GOVERNMENT OF WESTERN AUSTRALIA

SWAN RIVER TRUST

NON-NUTRIENT CONTAMINANTS IN THE SWAN CANNING RIVER SYSTEM

SUMMARY PAPER

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Acronyms and symbols

ANZECC.....Australian and New Zealand Environment and Conservation Council

ARMCANZ.....Agriculture and Resource Management Council of Australia and New Zealand

DoW.....Department of Water

ISQGs.....Interim Sediment Quality Guidelines

MoE .....Ministry of Environment

NHMRC .....National Health and Medical Research Council

NMI .....National Measurement Institute

NNCP .....Non-nutrient Contaminants Program

OC .....Organochlorine

OP .....Organophosphorus

PAHs.....Polycyclic aromatic hydrocarbons

PCBs .....Polychlorinated biphenyls

TPHs.....Total petroleum hydrocarbons

EXECUTIVE SUMMARY

The Swan River Trust's Non-nutrient Contaminants Program (NNCP) was a three-year program to determine the nature of contaminants (other than nutrients) delivered to and present in the Swan Canning river system. Non-nutrient contaminants include: pathogens; heavy metals; low-level persistent organic compounds such as pesticides and herbicides; polycyclic aromatic hydrocarbons (PAHs); polychlorinated biphenyls (PCBs) and anionic surfactants; in addition to contaminants resulting from disturbed acid sulphate soils and sediments.

The Department of Water (DoW) undertook the NNCP on the Trust's behalf through a series of assessment studies conducted in the Swan Canning Catchment. These included:

* a baseline study of contaminants in the Swan and Canning catchment drainage system (Nice et al 2009);

* a baseline study of contaminants in groundwater at disused waste disposal sites in the Swan Canning catchment (Evans 2009);

* a baseline study of organic contaminants in the Swan and Canning catchment drainage system using passive sampling devices (Foulsham et al 2009); and

* a baseline study of contaminants in the sediments of the Swan and Canning estuaries (Nice 2009);

This Summary Paper provides an overview of information adapted from two of the four DoW reports (Nice et al 2009; Nice 2009).

The NNCP assessment of contaminants in the drainage system identified and quantified a range of contaminants typical of an urbanised catchment. From this baseline information, sub-catchments of potential concern were identified and prioritised for further investigation.

The groundwater quality study (Evans 2009) investigated bores across three historic landfill sites to broadly characterise the groundwater as a potential source of contamination when assessed against the ANZECC and ARMCANZ guidelines (2000). The study indicated that the groundwater had variable types and concentrations of contaminants present dependent on the type of waste, landfill age and biogeochemical reactions occurring in the groundwater itself. The report indicated a gap in understanding of how the contaminants may impact on the surrounding environment and the high levels of contaminants found in the groundwater were not reflected in the river sediment study.

The passive sampling devices study (Foulsham et al 2009) investigated the use of new technology to detect low levels of specific contaminants in the Swan Canning drainage network and while it is not included in this Summary Report results indicate it to be promising technology.

The NNCP sediment survey assessed 20 sites in the Swan and Canning rivers for metals and other contaminants, and applied Interim Sediment Quality Guidelines (ANZECC and ARMCANZ 2000) to the collected data. Sites were prioritised into three categories based on the number of contaminants that exceeded guidelines and guideline level exceeded.

SECTION 1 SWAN CANNING CATCHMENT DRAINAGE SYSTEM STUDY

During 2006, 77 individual drain sites were assessed in 27 sub-catchments (Figures 1 and 2). Surface water (grab) and surface sediment (core) samples were analysed to test for a comprehensive suite of contaminants and water quality parameters known to be associated with stormwater. These comprised: polycyclic aromatic hydrocarbons (PAHs); total petroleum hydrocarbons (TPHs); polychlorinated biphenyls (PCBs); organochlorine (OC) pesticides; organophosphorus (OP) pesticides; herbicides; anionic surfactants; metals; chromium reducible sulphur suite; microbial parameters (faecal coliforms and enterococci); major ions; and physical parameters. Representative compounds from these parameter groups were selected based on factors such as land uses in the Swan Canning Catchment, known toxicity of compounds to aquatic organisms, persistence of these compounds in the environment and the availability of current laboratory analytical techniques. In addition, nutrient parameters were assessed.

The results were compared across sub-catchments (and individual drains in sub-catchments where appropriate). In addition, where guidelines were available for particular parameters, these were applied to the data. A rationale for the selection of guidelines and their limitations and/or modifications with regard to the current dataset, was provided, although it should be emphasised that guidelines do not exist for stormwater and associated sediments.

Generally, the guidelines applied were conservative, relating to ecosystem health because it was recognised that although samples were collected from a series of drains and associated waterways, these drained into the ecologically sensitive Swan Canning river system. Therefore the use of guidelines in this study was to provide a general frame of reference as to the state of water quality and sediments in the drains. Where the referenced guidelines were exceeded, this does not indicate that “standards” are not being met. It is as an indication that further consideration should be given to the situation, most probably in the form of targeted impact studies in the downstream receiving environment.

Based on the information presented in this baseline study, sub-catchments of potential concern were identified and listed with their associated contaminants in order of priority (Table 1).

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

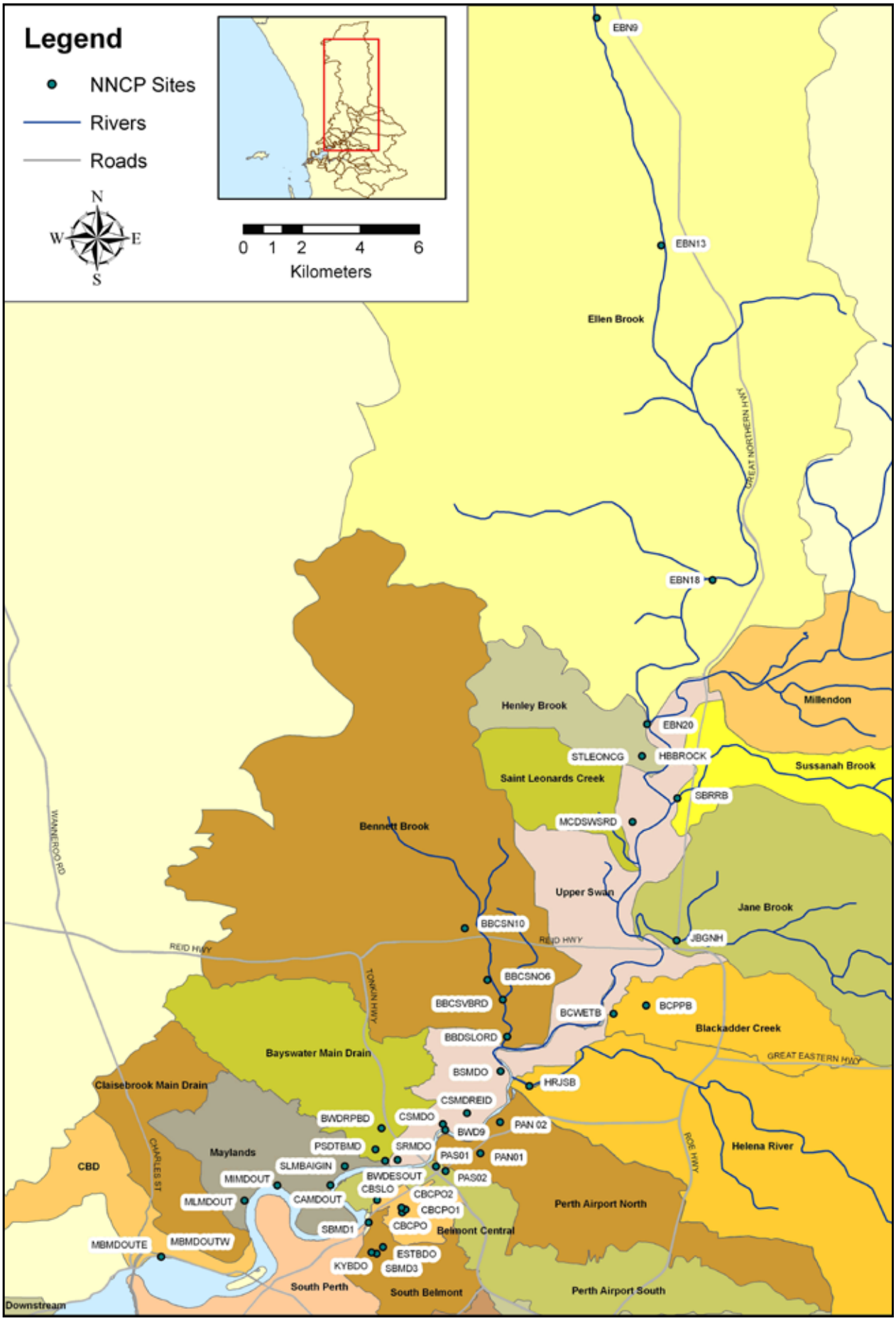

Figure 1 Drain sample sites in the Swan Catchment

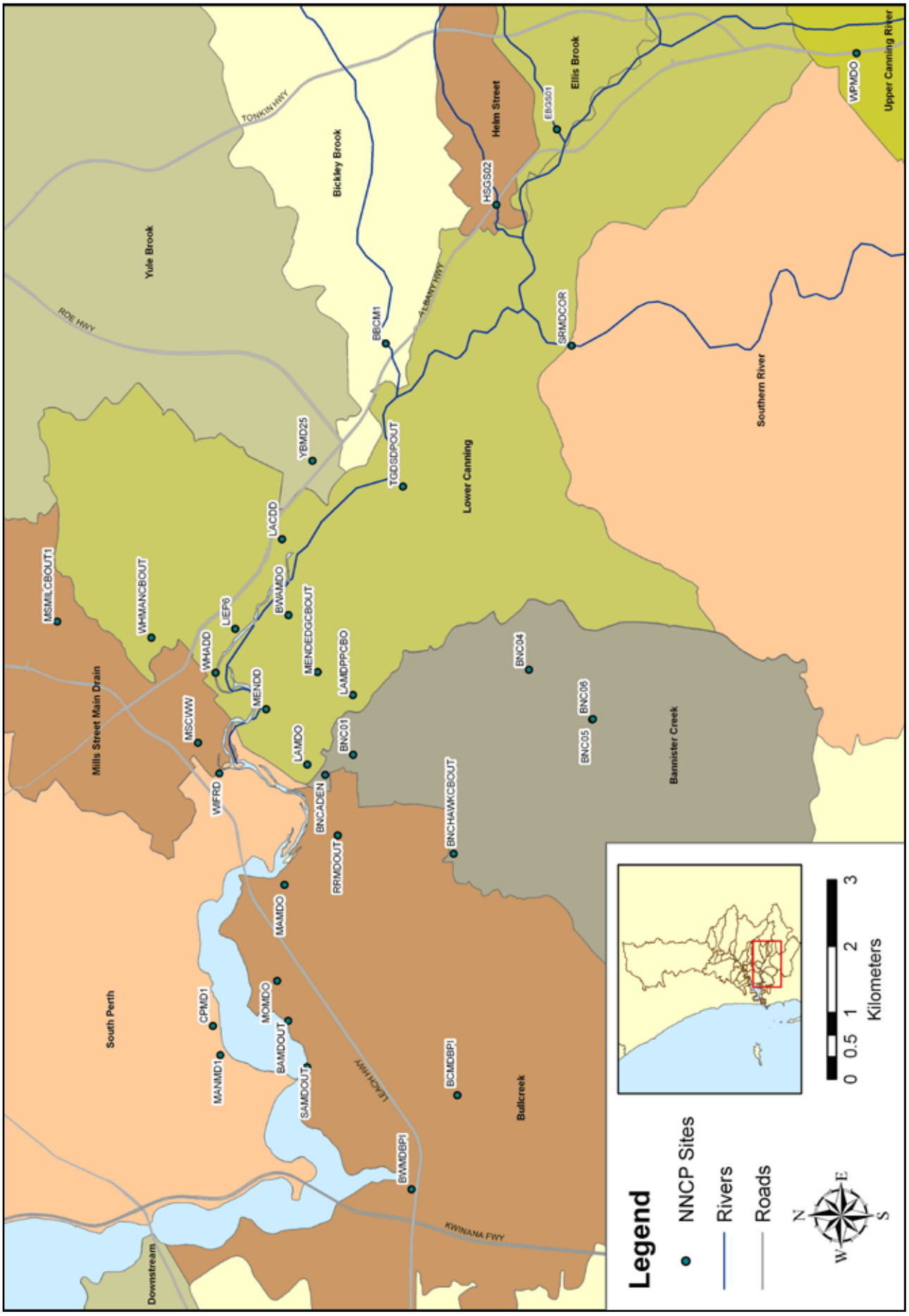

Figure 2 Drain sample sites in the Canning Catchment

Table 1 Prioritisation of sub-catchments based on associated contaminants

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

Note:

a) This prioritisation of sub-catchments was based on the number of variables where guidelines were exceeded and/or where concentrations were consistently high, in addition to the potential for ecological harm based on the type of variable.

b) In addition, microbial levels exceeded guidelines at all sub-catchments.

c) There may be potential issues with metals for all sub-catchments (only the priority metal areas are listed above – those that were consistently high in metal concentrations and consistently exceeded guidelines).

d) Acidification of sediments does not currently appear to be an issue. However, sub-catchments that contain sites that may potentially be of concern if disturbed (and complete oxidation occurred) are: Helena River, Bennett Brook, South Belmont, Central Belmont, Ellen Brook, Blackadder Creek, Lower Canning, Bullcreek, South Perth and Mills Street Main Drain.

On a parameter by parameter basis

Polycyclic aromatic hydrocarbons (PAHs)

PAHs are typical components of asphalts, fuels, oils, greases, creosote and roofing tar and are also formed during the incomplete burning of fuels, garbage or other organic substances. PAHs were typically only found in the sediments of the drains. Individual PAHs consistently exceeded the guidelines applied at the Helena River, Perth Airport South and Central Business District, with occasional exceedances being reported at Blackadder Creek, Maylands, Central Belmont, Bullcreek, Mills Street Main Drain and Lower Canning sub-catchments.

Total petroleum hydrocarbons (TPHs)

TPHs originate from crude oil, are relatively volatile and are most likely to enter the environment as a result of road runoff containing vehicle fuel and oils. These compounds were only detected sporadically, and only in the sediments of sites in the Maylands, Upper Swan, Central Belmont, Bennett Brook, Lower Canning, Mills Street Main Drain, Ellen Brook, Susannah Brook, Bayswater Main Drain and Bullcreek sub-catchments.

Polychlorinated biphenyls (PCBs)

PCBs have had a variety of applications, including fluids for capacitors and transformers, heat transfer fluids, lubricating and cutting oils, additives in pesticides, plastics and reactive flame retardants. A ban on the importation of PCBs has been in place in Australia since 1979 but their presence was investigated in this study because they are highly persistent compounds and are ubiquitous in the environment.

PCBs were not detected in either sediment or surface water samples in this study. However, it was recommended that the non-detect data be treated with caution, as the laboratory limit of reporting was relatively high compared to concentrations of these compounds that are known to cause deleterious effects to environmental health.

Organochlorine (OC) pesticides

OC pesticides are applied to prevent, destroy or repel pests of agriculture, livestock and buildings. Their use has been phased out in Australia but they are often still present in the environment due to their persistent nature.

OC pesticides were more common in sediments than surface water. OC pesticides were detected at the Bayswater Main Drain, Blackadder Creek, Central Belmont Main Drain, South Belmont Main Drain, Helena River, Maylands, Upper Swan, Mills Street Main Drain and Lower Canning sub-catchments. They were consistently above guideline limits (where available). Chlordane and dieldrin were the most frequently reported OC pesticides and Helena River had the highest number of individual OC pesticides detected and typically the highest concentrations.

Organophosphorus (OP) pesticides

Similar to OC pesticides, these compounds are designed to prevent, destroy or repel pests. OP pesticides were not detected in either sediments or surface water in this study. As for PCBs, it was recommended that non-detect data be treated with caution, based on the laboratory limits of reporting.

Herbicides

Herbicides are compounds used to destroy, control or inhibit the growth of plant-based

environmental pests. Herbicides were more commonly found in surface water than sediment samples, although they were only detected in a small proportion of the samples analysed. Herbicides were detected – sporadically present - at the Bayswater Main Drain, Bennett Brook, Blackadder Creek, Central Belmont Main Drain, Helena River, Jane Brook, Maylands, St Leonards Creek, Upper Swan, Bannister Creek, Bickley Brook, Helm Street Main Drain, Lower Canning, Mills Street Main Drain and Yule Brook sub-catchments.

There was an apparent peak in herbicide detections during the August sampling period, perhaps related to the season of application and subsequent runoff due to rainfall. Simazine and atrazine were the most frequently detected herbicides. Herbicides exceeded guideline levels on two occasions only (at the Upper Swan and Yule Brook sub-catchments).

Anionic surfactants

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

Metals

Metals occur naturally in the environment, although the majority of metals in the drain sediments and surface waters are likely to have originated from anthropogenic sources. Metals are found in road runoff containing by-products of fuel and lubricating oil combustion, products of tyre and brake wear and roof runoff. Additionally, atmospheric emissions through oil and coal combustion; and smelting and mining activities can contribute metals to the environment.

On a local scale, there are many small industries in the sub-catchments such as metal plating and auto-repair shops that may be contributing metals directly to the drains.

Of the suite of 14 metals, all were detected in sediment and surface water samples, with the exception of mercury, which was only detected in sediment samples. Generally, the Bayswater Main Drain, Blackadder Creek, Bannister Creek, Mills Street Main Drain and Upper Canning sub-catchments had significantly higher concentrations of metals than other sub-catchments. Additionally, where guideline levels are available, these were exceeded in the sediment at Central Belmont (cadmium, lead and zinc), Upper Swan and Mills Street Main Drain (copper, lead and zinc), Central Business District (copper), Blackadder Creek (lead and zinc) and Helena River, Helm Street, Maylands, Perth Airport South and Lower Canning (lead).

In the surface water, guidelines were exceeded in the majority of sub-catchments (aluminium, iron, zinc and copper), Bayswater Main Drain (chromium, cobalt, and lead), Mills Street Main Drain and Bickley Brook (lead and chromium), Bannister Creek, Bullcreek and South Belmont (chromium) and Upper Swan (cobalt).

Chromium reducible sulphur suite

The chromium reducible sulphur suite is a set of analytical methods conducted to determine the presence of the potential for acid sulphate soils. Acid sulphate soils contain a naturally occurring horizon of sulphidic sediments, which, when disturbed, oxidise and produce sulphuric acid and iron oxides.

Acidification of sediments was not considered to be an issue at any of the sites sampled. However, in general, stored acidity with the potential to be of environmental concern was observed more frequently at sites in sub-catchments draining into the Swan River than the Canning River. Potential

acidity was generally observed in higher concentrations at sites in sub-catchments that drain into the Swan River than the Canning River.

Microbial parameters (faecal coliforms and enterococci)

Faecal coliforms and enterococci are bacterial organisms that are often used as an indicator of faecal pollution in water. They are generally a component of water quality parameters that are used to determine the suitability of a waterbody for recreational purposes. While many of the drainage systems of the Swan Canning system were not designed with that purpose in mind, it was acknowledged that people do use some of these sites for recreational purposes. Therefore, there is the potential for human exposure to these bacteria. Faecal coliforms and enterococci are not exclusive to humans, being produced by all warm-blooded animals. Their presence in the environment may be attributable to a variety of sources including: sewer overflow; septic tanks; faecal matter from piggeries; poultry farms; dairies and stock holding yards; and dog faeces from neighbouring recreational areas.

While human health assessment was outside the scope of this study, faecal coliforms and enterococci were analysed and detected in all sub-catchments and primary contact recreational guidelines were exceeded for either one or both parameter at all sub-catchments. Secondary contact recreational guidelines were also exceeded for either one or both parameters at Blackadder Creek, Central Business District, Helena River, Henley Brook, Maylands, Perth Airport North, Perth Airport South, Bannister Creek, Bickley Brook, Lower Canning, Mills Street Main Drain and Upper Canning.

Major ions

Chloride to sulphate ratios in surface waters of some sub-catchments indicated that an external source of sulphate (possibly from fertiliser use) was potentially entering the system. This occurred at the Bayswater Main Drain, Central Belmont Main Drain, Perth Airport South, South Belmont, Bannister Creek, Bennet Brook, Bickley Brook, Mills Street Main Drain and South Perth sub-catchments. The highest fluoride levels were detected at Helena River, Blackadder Creek and Bayswater Main Drain and high alkalinity was recorded in the Upper Swan and Lower Canning sub-catchments.

Physical parameters

The Perth Metropolitan area experienced the driest year on record in 2006 with annual rainfall of below 470mm compared to the average annual rainfall of 860 mm. Consequently, the drains did not receive the usual flow and concomitant dilution and conversely the usual load of contaminants from runoff events may not have reached the waterways during this period. Concentrations of total suspended solids appeared to be influenced by those rainfall events that did occur (higher suspended solids after rainfall) and were more evident in the agricultural dominated sub-catchments.

Most sub-catchments were in the acceptable range for pH except St Leonards Creek, Susannah Brook and South Perth, each of which, exhibited low pH. Twelve individual drain sites exhibited high electrical conductivity suggesting their water quality may be influenced by estuarine mixing. Dissolved oxygen levels were generally poor in most sub-catchments.

SECTION 2 SWAN CANNING ESTUARY SEDIMENT SURVEY

The Swan and Canning Estuary Sediment Survey was a snapshot study conducted in November 2007. Twenty sites were assessed in the Swan Canning system for metals, organochlorine (OC) pesticides and polycyclic aromatic hydrocarbons (PAHs) bound to the surficial sediments (top 3cm). Sites and contaminants were selected based on information generated from earlier components of the NNCP and other local studies.

Sites in this study were generally located downstream from stormwater drains and/or in the vicinity of disused waste disposal sites that were identified as priority areas in the previous phases of the NNCP (Nice et al 2009).

Contaminants from all three groups were detected in the sediments across the 20 sites. Interim Sediment Quality Guidelines (ISQGs: Low and High Trigger Values - ANZECC and ARMCANZ, 2000) were applied to the data and sites were prioritised into three categories (Priority 1, Priority 2 and Low Priority) based on the number of contaminants that exceeded guidelines and guideline level exceeded. For contaminants where ISQGs have not yet been established, an alternative guideline was sought (and in some cases was also exceeded). Figure 3 shows the spatial distribution of the three priority groups throughout the 20 sites monitored in the Swan Canning river system.

The middle portion of the Swan River comprising sites 9, 10, 11, 12 and 13 was the highest priority area along with sites 17 and 20 in the Canning River (see Figure 3). Of these seven priority 1 sites, site 11 had the greatest number of Interim Sediment Quality Guidelines (ISQGs) exceedances. A list of the contaminants of potential concern at each site is provided in Table 2.

Prioritisation of the 20 sites in this way facilitates management decisions regarding the necessity for further investigation. Recommendations for further investigation have been made following the principles of the ANZECC and ARMCANZ guidelines (2000). These comprise a combination of toxicity and/or in-situ bioaccumulation studies focussing in the first instance on the area around site 11, followed by ecological investigations if deemed relevant. Knowledge gained from the study can be applied to the other priority 1 and 2 sites in a targeted approach, specific to relevant contaminants and organisms.

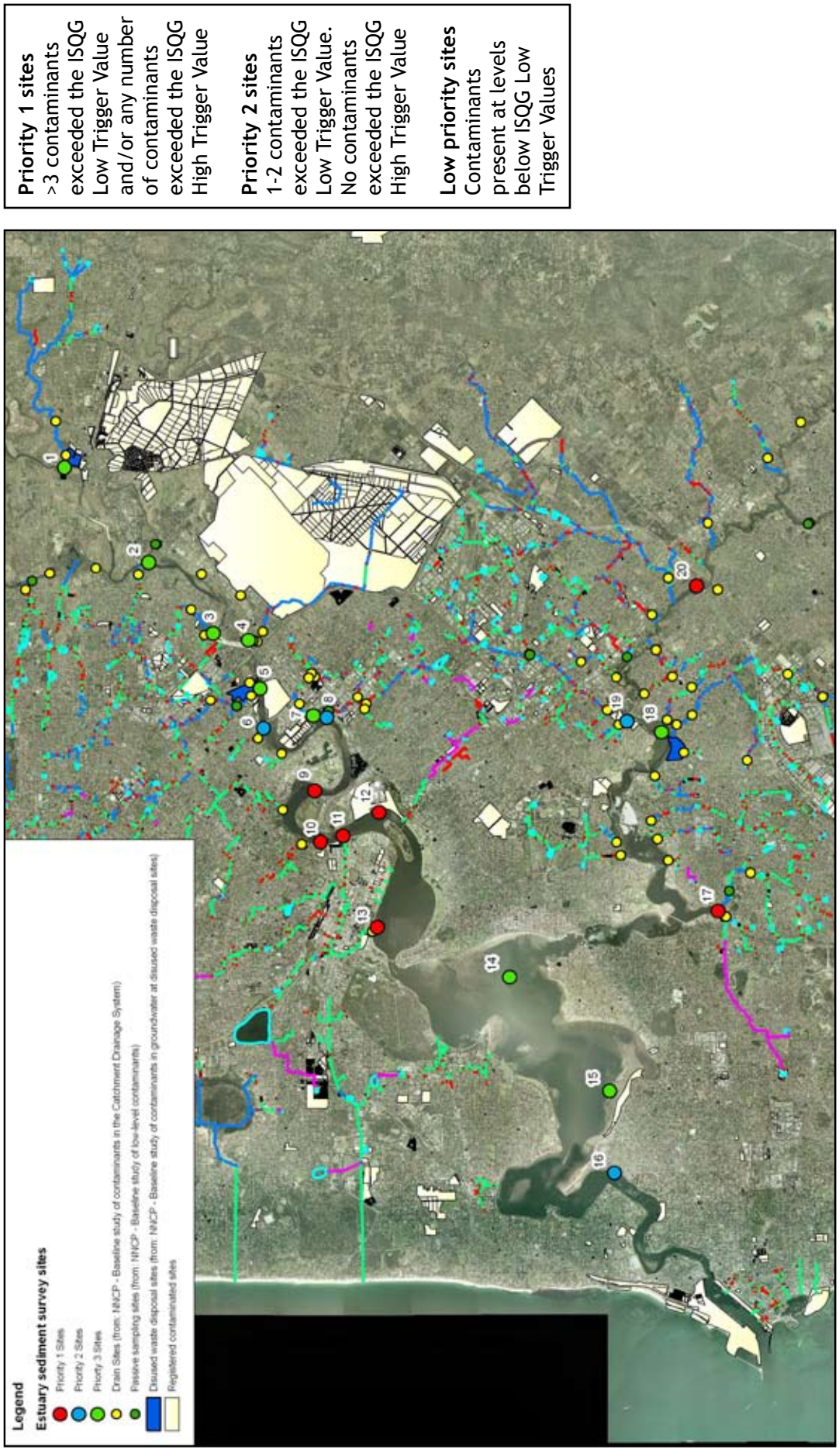

Figure 3 Site prioritisation in the Swan Canning river system

Table 2 Prioritisation of sites for follow up investigation based on contaminants of potential concern

Priority	Site number	Contaminants of potential concern
1	11	zinc*, lead, copper, DDE-p,p, dieldrin
1	10	zinc, lead, DDE-p,p, dieldrin
1	17	zinc, mercury, lead, selenium
1	9	zinc, lead, dieldrin
1	12	zinc, lead, dieldrin
1	20	zinc, lead, selenium
1	13	zinc*, lead
2	16	mercury, lead
2	6	dieldrin, manganese
2	19	zinc, lead
2	8	dieldrin
3	1	contaminants present but not exceeding guidelines (ANZECC and ARMCANZ, 2000)
3	2	
3	3	
3	4	
3	5	
3	7	
3	14	
3	15	
3	18	

* denotes contaminants that exceeded high and low ISQGs

Red indicates Priority 1 sites, where > 3 contaminants exceeded the ISQG Low Trigger Value and/or any number of contaminants exceeded the ISQG High Trigger Value.

Blue indicates Priority 2 sites, where 1-2 contaminants exceeded the ISQG Low Trigger Value (and the alternative guideline value where relevant). No contaminants exceeded the ISQG High Trigger Value.

Green indicates Priority 3 sites, where contaminants were present at levels below ISQG Low Trigger Value (or alternative guideline values where relevant).

SECTION 3 CONCLUSIONS

The suite of investigations conducted in the Non-nutrient Contaminants Program collected baseline data on contaminants with the potential to impact the ecologically sensitive Swan Canning river system.

Drainage network

The first NNCP report identified and quantified a range of surface water and sediment based non-nutrient contaminants in stormwater drains in the Swan Canning river system. The investigation has enabled sub-catchments of concern to be identified based on the types, frequencies and quantities of contaminants found.

Of the non-nutrient contaminants examined in this study, those most likely to exist in the sediments of the Swan Canning Catchment drainage system are PAHs, petroleum hydrocarbons and OC Pesticides. Those most likely to exist in the surface water are: microbial parameters (faecal coliforms and enterococci); and herbicides and anionic surfactants. Metals were consistently detected in water and sediments (with the exception of mercury that was only detected in the sediments).

River sediments

A second study aimed to determine the nature of non-nutrient contaminants present in the sediments of the Swan Canning river system. The sites assessed targeted areas adjacent to landfill and high priority drainage sites. Contaminants were detected at all sites, with ISQGs for some contaminants (ANZECC and ARMCANZ 2000) exceeded at some sites. Based on the parameters assessed, contamination appeared more pronounced in the middle section of the Swan River with site 11 having the greatest number of ISQG exceedances.

The contaminants detected in the Swan Canning sediments were not unusual when compared with other cities (Birch and Taylor 1999; McCready et al 2004; McCready et al 2006).

Future biological assessment

Based on the information gained from this study, subsequent research will assess organism response to these contaminants. A range of ecotoxicological and ecological studies is appropriate. The NNCP reports recommended careful consideration of the type of future biological assessment selected.

By incorporating ecological, ecotoxicological and chemical studies in an assessment of the impacts of non-nutrient contaminants (Figure 4) on the Swan Canning river system, a “weight-of-evidence” approach can be applied, the underlying principle of which is that multiple lines of evidence reduce uncertainty in impact assessments (Chapman et al 1997).

Human health implications

The primary objective of the NNCP was to determine the nature (types, concentrations and spatial variability) of non-nutrient contaminants delivered to and present in the Swan Canning river system. The NNCP was not intended as an investigation into human health implications of contaminants, but rather a baseline study of contamination in the drains, selected disused waste facilities and estuarine sediments of the Swan Canning river system.

The Swan River Trust has consulted the Department of Health regarding the findings of this study and the implications for recreational activity in these areas of the river system.

The Swan and Canning rivers are regularly monitored for microbial contaminants during the bathing

season (November to April) by the Environmental Health Directorate of the Department of Health of Western Australia. Further information about this program can be accessed from their website: http://www.healthyswimming.health.wa.gov.au.

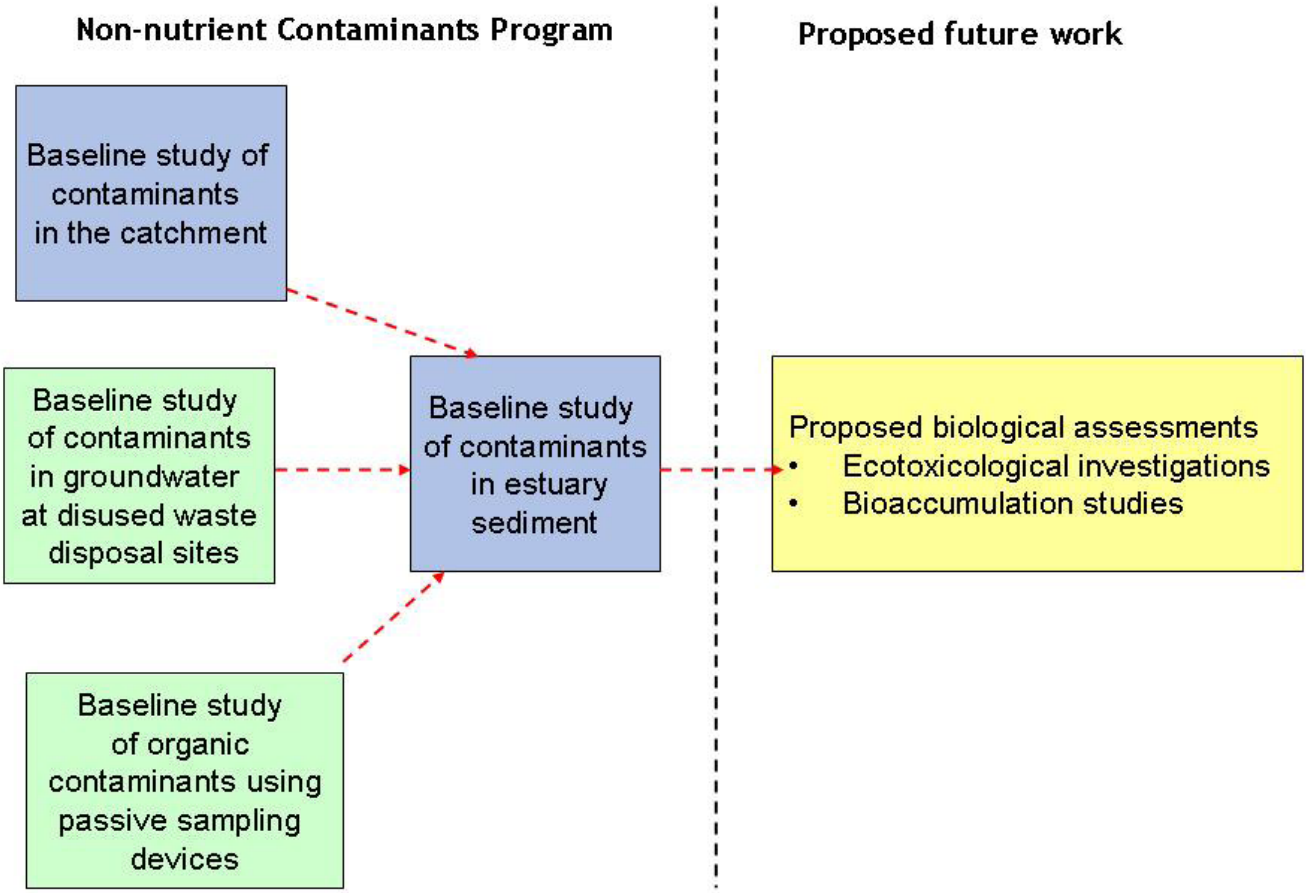

Figure 4 Multiple lines of evidence to determine the impact of contaminants on the Swan Canning river system

REFERENCES

ANZECC and ARMCANZ 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, Australia and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand.

Birch, G & Taylor, S 1999, 'Source of heavy metals in sediments of the Port Jackson estuary, Australia' *The Science of the Total Environment,* vol. 227, pp. 123-138.

Chapman, PM, Anderson, BS, Carr, RS, Engle, V, Haverland, P, Hameedi, J, Hyland, J, Ingersoll, C, Long, E, Rodgers, J, Sibley, S, Smith, P, Swartz, R, Thompson, B, & Windom, H 1997, 'General guidelines for using the Sediment Quality Triad (SQT)*' Marine Pollution Bulletin,* vol. 34, pp. 368-372.

Evans, S 2009, *A baseline study of contaminants in groundwater at disused waste disposal sites in the Swan Canning catchment*, Department of Water Report to Swan River Trust.

Foulsham, G, Nice, HE, Fisher, S, Mueller, J, Bartkow, M & Komorova, T 2009, *A baseline study of organic contaminants in the Swan and Canning catchment drainage system using passive sampling devices*, Department of Water report to Swan River Trust.

McCready, S, Spyrakis G et al 2004, 'Toxicity of surficial sediments from Sydney Harbour and vicinity, Australia' *Environmental Monitoring and Assessment,* vol. 96, pp. 53-86.

McCready, S, Birch, GF et al 2006, 'Metallic and organic contaminants in sediments of Sydney Harbour, Australia and vicinity - a chemical dataset for evaluating sediment quality guidelines' *Environment International,* vol. 32, pp. 455-465.

Ministry of Environment, Government of British Columbia 2006, *British Columbia Approved Water Quality Guidelines*, viewed January 2008, <http://www.env.gov.bc.ca/wat/wq/BCguidelines/approv_wq_guide/approved.html>.

Nice, HE 2009 *A baseline study of contaminants in the sediments of the Swan and Canning estuaries*, Department of Water report to Swan River Trust.

Nice, HE, Grassi, M, Foulsham, G, Morgan, B, Evans, SJ & Robb, M 2009, *A baseline study of contaminants in the Swan and Canning catchment drainage system*, Department of Water report to Swan River Trust.

National Health and Medical Research Council 2008, *Guidelines for Managing Risks in Recreational Water*.

Wakida, FT & Lerner, DN 2005, 'Non-agricultural sources of groundwater nitrate: a review and case study' *Water Research*, vol. 39, pp. 3-16.

Westbrook, SJ, Rayner, JL, Davis, GB, Clement, TP, Bjerg, PL & Fisher, SJ 2005, 'Interaction between shallow groundwater, saline surface water and contaminant discharge at seasonally and tidally forced estuarine boundary', *Journal of Hydrology*, vol. 302, pp. 255-269.

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