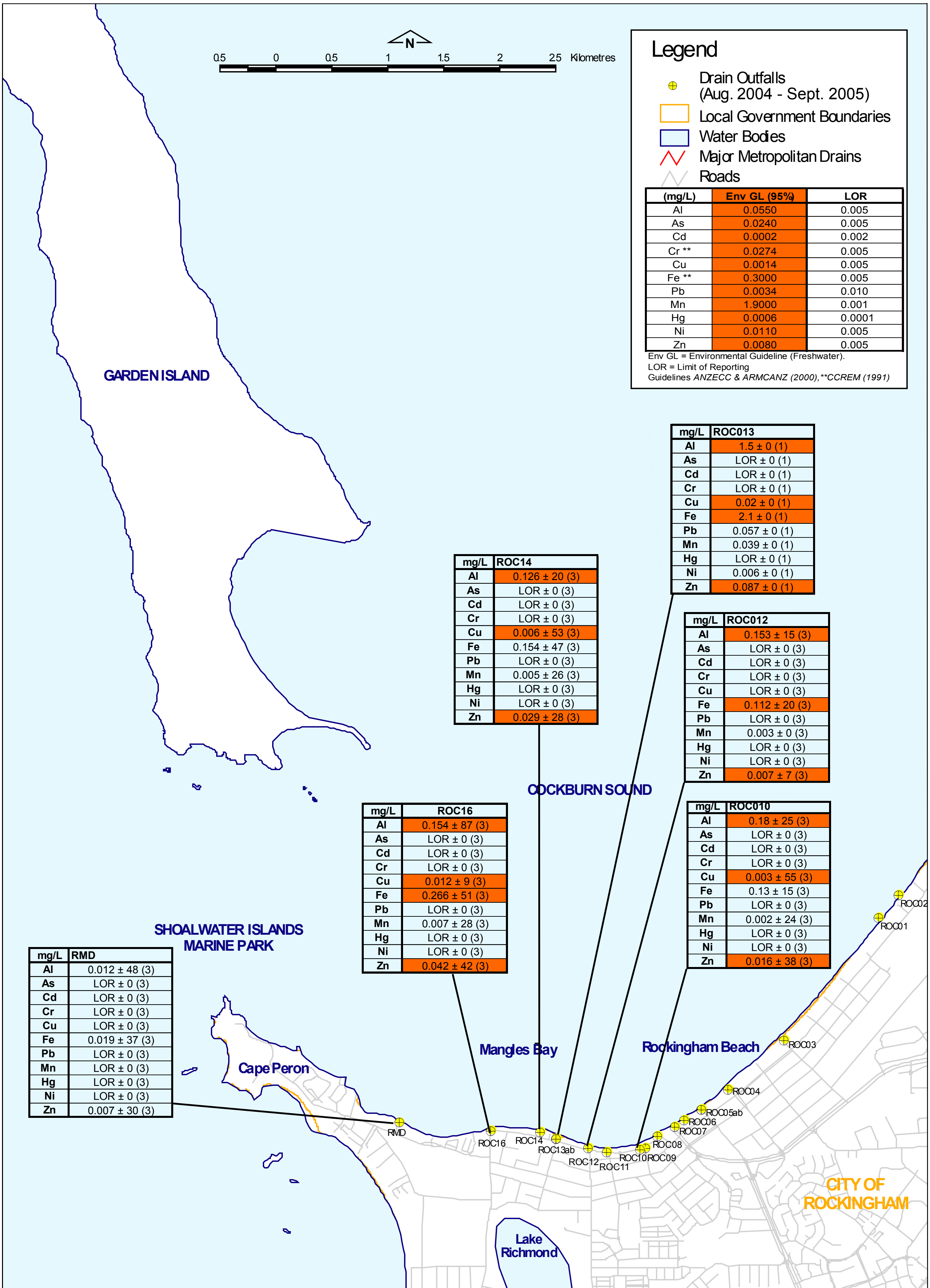
mg/L	ROC06
Al	0.413 ± 24 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	LOR ± 0 (3)
Fe	0.36 ± 44 (3)
Pb	LOR ± 0 (3)
Mn	0.008 ± 54 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.060 ± 49 (3)

mg/L	ROC03
Al	0.187 ± 68 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.005 ± 45 (3)
Fe	0.160 ± 80 (3)
Pb	LOR ± 0 (3)
Mn	0.006 ± 50 (3)
Hg	LOR ± 0 (3)
Ni	0.003 ± 43 (3)
Zn	0.014 ± 60 (3)

mg/L	ROC07
Al	0.226 ± 50 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.005 ± 47 (3)
Fe	0.128 ± 30 (3)
Pb	LOR ± 0 (3)
Mn	0.002 ± 21 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.03 ± 55 (3)

mg/L	ROC08
Al	0.25 ± 62 (2)
As	LOR ± 0 (2)
Cd	LOR ± 0 (2)
Cr	LOR ± 0 (2)
Cu	0.005 ± 79 (2)
Fe	0.19 ± 0 (2)
Pb	LOR ± 0 (2)
Mn	0.005 ± 12 (2)
Hg	LOR ± 0 (2)
Ni	LOR ± 0 (2)
Zn	0.038 ± 70 (2)

Appendix W Average total metal concentrations (mg/L ± coefficient of variation (n)) for each Rockingham drain site (1 of 3).



(mg/L)	Env GL (95%)	LOR
Al	0.0550	0.005
As	0.0240	0.005
Cd	0.0002	0.002
Cr **	0.0274	0.005
Cu	0.0014	0.005
Fe **	0.3000	0.005
Pb	0.0034	0.010
Mn	1.9000	0.001
Hg	0.0006	0.0001
Ni	0.0110	0.005
Zn	0.0080	0.005

mg/L	ROC013
Al	1.5 ± 0 (1)
As	LOR ± 0 (1)
Cd	LOR ± 0 (1)
Cr	LOR ± 0 (1)
Cu	0.02 ± 0 (1)
Fe	2.1 ± 0 (1)
Pb	0.057 ± 0 (1)
Mn	0.039 ± 0 (1)
Hg	LOR ± 0 (1)
Ni	0.006 ± 0 (1)
Zn	0.087 ± 0 (1)

mg/L	ROC14
Al	0.126 ± 20 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.006 ± 53 (3)
Fe	0.154 ± 47 (3)
Pb	LOR ± 0 (3)
Mn	0.005 ± 26 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.029 ± 28 (3)

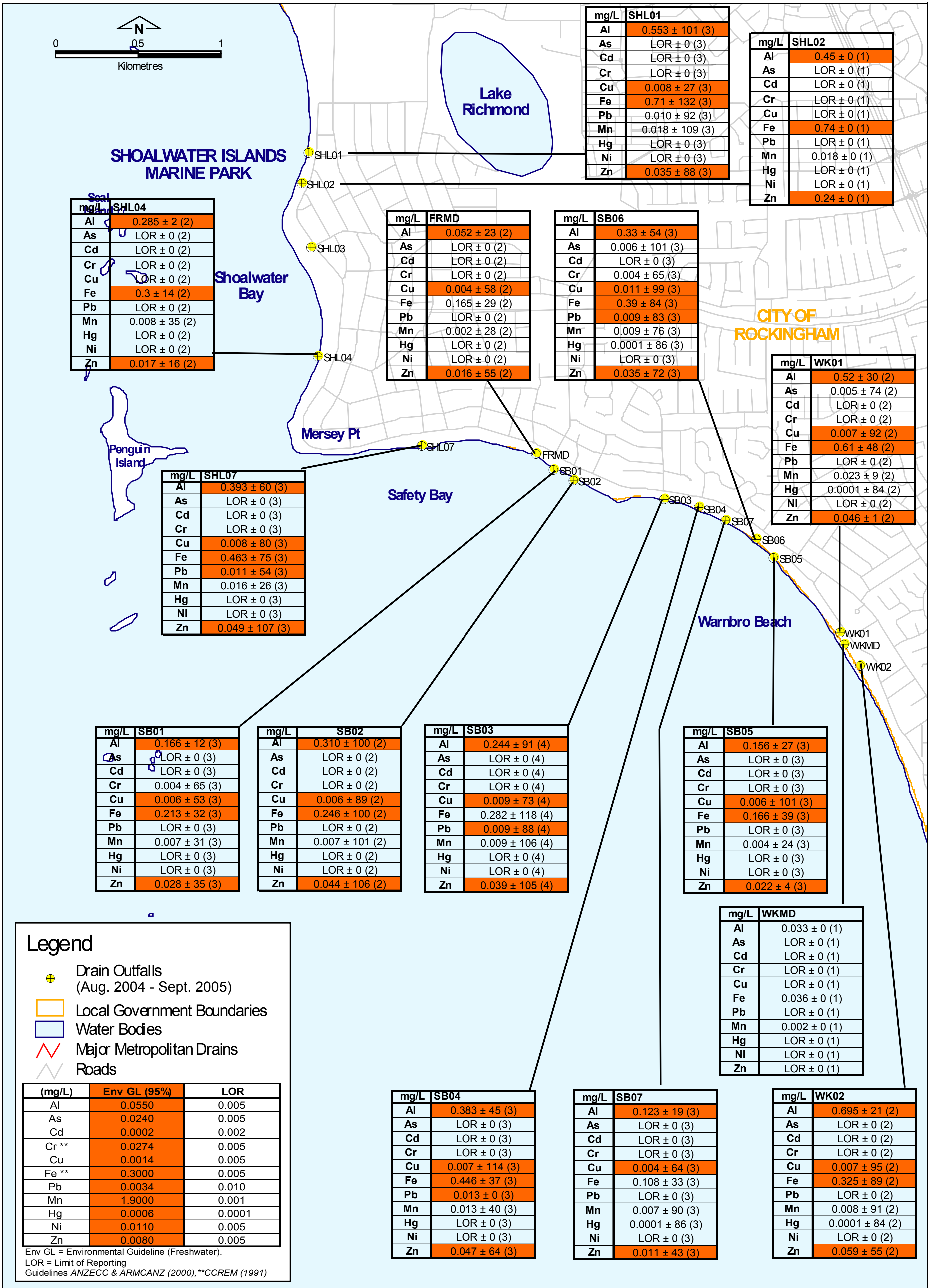
mg/L	ROC012
Al	0.153 ± 15 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	LOR ± 0 (3)
Fe	0.112 ± 20 (3)
Pb	LOR ± 0 (3)
Mn	0.003 ± 0 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.007 ± 7 (3)

mg/L	ROC16
Al	0.154 ± 87 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.012 ± 9 (3)
Fe	0.266 ± 51 (3)
Pb	LOR ± 0 (3)
Mn	0.007 ± 28 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.042 ± 42 (3)

mg/L	ROC010
Al	0.18 ± 25 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.003 ± 55 (3)
Fe	0.13 ± 15 (3)
Pb	LOR ± 0 (3)
Mn	0.002 ± 24 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.016 ± 38 (3)

mg/L	RMD
Al	0.012 ± 48 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	LOR ± 0 (3)
Fe	0.019 ± 37 (3)
Pb	LOR ± 0 (3)
Mn	LOR ± 0 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.007 ± 30 (3)

Appendix X Average total metal concentrations (mg/L ± coefficient of variation (n)) for each Rockingham drain site (2 of 3).



mg/L	SHL01
Al	0.553 ± 101 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.008 ± 27 (3)
Fe	0.71 ± 132 (3)
Pb	0.010 ± 92 (3)
Mn	0.018 ± 109 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.035 ± 88 (3)

mg/L	SHL02
Al	0.45 ± 0 (1)
As	LOR ± 0 (1)
Cd	LOR ± 0 (1)
Cr	LOR ± 0 (1)
Cu	LOR ± 0 (1)
Fe	0.74 ± 0 (1)
Pb	LOR ± 0 (1)
Mn	0.018 ± 0 (1)
Hg	LOR ± 0 (1)
Ni	LOR ± 0 (1)
Zn	0.24 ± 0 (1)

mg/L	SHL04
Al	0.285 ± 2 (2)
As	LOR ± 0 (2)
Cd	LOR ± 0 (2)
Cr	LOR ± 0 (2)
Cu	LOR ± 0 (2)
Fe	0.3 ± 14 (2)
Pb	LOR ± 0 (2)
Mn	0.008 ± 35 (2)
Hg	LOR ± 0 (2)
Ni	LOR ± 0 (2)
Zn	0.017 ± 16 (2)

mg/L	FRMD
Al	0.052 ± 23 (2)
As	LOR ± 0 (2)
Cd	LOR ± 0 (2)
Cr	LOR ± 0 (2)
Cu	0.004 ± 58 (2)
Fe	0.165 ± 29 (2)
Pb	LOR ± 0 (2)
Mn	0.002 ± 28 (2)
Hg	LOR ± 0 (2)
Ni	LOR ± 0 (2)
Zn	0.016 ± 55 (2)

mg/L	SB06
Al	0.33 ± 54 (3)
As	0.006 ± 101 (3)
Cd	LOR ± 0 (3)
Cr	0.004 ± 65 (3)
Cu	0.011 ± 99 (3)
Fe	0.39 ± 84 (3)
Pb	0.009 ± 83 (3)
Mn	0.009 ± 76 (3)
Hg	0.0001 ± 86 (3)
Ni	LOR ± 0 (3)
Zn	0.035 ± 72 (3)

mg/L	WK01
Al	0.52 ± 30 (2)
As	0.005 ± 74 (2)
Cd	LOR ± 0 (2)
Cr	LOR ± 0 (2)
Cu	0.007 ± 92 (2)
Fe	0.61 ± 48 (2)
Pb	LOR ± 0 (2)
Mn	0.023 ± 9 (2)
Hg	0.0001 ± 84 (2)
Ni	LOR ± 0 (2)
Zn	0.046 ± 1 (2)

mg/L	SHL07
Al	0.393 ± 60 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.008 ± 80 (3)
Fe	0.463 ± 75 (3)
Pb	0.011 ± 54 (3)
Mn	0.016 ± 26 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.049 ± 107 (3)

mg/L	SB01
Al	0.166 ± 12 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	0.004 ± 65 (3)
Cu	0.006 ± 53 (3)
Fe	0.213 ± 32 (3)
Pb	LOR ± 0 (3)
Mn	0.007 ± 31 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.028 ± 35 (3)

mg/L	SB02
Al	0.310 ± 100 (2)
As	LOR ± 0 (2)
Cd	LOR ± 0 (2)
Cr	LOR ± 0 (2)
Cu	0.006 ± 89 (2)
Fe	0.246 ± 100 (2)
Pb	LOR ± 0 (2)
Mn	0.007 ± 101 (2)
Hg	LOR ± 0 (2)
Ni	LOR ± 0 (2)
Zn	0.044 ± 106 (2)

mg/L	SB03
Al	0.244 ± 91 (4)
As	LOR ± 0 (4)
Cd	LOR ± 0 (4)
Cr	LOR ± 0 (4)
Cu	0.009 ± 73 (4)
Fe	0.282 ± 118 (4)
Pb	0.009 ± 88 (4)
Mn	0.009 ± 106 (4)
Hg	LOR ± 0 (4)
Ni	LOR ± 0 (4)
Zn	0.039 ± 105 (4)

mg/L	SB05
Al	0.156 ± 27 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.006 ± 101 (3)
Fe	0.166 ± 39 (3)
Pb	LOR ± 0 (3)
Mn	0.004 ± 24 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.022 ± 4 (3)

mg/L	WKMD
Al	0.033 ± 0 (1)
As	LOR ± 0 (1)
Cd	LOR ± 0 (1)
Cr	LOR ± 0 (1)
Cu	LOR ± 0 (1)
Fe	0.036 ± 0 (1)
Pb	LOR ± 0 (1)
Mn	0.002 ± 0 (1)
Hg	LOR ± 0 (1)
Ni	LOR ± 0 (1)
Zn	LOR ± 0 (1)

mg/L	SB04
Al	0.383 ± 45 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.007 ± 114 (3)
Fe	0.446 ± 37 (3)
Pb	0.013 ± 0 (3)
Mn	0.013 ± 40 (3)
Hg	LOR ± 0 (3)
Ni	LOR ± 0 (3)
Zn	0.047 ± 64 (3)

mg/L	SB07
Al	0.123 ± 19 (3)
As	LOR ± 0 (3)
Cd	LOR ± 0 (3)
Cr	LOR ± 0 (3)
Cu	0.004 ± 64 (3)
Fe	0.108 ± 33 (3)
Pb	LOR ± 0 (3)
Mn	0.007 ± 90 (3)
Hg	0.0001 ± 86 (3)
Ni	LOR ± 0 (3)
Zn	0.011 ± 43 (3)

mg/L	WK02
Al	0.695 ± 21 (2)
As	LOR ± 0 (2)
Cd	LOR ± 0 (2)
Cr	LOR ± 0 (2)
Cu	0.007 ± 95 (2)
Fe	0.325 ± 89 (2)
Pb	LOR ± 0 (2)
Mn	0.008 ± 91 (2)
Hg	0.0001 ± 84 (2)
Ni	LOR ± 0 (2)
Zn	0.059 ± 55 (2)

(mg/L)	Env GL (95%)	LOR
Al	0.0550	0.005
As	0.0240	0.005
Cd	0.0002	0.002
Cr **	0.0274	0.005
Cu	0.0014	0.005
Fe **	0.3000	0.005
Pb	0.0034	0.010
Mn	1.9000	0.001
Hg	0.0006	0.0001
Ni	0.0110	0.005
Zn	0.0080	0.005

Env GL = Environmental Guideline (Freshwater).
LOR = Limit of Reporting
Guidelines *ANZECC & ARMCANZ (2000),**CCREM (1991)*

Appendix Y Average total metal concentrations (mg/L ± coefficient of variation (n)) for each Rockingham drain site (3 of 3).

Appendix Z

Contaminant load estimates in Perth coastal stormwater drains

19 February 2007

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Summary

This report provides estimates of total annual load for 22 different contaminants for 20 of the drains observed in the Perth Beach Health Study. It also provides estimated contaminant loads for a Rockingham drain (ROC04) based on approximately 6 weeks of measured flow depth at the drain.

Method

Two different techniques were used to prepare the contaminant loads presented in this report. The first technique involves prediction of contaminant discharge based on catchment area, median annual rainfall and discrete measurements of contaminant concentrations at each drain to give a Total Annual Load. The second technique uses water depth measurements at a Rockingham drain (ROC04) and predicts actual discharge for the measurement period using Manning's equation. Contaminant loads for the measurement period at that drain are then estimated based on discrete measurements of contaminant concentrations at the drain.

Technique 1: Total Annual Load

Estimates of contaminant loads were calculated for 20 of the Perth Beach Health Study drains sampled in 2005. These drains were chosen based on the availability of catchment area information. The areas of catchments in Cottesloe were obtained from a drainage study (McDowall Affleck Pty Ltd, 1995), while areas of catchments in Wanneroo, Joondalup, and Stirling were measured from drainage charts obtained from the relevant town councils. An estimate of annual discharge was calculated based on catchment area, median annual rainfall, and a runoff coefficient.

Annual Discharge = catchment area X median annual rainfall X runoff coefficient

Median annual rainfall (854mm) was obtained for the Perth Regional Office from the Bureau of Meteorology. Runoff coefficients for urban areas are typically between 0.20 and 0.70 (Chiew et al., 1997). This is the fraction of impervious surfaces (pavements, roads and roofs) in a typical Australian urban area. The lower end of this range (0.2) was chosen as the runoff coefficient for this study since road density along the Perth coast was assumed to be relatively low and runoff from roofs in Perth is not directed through the storm drain system. However, the runoff coefficient would likely be higher if a particular catchment contained a high density of car parks. Estimates could be improved by calibrating the runoff coefficient for each drain by either measuring the actual road area drained, or directly measuring drain discharge to determine the discharge-rainfall relationship.

Annual load for each contaminant was calculated by multiplying the annual discharge by the contaminant concentration. This was calculated for maximum, minimum and average concentrations measured at each drain during 2005. These three different estimates were made for annual load to attempt to take into account the large variability in concentrations measured at each drain. It should be stressed that these are estimates which assume constant contaminant levels for the full duration of each flow event and among flow events over the year.

Technique 2: Rockingham Flow Information

Water depths were measured by a pressure sensor at a stormwater drain in Rockingham (ROC04) from 12/06/06 to 19/07/06 and 19/08/06 to 30/08/06. The approximately 6 weeks of data collected by this sensor could not be used to accurately calculate a discharge rate since the accessible section of the drain was perfectly horizontal (The slope, cross sectional area and roughness of the drain are required in order to estimate discharge from the depth measurement provided by the sensor). Flow in the drain was either driven by a very small slope or more likely a head of water in the collection drain.

However, discharge could be estimated assuming a small slope as input into the standard Manning Equation:

$$Q = \frac{AR^{2/3}S^{1/2}}{n}$$

where: Q = discharge rate (m^3s^{-1})
A = cross sectional area of flow
R = hydraulic radius (area/wetted perimeter)
S = slope of channel
n = Manning's coefficient (0.011 for smooth concrete)

Total discharge for the measurement period was calculated by summing the discharge (discharge rate x time) for each water level measurement.

Calculated estimates of total discharge for this drain assuming, a very gentle slope of 0.0005 and 0.002, were 2940 m^3 and 5880 m^3 respectively for the 6 weeks of record. It is not unreasonable to assume a slope of 0.001 which would give a discharge of 4160 m^3 for the time period defined above. Total contaminate loads were estimated for this short time period using concentrations measured at the drain (Table 23) based on a discharge of 4160 m^3.

References

Chiew, F.H.S., Mudgway, L.B., Duncan, H.P., and McMahon, T.A., 1997. Urban Stormwater Pollution. Cooperative Research Centre for Catchment Hydrology, Industry Report 97/5

McDowall Affleck Pty Ltd., 1995. Town of Cottesloe Drainage Study Part 2: Catchment area anaysis. Perth, WA.

Table 1: Bacteria (primary contact) - coliforms

Site	Catchment area (ha)	Coliforms (organisms/100mL)			Discharge (m^3/year)	Estimated annual load (organisms)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	2300	1500	1900	6150	1.41E+13	9.23E+12	1.17E+13
WAN04	1.3	2900	270	1585	2221	6.44E+12	6.00E+11	3.52E+12
WAN05	9.9	5100	560	2890	16913	8.63E+13	9.47E+12	4.89E+13
NST05 (JND02)	9.1	2000	520	1140	15512	3.10E+13	8.07E+12	1.77E+13
NST04 (JND03)*	15.7	2800	-	1188	26736	7.49E+13	-	3.18E+13
NST03 (JND04)	11.1***	30000	-	7480	18997	5.70E+14	-	1.42E+14
NST01(JND05)		4400	-	2560	18997	8.36E+13	-	4.86E+13
STG01	11.3	10000	-	2758	19305	1.93E+14	-	5.32E+13
STG05	4.4	120000	-	45760	7517	9.02E+14	-	3.44E+14
STG06	0.3	2700	150	850	513	1.38E+12	7.69E+10	4.36E+11
STG07*	4.4	80000	-	17072	7517	6.01E+14	-	1.28E+14
STG08	5	30000	-	7334	8542	2.56E+14	-	6.26E+13
STG09ab	8.8	2900	-	1492.5	15034	4.36E+13	-	2.24E+13
COT02*	6.5	110000	200	25264	11161	1.23E+15	2.23E+12	2.82E+14
COT04	14.3	90000	-	17866.667	24476	2.20E+15	-	4.37E+14
COT05	0.6	560	-	266	1023	5.73E+11	-	2.72E+11
COT06	0.4	9200	-	2410	757	6.96E+12	-	1.82E+12
COT07	2.9**	3500	-	1067.5	4889	1.71E+13	-	5.22E+12
COT08		5600	-	1496.6667	4889	2.74E+13	-	7.32E+12
COT10	7.9	3400	200	1553.3333	13464	4.58E+13	2.69E+12	2.09E+13

Table 2: Bacteria (primary contact) - enterococci

Site	Catchment area (ha)	Enterococci (organisms/100mL)			Discharge (m^3/year)	Estimated annual load (organisms)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	500	360	430	6150	3.08E+12	2.21E+12	2.64E+12
WAN04	1.3	220	170	195	2221	4.89E+11	3.78E+11	4.33E+11
WAN05	9.9	4600	140	2080	16913	7.78E+13	2.37E+12	3.52E+13
NST05 (JND02)	9.1	1800	690	1330	15512	2.79E+13	1.07E+13	2.06E+13
NST04 (JND03)*	15.7	8700	-	3410	26736	2.33E+14	-	9.12E+13
NST03 (JND04)	11.1***	14000	-	5260	18997	2.66E+14	-	9.99E+13
NST01(JND05)		3700	-	1510	18997	7.03E+13	-	2.87E+13
STG01	11.3	4400	-	2260	19305	8.49E+13	-	4.36E+13
STG05	4.4	24000	-	13140	7517	1.80E+14	-	9.88E+13
STG06	0.3	460	190	305	513	2.36E+11	9.74E+10	1.56E+11
STG07*	4.4	6500	-	2924	7517	4.89E+13	-	2.20E+13
STG08	5	8200	-	2228	8542	7.00E+13	-	1.90E+13
STG09ab	8.8	730	-	470	15034	1.10E+13	-	7.07E+12
COT02*	6.5	7300	120	2450	11161	8.15E+13	1.34E+12	2.73E+13
COT04	14.3	5200	-	3366.6667	24476	1.27E+14	-	8.24E+13
COT05	0.6	24000	-	5032	1023	2.46E+13	-	5.15E+12
COT06	0.4	1800	-	860	757	1.36E+12	-	6.51E+11
COT07	2.9**	8700	290	3240	4889	4.25E+13	1.42E+12	1.58E+13
COT08		24000	-	6231	4889	1.17E+14	-	3.05E+13
COT10	7.9	3400	200	1553.3333	13464	4.58E+13	2.69E+12	2.09E+13

Table 3: Total Petroleum Hydrocarbons (TPH) – total hydrocarbons

Site	Catchment area (ha)	Total Hydrocarbons (mg/L; LOR=0.250)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	-	-	LOR	6150	-	-	-
WAN04	1.3	-	-	LOR	2221	-	-	-
WAN05	9.9	-	-	LOR	16913	-	-	-
NST05 (JND02)	9.1	-	-	LOR	15512	-	-	-
NST04 (JND03)*	15.7	-	-	LOR	26736	-	-	-
NST03 (JND04)	11.1***	-	-	LOR	18997	-	-	-
NST01(JND05)		4.4	-	LOR	18997	83.589	-	-
STG01	11.3	-	-	LOR	19305	-	-	-
STG05	4.4	-	-	LOR	7517	-	-	-
STG06	0.3	-	-	LOR	513	-	-	-
STG07*	4.4	-	-	LOR	7517	-	-	-
STG08	5	-	-	LOR	8542	-	-	-
STG09ab	8.8	-	-	LOR	15034	-	-	-
COT02*	6.5	0.6	-	0.271	11161	6.697	-	3.025
COT04	14.3	-	-	LOR	24476	-	-	-
COT05	0.6	0.72	-	0.376	1023	0.737	-	0.385
COT06	0.4	0.41	-	0.2425	757	0.310	-	0.184
COT07	2.9**	0.41	-	0.19625	4889	2.005	-	0.960
COT08		-	-	LOR	4889	-	-	-
COT10	7.9	0.11	-	0.495	13464	14.810	-	6.665

Table 4: Volatile organic hydrocarbons - BTEX

Site	Catchment area (ha)	BTEX (mg/L; LOR=0.005)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	-	-	LOR	6150	-	-	-
WAN04	1.3	-	-	LOR	2221	-	-	-
WAN05	9.9	-	-	LOR	16913	-	-	-
NST05 (JND02)	9.1	-	-	LOR	15512	-	-	-
NST04 (JND03)*	15.7	-	-	LOR	26736	-	-	-
NST03 (JND04)	11.1***	-	-	LOR	18997	-	-	-
NST01(JND05)		-	-	LOR	18997	-	-	-
STG01	11.3	-	-	LOR	19305	-	-	-
STG05	4.4	-	-	LOR	7517	-	-	-
STG06	0.3	0.055	-	0.020	513	0.028	-	0.010
STG07*	4.4	-	-	LOR	7517	-	-	-
STG08	5	-	-	LOR	8542	-	-	-
STG09ab	8.8	-	-	LOR	15034	-	-	-
COT02*	6.5	-	-	LOR	11161	-	-	-
COT04	14.3	-	-	LOR	24476	-	-	-
COT05	0.6	-	-	LOR	1023	-	-	-
COT06	0.4	-	-	LOR	757	-	-	-
COT07	2.9**	-	-	LOR	4889	-	-	-
COT08		-	-	LOR	4889	-	-	-
COT10	7.9	-	-	LOR	13464	-	-	-

Table 5: Nitrogen – sol ox

Site	Catchment area (ha)	sol ox (mg/L)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.084	0.005	0.045	6150	0.517	0.031	0.274
WAN04	1.3	0.1	0.037	0.069	2221	0.222	0.082	0.152
WAN05	9.9	0.23	0.005	0.078	16913	3.890	0.085	1.319
NST05 (JND02)	9.1	0.15	0.021	0.075	15512	2.327	0.326	1.169
NST04 (JND03)*	15.7	0.15	0.058	0.098	26736	4.010	1.551	2.627
NST03 (JND04)	11.1***	0.17	0.057	0.114	18997	3.230	1.083	2.170
NST01(JND05)		0.099	0.038	0.061	18997	1.881	0.722	1.164
STG01	11.3	0.13	0.061	0.1	19305	2.510	1.178	1.921
STG05	4.4	0.2	0.11	0.173	7517	1.503	0.827	1.297
STG06	0.3	0.16	0.005	0.095	513	0.082	0.003	0.049
STG07*	4.4	0.2	0.067	0.137	7517	1.503	0.504	1.026
STG08	5	4.1	0.14	1.195	8542	35.022	1.196	10.208
STG09ab	8.8	0.13	0.038	0.078	15034	1.954	0.571	1.178
COT02*	6.5	0.21	0.037	0.096	11161	2.344	0.413	1.074
COT04	14.3	0.31	0.005	0.123	24476	7.588	0.122	3.020
COT05	0.6	0.58	0.005	0.291	1023	0.594	0.005	0.298
COT06	0.4	0.3	0.1	0.17	757	0.227	0.076	0.129
COT07	2.9**	0.16	0.005	0.077	4889	0.782	0.024	0.378
COT08		0.24	0.005	0.093	4889	1.173	0.024	0.455
COT10	7.9	0.24	0.005	0.087	13464	3.231	0.067	1.167

Table 6: Nitrogen – total kjel

Site	Catchment area (ha)	Total kjel (mg/L)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.57	0.055	0.313	6150	3.5	0.3	1.9
WAN04	1.3	0.29	0.049	0.17	2221	0.6	0.1	0.4
WAN05	9.9	0.8	0.013	0.411	16913	13.5	0.2	6.9
NST05 (JND02)	9.1	0.43	0.2	0.287	15512	6.7	3.1	4.4
NST04 (JND03)*	15.7	0.73	0.29	0.478	26736	19.5	7.8	12.8
NST03 (JND04)	11.1***	1.7	0.5	1.135	18997	32.3	9.5	21.6
NST01(JND05)		0.86	0.072	0.358	18997	16.3	1.4	6.8
STG01	11.3	0.79	0.071	0.445	19305	15.3	1.4	8.6
STG05	4.4	0.66	0.17	0.453	7517	5.0	1.3	3.4
STG06	0.3	1.3	0.32	0.575	513	0.7	0.2	0.3
STG07*	4.4	2.4	0.14	0.858	7517	18.0	1.1	6.4
STG08	5	0.79	0.18	0.468	8542	6.7	1.5	4.0
STG09ab	8.8	0.88	0.12	0.387	15034	13.2	1.8	5.8
COT02*	6.5	0.72	0.23	0.436	11161	8.0	2.6	4.9
COT04	14.3	1.3	0.28	0.64	24476	31.8	6.9	15.7
COT05	0.6	14	0.32	4.213	1023	14.3	0.3	4.3
COT06	0.4	1.7	0.28	0.688	757	1.3	0.2	0.5
COT07	2.9**	0.69	0.3	0.465	4889	3.4	1.5	2.3
COT08		0.72	0.38	0.526	4889	3.5	1.9	2.6
COT10	7.9	0.69	0.3	0.453	13464	9.3	4.0	6.1

Table 7: Nitrogen – TN, pTN

Site	Catchment area (ha)	TN. pTN (mg/L)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.66	0.063	0.362	6150	4.1	0.4	2.2
WAN04	1.3	0.39	0.086	0.238	2221	0.9	0.2	0.5
WAN05	9.9	1	0.013	0.481	16913	16.9	0.2	8.1
NST05 (JND02)	9.1	0.59	0.25	0.367	15512	9.2	3.9	5.7
NST04 (JND03)*	15.7	0.8	0.35	0.58	26736	21.4	9.4	15.5
NST03 (JND04)	11.1***	1.9	0.6	1.273	18997	36.1	11.4	24.2
NST01(JND05)		0.91	0.13	0.42	18997	17.3	2.5	8.0
STG01	11.3	0.9	0.13	0.545	19305	17.4	2.5	10.5
STG05	4.4	0.81	0.36	0.625	7517	6.1	2.7	4.7
STG06	0.3	1.4	0.34	0.673	513	0.7	0.2	0.3
STG07*	4.4	2.5	0.21	1	7517	18.8	1.6	7.5
STG08	5	4.9	0.32	1.665	8542	41.9	2.7	14.2
STG09ab	8.8	1	0.16	0.463	15034	15.0	2.4	7.0
COT02*	6.5	0.93	0.26	0.53	11161	10.4	2.9	5.9
COT04	14.3	1.4	0.29	0.758	24476	34.3	7.1	18.6
COT05	0.6	15	0.32	4.633	1023	15.3	0.3	4.7
COT06	0.4	2	0.38	0.86	757	1.5	0.3	0.7
COT07	2.9**	0.68	0.42	0.54	4889	3.3	2.1	2.6
COT08		0.72	0.46	0.618	4889	3.5	2.2	3.0
COT10	7.9	0.72	0.38	0.537	13464	9.7	5.1	7.2

Table 8: Nitrogen – NH_4^+

Site	Catchment area (ha)	NH_4^+ (mg/L)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.032	0.013	0.023	6150	0.20	0.08	0.14
WAN04	1.3	0.052	0.012	0.032	2221	0.12	0.03	0.07
WAN05	9.9	0.11	0.018	0.064	16913	1.86	0.30	1.07
NST05 (JND02)	9.1	0.039	0.019	0.032	15512	0.60	0.29	0.50
NST04 (JND03)*	15.7	0.13	0.026	0.056	26736	3.48	0.70	1.50
NST03 (JND04)	11.1***	0.19	0.032	0.079	18997	3.61	0.61	1.51
NST01(JND05)		0.17	0.02	0.062	18997	3.23	0.38	1.18
STG01	11.3	0.073	0.005	0.036	19305	1.41	0.10	0.69
STG05	4.4	0.14	0.074	0.119	7517	1.05	0.56	0.89
STG06	0.3	0.11	0.01	0.063	513	0.06	0.01	0.03
STG07*	4.4	0.12	0.051	0.084	7517	0.90	0.38	0.63
STG08	5	0.14	0.023	0.076	8542	1.20	0.20	0.65
STG09ab	8.8	0.078	0.062	0.071	15034	1.17	0.93	1.07
COT02*	6.5	0.12	0.005	0.065	11161	1.34	0.06	0.72
COT04	14.3	0.47	0.035	0.184	24476	11.50	0.86	4.50
COT05	0.6	2.9	0.005	0.839	1023	2.97	0.01	0.86
COT06	0.4	0.31	0.025	0.13	757	0.23	0.02	0.10
COT07	2.9**	0.11	0.025	0.084	4889	0.54	0.12	0.41
COT08		0.37	0.017	0.118	4889	1.81	0.08	0.57
COT10	7.9	0.1	0.015	0.044	13464	1.35	0.20	0.59

Table 9: Phosphorus – TP, pTP

Site	Catchment area (ha)	TP, pTP (mg/L)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.13	0.042	0.086	6150	0.80	0.26	0.53
WAN04	1.3	0.08	0.051	0.066	2221	0.18	0.11	0.15
WAN05	9.9	0.12	0.035	0.07	16913	2.03	0.59	1.18
NST05 (JND02)	9.1	0.089	0.072	0.079	15512	1.38	1.12	1.23
NST04 (JND03)*	15.7	0.12	0.065	0.088	26736	3.21	1.74	2.34
NST03 (JND04)	11.1***	0.32	0.12	0.22	18997	6.08	2.28	4.18
NST01(JND05)		0.13	0.033	0.078	18997	2.47	0.63	1.48
STG01	11.3	0.3	0.044	0.16	19305	5.79	0.85	3.08
STG05	4.4	0.1	0.04	0.069	7517	0.75	0.30	0.52
STG06	0.3	0.099	0.058	0.084	513	0.05	0.03	0.04
STG07*	4.4	0.13	0.045	0.082	7517	0.98	0.34	0.61
STG08	5	0.077	0.05	0.064	8542	0.66	0.43	0.54
STG09ab	8.8	0.17	0.023	0.074	15034	2.56	0.35	1.12
COT02*	6.5	0.082	0.027	0.054	11161	0.92	0.30	0.61
COT04	14.3	0.23	0.064	0.129	24476	5.63	1.57	3.15
COT05	0.6	0.68	0.068	0.267	1023	0.70	0.07	0.27
COT06	0.4	0.12	0.035	0.062	757	0.09	0.03	0.05
COT07	2.9**	0.23	0.038	0.104	4889	1.12	0.19	0.51
COT08		0.52	0.047	0.201	4889	2.54	0.23	0.98
COT10	7.9	0.25	0.037	0.118	13464	3.37	0.50	1.59

Table 10: Phosphorus – sol react

Site	Catchment area (ha)	sol react (mg/L)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.018	0.017	0.018	6150	0.111	0.105	0.108
WAN04	1.3	0.024	0.022	0.023	2221	0.053	0.049	0.051
WAN05	9.9	0.036	0.015	0.027	16913	0.609	0.254	0.448
NST05 (JND02)	9.1	0.029	0.027	0.028	15512	0.450	0.419	0.429
NST04 (JND03)*	15.7	0.032	0.016	0.024	26736	0.856	0.428	0.642
NST03 (JND04)	11.1***	0.085	0.054	0.067	18997	1.615	1.026	1.278
NST01(JND05)		0.03	0.018	0.023	18997	0.570	0.342	0.427
STG01	11.3	0.061	0.018	0.04	19305	1.178	0.347	0.763
STG05	4.4	0.049	0.021	0.034	7517	0.368	0.158	0.254
STG06	0.3	0.027	0.015	0.022	513	0.014	0.008	0.011
STG07*	4.4	0.048	0.018	0.031	7517	0.361	0.135	0.235
STG08	5	0.038	0.012	0.023	8542	0.325	0.103	0.192
STG09ab	8.8	0.046	0.015	0.026	15034	0.692	0.226	0.396
COT02*	6.5	0.12	0.016	0.038	11161	1.339	0.179	0.424
COT04	14.3	0.36	0.027	0.117	24476	8.811	0.661	2.869
COT05	0.6	0.37	0.018	0.167	1023	0.379	0.018	0.171
COT06	0.4	0.062	0.01	0.027	757	0.047	0.008	0.020
COT07	2.9**	0.11	0.025	0.061	4889	0.538	0.122	0.299
COT08		0.45	0.025	0.147	4889	2.200	0.122	0.718
COT10	7.9	0.18	0.02	0.062	13464	2.424	0.269	0.839

Table 11: Total Suspended Solids (TSS)

Site	Catchment area (ha)	TSS (mg/L)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	130	18	74	6150	800	111	455
WAN04	1.3	89	17	53	2221	198	38	118
WAN05	9.9	22	6	15.5	16913	372	101	262
NST05 (JND02)	9.1	39	12	24.3333	15512	605	186	377
NST04 (JND03)*	15.7	60	26	39.5	26736	1604	695	1056
NST03 (JND04)	11.1***	170	19	67	18997	3230	361	1273
NST01(JND05)		66	10	38.75	18997	1254	190	736
STG01	11.3	328	12	166.75	19305	6332	232	3219
STG05	4.4	35	1	18.5	7517	263	8	139
STG06	0.3	494	7	150.25	513	253	4	77
STG07*	4.4	61	1	33	7517	459	8	248
STG08	5	111	21	51	8542	948	179	436
STG09ab	8.8	294	1	99	15034	4420	15	1488
COT02*	6.5	50	13	23.8	11161	558	145	266
COT04	14.3	77	8	32.2	24476	1885	196	788
COT05	0.6	102	14	48	1023	104	14	49
COT06	0.4	36	2	14.75	757	27	2	11
COT07	2.9**	169	7	81	4889	826	34	396
COT08		103	9	35.8	4889	504	44	175
COT10	7.9	303	6	61.6667	13464	4080	81	830

Table 12: Metals - aluminium

Site	Catchment area (ha)	Al (mg/L; LOR=0.005)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	1.3	0.37	0.835	6150	8.0	2.3	5.1
WAN04	1.3	0.8	0.28	0.54	2221	1.8	0.6	1.2
WAN05	9.9	0.35	0.18	0.265	16913	5.9	3.0	4.5
NST05 (JND02)	9.1	0.6	0.29	0.457	15512	9.3	4.5	7.1
NST04 (JND03)*	15.7	0.84	0.66	0.723	26736	22.5	17.6	19.3
NST03 (JND04)	11.1***	1.3	0.45	0.778	18997	24.7	8.5	14.8
NST01(JND05)		0.39	0.15	0.313	18997	7.4	2.8	5.9
STG01	11.3	1.8	0.16	1.015	19305	34.7	3.1	19.6
STG05	4.4	0.71	0.15	0.423	7517	5.3	1.1	3.2
STG06	0.3	1.9	0.28	1.22	513	1.0	0.1	0.6
STG07*	4.4	1.8	0.16	0.945	7517	13.5	1.2	7.1
STG08	5	0.79	0.3	0.533	8542	6.7	2.6	4.5
STG09ab	8.8	2.3	0.092	0.867	15034	34.6	1.4	13.0
COT02*	6.5	0.52	0.2	0.35	11161	5.8	2.2	3.9
COT04	14.3	0.6	0.2	0.47	24476	14.7	4.9	11.5
COT05	0.6	1.3	0.23	0.683	1023	1.3	0.2	0.7
COT06	0.4	0.53	0.21	0.358	757	0.4	0.2	0.3
COT07	2.9**	1.4	0.29	0.723	4889	6.8	1.4	3.5
COT08		1.1	0.39	0.734	4889	5.4	1.9	3.6
COT10	7.9	1.9	0.2	0.65	13464	25.6	2.7	8.8

Table 13: Metals - arsenic

Site	Catchment area (ha)	As (mg/L; LOR=0.005)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	-	-	LOR	6150	-	-	-
WAN04	1.3	-	-	LOR	2221	-	-	-
WAN05	9.9	-	-	LOR	16913	-	-	-
NST05 (JND02)	9.1	-	-	LOR	15512	-	-	-
NST04 (JND03)*	15.7	-	-	LOR	26736	-	-	-
NST03 (JND04)	11.1***	-	-	LOR	18997	-	-	-
NST01(JND05)		-	-	LOR	18997	-	-	-
STG01	11.3	-	-	LOR	19305	-	-	-
STG05	4.4	-	-	LOR	7517	-	-	-
STG06	0.3	-	-	LOR	513	-	-	-
STG07*	4.4	-	-	LOR	7517	-	-	-
STG08	5	-	-	LOR	8542	-	-	-
STG09ab	8.8	-	-	LOR	15034	-	-	-
COT02*	6.5	-	-	LOR	11161	-	-	-
COT04	14.3	-	-	LOR	24476	-	-	-
COT05	0.6	-	-	LOR	1023	-	-	-
COT06	0.4	-	-	LOR	757	-	-	-
COT07	2.9**	-	-	LOR	4889	-	-	-
COT08		-	-	LOR	4889	-	-	-
COT10	7.9	-	-	LOR	13464	-	-	-

Table 14: Metals - cadmium

Site	Catchment area (ha)	Cd (mg/L; LOR=0.002)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	-	-	LOR	6150	-	-	-
WAN04	1.3	-	-	LOR	2221	-	-	-
WAN05	9.9	-	-	LOR	16913	-	-	-
NST05 (JND02)	9.1	-	-	LOR	15512	-	-	-
NST04 (JND03)*	15.7	-	-	LOR	26736	-	-	-
NST03 (JND04)	11.1***	-	-	LOR	18997	-	-	-
NST01(JND05)		-	-	LOR	18997	-	-	-
STG01	11.3	-	-	LOR	19305	-	-	-
STG05	4.4	-	-	LOR	7517	-	-	-
STG06	0.3	-	-	LOR	513	-	-	-
STG07*	4.4	-	-	LOR	7517	-	-	-
STG08	5	-	-	LOR	8542	-	-	-
STG09ab	8.8	-	-	LOR	15034	-	-	-
COT02*	6.5	-	-	LOR	11161	-	-	-
COT04	14.3	-	-	LOR	24476	-	-	-
COT05	0.6	-	-	LOR	1023	-	-	-
COT06	0.4	-	-	LOR	757	-	-	-
COT07	2.9**	-	-	LOR	4889	-	-	-
COT08		-	-	LOR	4889	-	-	-
COT10	7.9	-	-	LOR	13464	-	-	-

Table 15: Metals - chromium

Site	Catchment area (ha)	Cr (mg/L; LOR=0.005)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.006	-	LOR	6150	0.037	-	-
WAN04	1.3	-	-	LOR	2221	-	-	-
WAN05	9.9	-	-	LOR	16913	-	-	-
NST05 (JND02)	9.1	-	-	LOR	15512	-	-	-
NST04 (JND03)*	15.7	0.008	-	LOR	26736	0.214	-	-
NST03 (JND04)	11.1***	0.006	-	LOR	18997	0.114	-	-
NST01(JND05)		-	-	LOR	18997	-	-	-
STG01	11.3	0.014	-	0.007	19305	0.270	-	0.141
STG05	4.4	0.014	-	0.005	7517	0.105	-	0.040
STG06	0.3	0.05	-	0.016	513	0.026	-	0.008
STG07*	4.4	0.009	-	LOR	7517	0.065	-	-
STG08	5	0.006	-	LOR	8542	0.048	-	-
STG09ab	8.8	0.006	-	LOR	15034	0.090	-	-
COT02*	6.5	-	-	LOR	11161	-	-	-
COT04	14.3	-	-	LOR	24476	-	-	-
COT05	0.6	-	-	LOR	1023	-	-	-
COT06	0.4	0.007	-	LOR	757	0.005	-	-
COT07	2.9**	-	-	LOR	4889	-	-	-
COT08		0.007	-	LOR	4889	0.034	-	-
COT10	7.9	0.006	-	0.005	13464	0.081	-	0.063

Table 16: Metals - copper

Site	Catchment area (ha)	Cu (mg/L; LOR=0.005)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.033	LOR	0.018	6150	0.203	-	0.109
WAN04	1.3	0.01	LOR	0.006	2221	0.022	-	0.014
WAN05	9.9	0.012	LOR	0.008	16913	0.203	-	0.133
NST05 (JND02)	9.1	0.016	0.008	0.012	15512	0.248	0.124	0.186
NST04 (JND03)*	15.7	0.02	0.01	0.015	26736	0.535	0.267	0.401
NST03 (JND04)	11.1***	0.024	0.007	0.013	18997	0.456	0.133	0.237
NST01(JND05)		0.013	0.009	0.011	18997	0.247	0.171	0.204
STG01	11.3	0.041	0.007	0.024	19305	0.792	0.135	0.458
STG05	4.4	0.031	0.011	0.021	7517	0.233	0.083	0.160
STG06	0.3	0.023	0.007	0.016	513	0.012	0.004	0.008
STG07*	4.4	0.032	LOR	0.015	7517	0.241	-	0.112
STG08	5	0.02	0.009	0.015	8542	0.171	0.077	0.126
STG09ab	8.8	0.035	LOR	0.016	15034	0.526	-	0.238
COT02*	6.5	0.022	0.011	0.016	11161	0.246	0.123	0.174
COT04	14.3	0.024	0.008	0.015	24476	0.587	0.196	0.357
COT05	0.6	0.081	0.009	0.033	1023	0.083	0.009	0.034
COT06	0.4	0.042	0.01	0.019	757	0.032	0.008	0.015
COT07	2.9**	0.03	0.011	0.017	4889	0.147	0.054	0.082
COT08		0.017	0.013	0.015	4889	0.083	0.064	0.073
COT10	7.9	0.036	0.01	0.019	13464	0.485	0.135	0.254

Table 17: Metals - iron

Site	Catchment area (ha)	Fe (mg/L; LOR=0.005)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.26	0.15	0.205	6150	1.6	0.9	1.3
WAN04	1.3	0.7	0.21	0.455	2221	1.6	0.5	1.0
WAN05	9.9	0.31	0.19	0.243	16913	5.2	3.2	4.1
NST05 (JND02)	9.1	0.54	0.22	0.41	15512	8.4	3.4	6.4
NST04 (JND03)*	15.7	0.5	0.36	0.423	26736	13.4	9.6	11.3
NST03 (JND04)	11.1***	1.4	0.33	0.7	18997	26.6	6.3	13.3
NST01(JND05)		0.33	0.13	0.227	18997	6.3	2.5	4.3
STG01	11.3	1.5	0.16	0.953	19305	29.0	3.1	18.4
STG05	4.4	0.51	0.1	0.3	7517	3.8	0.8	2.3
STG06	0.3	0.93	0.13	0.638	513	0.5	0.1	0.3
STG07*	4.4	0.99	0.038	0.519	7517	7.4	0.3	3.9
STG08	5	0.61	0.18	0.427	8542	5.2	1.5	3.6
STG09ab	8.8	2.3	0.038	0.803	15034	34.6	0.6	12.1
COT02*	6.5	0.5	0.2	0.336	11161	5.6	2.2	3.8
COT04	14.3	0.6	0.21	0.476	24476	14.7	5.1	11.7
COT05	0.6	1.7	0.15	0.773	1023	1.7	0.2	0.8
COT06	0.4	0.6	0.16	0.32	757	0.5	0.1	0.2
COT07	2.9**	1.6	0.24	0.69	4889	7.8	1.2	3.4
COT08		1	0.29	0.524	4889	4.9	1.4	2.6
COT10	7.9	2.4	0.19	0.673	13464	32.3	2.6	9.1

Table 18: Metals - lead

Site	Catchment area (ha)	Pb (mg/L; LOR=0.01)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.014	LOR	0.01	6150	0.086	-	0.058
WAN04	1.3	0.02	LOR	0.013	2221	0.044	-	0.028
WAN05	9.9	-	-	LOR	16913	0.085	-	-
NST05 (JND02)	9.1	0.015	-	LOR	15512	0.233	-	-
NST04 (JND03)*	15.7	-	-	LOR	26736	-	-	-
NST03 (JND04)	11.1***	0.069	LOR	0.022	18997	1.311	-	0.420
NST01(JND05)		0.014	LOR	0.011	18997	0.266	-	0.203
STG01	11.3	0.039	0.023	0.031	19305	0.753	0.444	0.592
STG05	4.4	0.025	LOR	0.012	7517	0.188	-	0.086
STG06	0.3	0.027	LOR	0.014	513	0.014	-	0.007
STG07*	4.4	0.019	LOR	0.011	7517	0.143	-	0.085
STG08	5	0.012	-	LOR	8542	0.103	-	-
STG09ab	8.8	0.029	LOR	0.013	15034	0.436	-	0.195
COT02*	6.5	-	-	LOR	11161	-	-	-
COT04	14.3	0.011	-	LOR	24476	0.269	-	-
COT05	0.6	0.02	LOR	0.011	1023	0.020	-	0.012
COT06	0.4	0.025	LOR	0.01	757	0.019	-	0.008
COT07	2.9**	0.03	LOR	0.015	4889	0.147	-	0.072
COT08		0.024	-	LOR	4889	0.117	-	-
COT10	7.9	0.053	LOR	0.014	13464	0.714	-	0.184

Table 19: Metals - manganese

Site	Catchment area (ha)	Mn (mg/L; LOR=0.001)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.026	0.004	0.015	6150	0.160	0.025	0.092
WAN04	1.3	0.013	0.004	0.009	2221	0.029	0.009	0.019
WAN05	9.9	0.006	0.003	0.005	16913	0.101	0.051	0.076
NST05 (JND02)	9.1	0.007	0.004	0.006	15512	0.109	0.062	0.088
NST04 (JND03)*	15.7	0.007	0.006	0.007	26736	0.187	0.160	0.178
NST03 (JND04)	11.1***	0.024	0.006	0.013	18997	0.456	0.114	0.241
NST01(JND05)		0.009	0.002	0.005	18997	0.171	0.038	0.089
STG01	11.3	0.037	0.002	0.019	19305	0.714	0.039	0.367
STG05	4.4	0.01	0.003	0.007	7517	0.075	0.023	0.053
STG06	0.3	0.018	0.004	0.012	513	0.009	0.002	0.006
STG07*	4.4	0.015	0.001	0.01	7517	0.113	0.008	0.073
STG08	5	0.01	0.004	0.008	8542	0.085	0.034	0.065
STG09ab	8.8	0.059	0.001	0.021	15034	0.887	0.015	0.311
COT02*	6.5	0.01	0.004	0.007	11161	0.112	0.045	0.078
COT04	14.3	0.012	0.01	0.011	24476	0.294	0.245	0.263
COT05	0.6	0.076	0.004	0.027	1023	0.078	0.004	0.028
COT06	0.4	0.032	0.003	0.011	757	0.024	0.002	0.009
COT07	2.9**	0.033	0.004	0.013	4889	0.161	0.020	0.065
COT08		0.019	0.005	0.009	4889	0.093	0.024	0.043
COT10	7.9	0.04	0.004	0.012	13464	0.539	0.054	0.167

Table 20: Metals - mercury

Site	Catchment area (ha)	Ag (mg/L; LOR=0.0001)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	-	-	LOR	6150	-	-	-
WAN04	1.3	-	-	LOR	2221	-	-	-
WAN05	9.9	-	-	LOR	16913	-	-	-
NST05 (JND02)	9.1	-	-	LOR	15512	-	-	-
NST04 (JND03)*	15.7	-	-	LOR	26736	-	-	-
NST03 (JND04)	11.1***	-	-	LOR	18997	-	-	-
NST01(JND05)		-	-	LOR	18997	-	-	-
STG01	11.3	-	-	LOR	19305	-	-	-
STG05	4.4	-	-	LOR	7517	-	-	-
STG06	0.3	-	-	LOR	513	-	-	-
STG07*	4.4	-	-	LOR	7517	-	-	-
STG08	5	-	-	LOR	8542	-	-	-
STG09ab	8.8	-	-	LOR	15034	-	-	-
COT02*	6.5	-	-	LOR	11161	-	-	-
COT04	14.3	-	-	LOR	24476	-	-	-
COT05	0.6	-	-	LOR	1023	-	-	-
COT06	0.4	-	-	LOR	757	-	-	-
COT07	2.9**	-	-	LOR	4889	-	-	-
COT08		-	-	LOR	4889	-	-	-
COT10	7.9	-	-	LOR	13464	-	-	-

Table 21: Metals - nickel

Site	Catchment area (ha)	Ni (mg/L; LOR=0.005)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	-	-	LOR	6150	-	-	-
WAN04	1.3	-	-	LOR	2221	-	-	-
WAN05	9.9	-	-	LOR	16913	-	-	-
NST05 (JND02)	9.1	-	-	LOR	15512	-	-	-
NST04 (JND03)*	15.7	-	-	LOR	26736	-	-	-
NST03 (JND04)	11.1***	-	-	LOR	18997	-	-	-
NST01(JND05)		-	-	LOR	18997	-	-	-
STG01	11.3	-	-	LOR	19305	-	-	-
STG05	4.4	-	-	LOR	7517	-	-	-
STG06	0.3	-	-	LOR	513	-	-	-
STG07*	4.4	-	-	LOR	7517	-	-	-
STG08	5	-	-	LOR	8542	-	-	-
STG09ab	8.8	-	-	LOR	15034	-	-	-
COT02*	6.5	-	-	LOR	11161	-	-	-
COT04	14.3	-	-	LOR	24476	-	-	-
COT05	0.6	-	-	LOR	1023	-	-	-
COT06	0.4	-	-	LOR	757	-	-	-
COT07	2.9**	-	-	LOR	4889	-	-	-
COT08		-	-	LOR	4889	-	-	-
COT10	7.9	-	-	LOR	13464	-	-	-

Table 22: Metals - zinc

Site	Catchment area (ha)	Zn (mg/L; LOR=0.005)			Discharge (m^3/year)	Estimated annual load (kg)		
		Max	Min	Mean		Max	Min	Mean
WAN03	3.6	0.09	0.02	0.053	6150	0.55	0.10	0.33
WAN04	1.3	0.05	0.02	0.035	2221	0.12	0.04	0.08
WAN05	9.9	0.43	0.01	0.131	16913	7.27	0.24	2.21
NST05 (JND02)	9.1	0.06	0.02	0.04	15512	0.88	0.37	0.63
NST04 (JND03)*	15.7	0.05	0.03	0.038	26736	1.20	0.78	1.00
NST03 (JND04)	11.1***	0.11	0.03	0.049	18997	2.09	0.51	0.93
NST01(JND05)		0.03	0.02	0.028	18997	0.63	0.38	0.53
STG01	11.3	0.12	0.01	0.064	19305	2.32	0.25	1.24
STG05	4.4	0.19	0.11	0.163	7517	1.43	0.83	1.22
STG06	0.3	0.11	0.04	0.088	513	0.06	0.02	0.04
STG07*	4.4	0.11	0.01	0.058	7517	0.83	0.05	0.43
STG08	5	0.07	0.03	0.05	8542	0.59	0.28	0.43
STG09ab	8.8	0.17	0.01	0.062	15034	2.56	0.08	0.94
COT02*	6.5	0.11	0.05	0.073	11161	1.23	0.58	0.81
COT04	14.3	0.11	0.04	0.068	24476	2.69	0.86	1.66
COT05	0.6	0.21	0.02	0.086	1023	0.21	0.02	0.09
COT06	0.4	0.16	0.02	0.066	757	0.12	0.02	0.05
COT07	2.9**	0.13	0.02	0.058	4889	0.64	0.09	0.28
COT08		0.07	0.02	0.041	4889	0.32	0.11	0.20
COT10	7.9	0.16	0.03	0.059	13464	2.15	0.36	0.80

Table 23: Contaminate loads discharged from ROC04 for the total time period 12/06/06 to 19/07/06 and 19/08/06 to 30/08/06

Coliforms (organisms/100mL)			Discharge for measurement period (m^3)	Estimated load for measurement period (organisms)		
Max	Min	Mean		Max	Min	Mean
850	320	557	4160	3536	1331	2317

Enterococci (organisms/100mL)			Discharge for measurement period (m^3)	Estimated load for measurement period (organisms)		
Max	Min	Mean		Max	Min	Mean
1200	140	550	4160	4992	582	2288

Total Hydrocarbons (mg/L; LOR=0.250)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
-	-	LOR	4160	-	-	-

BTEX (mg/L; LOR=0.005)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
-	-	LOR	4160	-	-	-

Nitrogen sol ox (mg/L)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
0.27	0.019	0.10933	4160	1.123	0.079	0.455

Nitrogen Total kjel (mg/L)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
0.37	0.27	0.33	4160	1.54	1.12	1.37

Nitrogen TN. pTN (mg/L)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
0.54	0.39	0.44	4160	2.25	1.62	1.83

Nitrogen NH_4^+ (mg/L)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
0.11	0.032	0.06367	4160	0.4576	0.1331	0.2649

Phosphorus TP, pTP (mg/L)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
0.1	0.055	0.74	4160	0.416	0.229	3.078

Phophorus sol react (mg/L)	Discharge for measurement	Estimated load for measurement period (kg)

Max	Min	Mean	period (m^3)	Max	Min	Mean
0.32	0.019	0.024	4160	1.331	0.079	0.100

TSS (mg/L)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
78	11	46	4160	324.48	45.76	191.36

Al (mg/L; LOR=0.005)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
0.57	0.13	0.35	4160	2.371	0.541	1.456

As (mg/L; LOR=0.005)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
-	-	LOR	4160	-	-	-

Cd (mg/L; LOR=0.002)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
-	-	LOR	4160	-	-	-

Cr (mg/L; LOR=0.005)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
-	-	LOR	4160	-	-	-

Cu (mg/L; LOR=0.005)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
0.008	0.006	0.007	4160	0.033	0.025	0.029

Fe (mg/L; LOR=0.005)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
0.69	0.061	0.35	4160	2.870	0.254	1.456

Pb (mg/L; LOR=0.01)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
-	-	LOR	4160	-	-	-

Mn (mg/L; LOR=0.001)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
0.015	0.003	0.008	4160	0.062	0.012	0.033

Ag (mg/L; LOR=0.0001)			Discharge for measurement	Estimated load for measurement period (kg)		

Max	Min	Mean	period (m^3)	Max	Min	Mean
-	-	LOR	4160	-	-	-

Ni (mg/L; LOR=0.005)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
-	-	LOR	4160	-	-	-

Zn (mg/L; LOR=0.005)			Discharge for measurement period (m^3)	Estimated load for measurement period (kg)		
Max	Min	Mean		Max	Min	Mean
0.037	0.017	0.026	4160	0.154	0.071	0.108

* Runoff from the catchment also flows through at least one other drain not included in the study.

** Runoff from the catchment flows through both drains.

*** Runoff from the catchment flows through both drains plus others not included in the study.

Glossary

ANZECC	Australian and New Zealand Environment and Conservation Council.
ARMCANZ	Agricultural and Resource Management Council of Australia and New Zealand.
BTEX	Total measure of Benzene, toluene, ethylbenzene and xylene.
CMD	Carine main drain – City of Stirling. Water Corporation drain.
COT	Cottesloe – stormwater outfall within the Town of Cottesloe.
CRMD	Collins Road main drain – City of Stirling. Water Corporation drain.
EGL	Environmental guideline trigger values (ANZECC & ARMCANZ, 2000)
FRP	Filterable reactive phosphorus is a laboratory measure of the available phosphorus in the water column. It is largely a measure of orthophosphate, the most stable kind of phosphate used by plants. Orthophosphate is produced by natural processes and is found in sewage.
HIL	Health-based investigation level (National Environment Protection, Assessment of Site Contamination, Measure, 1999).
HMD	Herdsman main drain – City of Cambridge. Water Corporation drain.
JND	Joondalup – stormwater outfall within the City of Joondalup.
Kjel	Total Kjeldahl Nitrogen is the organic component of nitrogen plus nitrogen as ammonia in the water sample. It is a calculated measure of nitrogen not readily available in the water column.
LGA	Local government authority.

NH4	Ammonium is an inorganic ion readily available to plants and algae, it is non-toxic. Together with nitrate and nitrate these ions are collectively referred to as Dissolved Inorganic Nitrogen (DIN).
NOx	Dissolved oxidised nitrogen (inorganic ions: Nitrate, NO^{3-} and nitrite, NO^{2-}).Both are readily available to plants and algae (ie. they are bioavailable).
NST	North Stirling – stormwater outfall within the City of Joondalup.
PAH	Polycyclic aromatic hydrocarbons are hydrogen compounds with multiple benzene rings. They are typical components of asphalts, fuels, oils and greases.
RGL	Recreational guideline values (ANZECC & ARMCANZ, 2000).
ROC	Rockingham – stormwater outfall within the City of Rockingham (north facing, Cockburn Sound).
SB	Safety Bay – stormwater outfall within the City of Rockingham (Warnbro Sound, north).
SHL	Shoalwater – stormwater outfall within the City of Rockingham (west facing, Shoalwater Bay).
STG	Stirling – stormwater outfall within the City of Stirling.
TN	Total nitrogen is a laboratory measure of all nitrogen in the water column (nitrate, nitrite, organic nitrogen and ammonia). Sources of nitrogen in stormwater include; fertilisers, industrial cleaning products, animal droppings, fallen leaves and plant debris.
TP	Total phosphorus is a measure of all the phosphorus in the water column either dissolved or particulate and available in a reactive, acid-hydrolysable or organically bound form. Reactive phosphorus is readily available, while organic phosphorus is released only by powerful oxidising agents. Sources of phosphorus include; tree leaves, domestic and agricultural fertilisers, industrial wastes, detergents and lubricants.

TPH	Total petroleum hydrocarbons include a broad family of compounds each with different physical, chemical, environmental and health characteristics. As a group, TPH is defined as the measurable amount of petroleum-based hydrocarbon in an environmental media. As there is no 'best' method for measuring total petroleum contamination comparisons between studies and to environmental quality criteria can be subjective. Sources include gas stations, spilt oil, chemicals.
WAN	Wanneroo – stormwater outfall within the City of Wanneroo.
WK	Waikiki – stormwater outfall within the City of Rockingham (Warnbro sound, south).
WKMD	Waikiki main drain – City of Rockingham. Water Corporation drain.

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Contributors

This report was written by Karen Wheeler and Dr Frances D'Souza with Dr Vanessa Forbes assisting with data (Water Resource Management (WRM) Division).

We acknowledge the kind assistance of the following people in helping us to collect samples: Dieter Tracey, Tracy Calvert, Dominic Heald, Jessica Huybregts, Dr Helen Astill and Emma van Looij (WRM); Kristel Wenziker, Erica Higginson and Brett Dal Pozzo (Swan Catchment Council), David Mort (City of Rockingham) and lastly Lesley Wheeler and Colleen Blackman (volunteers).

We are also grateful to Joel Hall and Luke Riley (WRM) for assistance with the regional maps and data tables and to Dr Jeff Doucette and Janet Oswald for the contaminant loads data.