GOVERNMENT OF WESTERN AUSTRALIA

SWAN RIVER TRUST

# Claisebrook in the Swan Estuary, Western Australia

## A synthesis of environmental information and historical retrospective

November 2013



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## *A synthesis of environmental information and historical retrospective*

Department of Water Technical Report prepared for the Swan River Trust

November 2013

**Swan River Trust**
Level 1, Fortescue Centre
20 Terrace Road
East Perth
Western Australia 6004

Telephone +61 8 9278 0900
Facsimile +61 8 9325 7149

www.swanrivertrust.wa.gov.au

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Cover: Historic image of East Perth Gasworks (source unknown).

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*Swan River Trust*

The Swan River Trust commissioned the Department of Water to undertake this investigation as part of Phase III of the Non-Nutrient Contaminant Program (NNCP).

*Department of Water*

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# 1. Introduction

Claisebrook is located within the suburb of East Perth on the Swan Estuary, Western Australia. It currently comprises mainly commercial properties, domestic dwellings and recreational areas (Claisebrook Village), which have been developed around a modified waterway known as Claisebrook Cove (Figure 1).

The Water Science Branch of the Department of Water (DoW), on behalf of the Swan River Trust (SRT), conducted a series of investigations between 2010 and 2013 examining the contamination within Claisebrook Cove and the adjacent Swan Estuary (Nice 2013a, Nice 2013b, Nice and Fisher 2011, Fisher 2013a). These studies were conducted in response to an earlier investigation of the Swan and Canning river and estuary system (Nice 2009) whereupon the Claisebrook area of the estuary was shown to be the highest priority of a number of locations based on types and concentrations of contaminants present in the sediments (Figure 2). Contaminant data also exists from investigations conducted in relation to the development of the site during the 1990s and ongoing compliance monitoring (Appendix 1, Data Sources).

This report presents the current status of contamination of the Swan Estuary in the vicinity of Claisebrook and assesses the associated potential causes in order to direct future management. In elucidating possible causes of the contamination in the Claisebrook area, it is important to first consider the history of the area. An historical retrospective of land use and associated management is presented in the following section.


Figure 1 Claisebrook Cove on the Swan Estuary.

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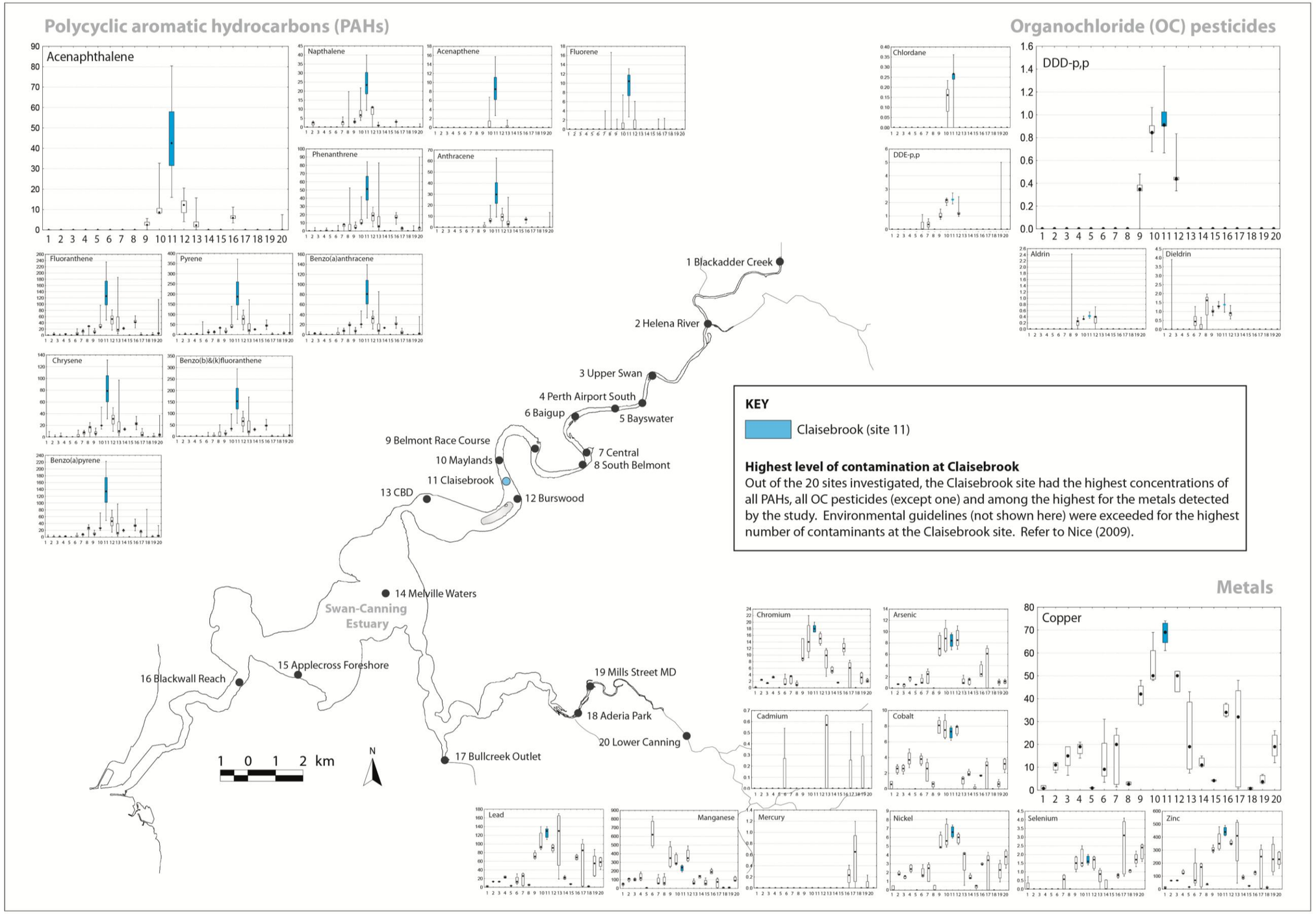


Figure 2 Contaminants assessed in the sediments at 20 sites in the Swan and Canning river and estuary system (data from Nice 2009).

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# 2. The history of Claisebrook and the surrounding area

**Pre-1830s**

The waterways currently known as Claisebrook Drain and Claisebrook Cove were first named in 1827 after naval surgeon Frederick Clause who was present on Captain James Stirling's expedition of the Swan River (Hay 1906). At this time Claisebrook drain was known as Clauses's Brook (a freshwater stream) and the area now occupied by Claisebrook Cove was named Clause's Lagoon (Figure 3).

Figure 3 Black Swans in Clause's Lagoon (Claisebrook Catchment Group 2013).

During the 1800s, Clause's Brook was a seasonal waterway, which was typically dry in summer and flowing in winter. Numerous interconnected freshwater lakes drained into the Swan River via Clause's Brook (Seddon 2004) (Figure 4).

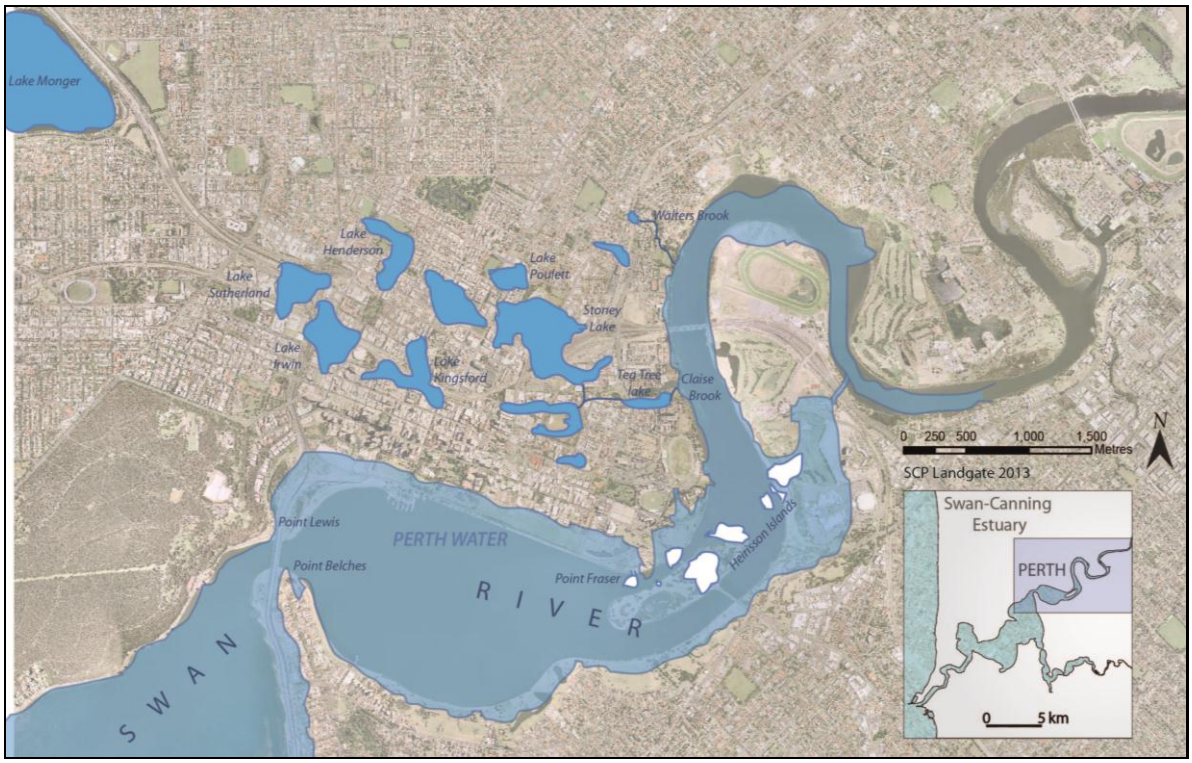



Figure 4 Freshwater lake system (1800s) superimposed on a present-day map (2013) draining to the Swan Estuary via Clause's Brook, later known as Claise Brook (position of lakes sourced from Seddon 2004).

**1830s – 1880s**

During the 1830s, a canal was cut through Burswood Peninsula (located across the estuary from Clause's Brook) to enable easier access to areas further upstream (Figure 5), thus creating Burswood Island. Between the 1830s and the 1850s Clause's Brook was increasingly referred to as Claise Brook (e.g. The Perth Gazette and Independent Journal of Politics and News 1851).

During the period, 1832 to 1880, land was reclaimed over the feeder lakes of Claise Brook, resulting in the drainage system becoming mainly underground and enabling the development of East Perth (Seddon 2004).

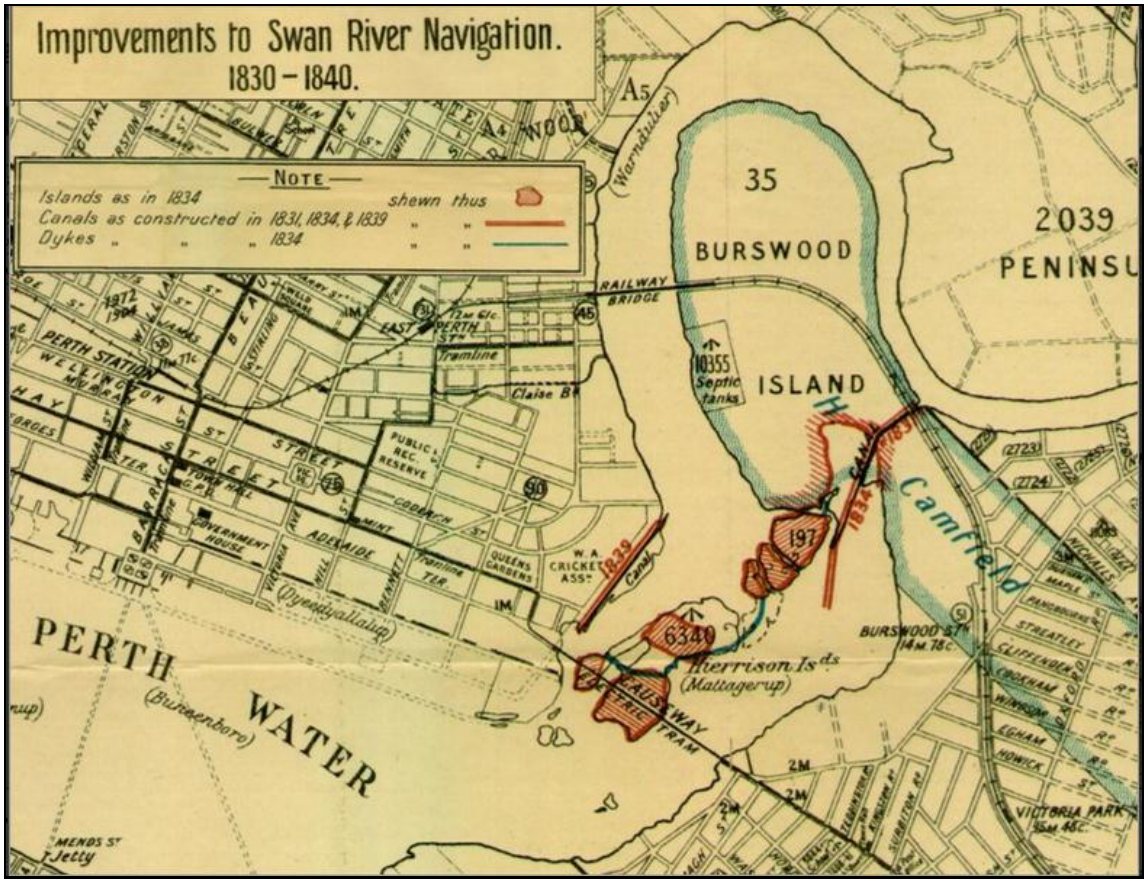



Figure 5 Sketch of Burswood Estate and the Peninsula, belonging to H. Camfield Esq., Swan River, Western Australia (source: State Library of Western Australia 2013a).

**Late 1800s through to early 1900s**

Burswood Island was developed for recreational activity, including the Burswood Golf Course (1895); and Burswood Race Course (1899), which later became Belmont Park Race Course (1902). Claise Brook was used as the main effluent outlet of Perth to the Swan River; and until a sewage treatment facility was built on Burswood Island in 1906, Claise Brook was often referred to as the 'main sewer of Perth, the site of the septic-tank treatment of sewage' (The West Australian 1906; Hay, 1906).

**1900s through to 1980s**

The land use in the area around Claise Brook was mainly industrial. During this period Claise Brook became known as Claisebrook Drain. The Claisebrook Drain ran north of the Perth central business district, carrying drainage from a variety of land uses, the most significant of which was the East Perth Gasworks; and others included the East Perth railway yards and workshops (Seddon

2004), and a concrete plant (Conacher 2000). The East Perth Power Station (Figure 6), while not discharging to Claisebrook Drain, was also a significant industry in the area, being located immediately upstream from the East Perth Gasworks site on the Swan Estuary.

Across the estuary, light industry was developed through the 1900s, with Burswood Island sustaining a variety of land uses over time. These included its use as an industrial waste tip, a cinder dump and a nightsoil and sewage dump. In 1998 Burswood soil was reported as contaminated with asbestos from a former industrial site operating between 1920 and 1981 and cement kiln dust and hydrocarbons from another site in operation since 1927 (EPA 1998).

The East Perth Power Station (Figure 6), located approximately 200 m upstream from Claisebrook Drain began operating in 1916 and was decommissioned in 1980. During its operation, it provided electricity to the Perth Metropolitan area (Layman 2011).

Figure 6 East Perth Power Station c. 1935 (State Library of Western Australia 2013b. Photographer: Stuart Gore).

The East Perth Gasworks (top right hand corner of Figure 6; and Figure 7 to Figure 9) was commissioned in 1922 and ceased operations in 1971 (EPA 1992a). The function of the gasworks was the conversion of coal to town gas (a fuel for lighting, cooking and heating) for the city of Perth (Western Mail 1923).

The gasworks site became the services depot for the State Energy Commission of WA (SECWA) during the 1980s. A contaminant assessment of the site was commenced by SECWA in 1989.

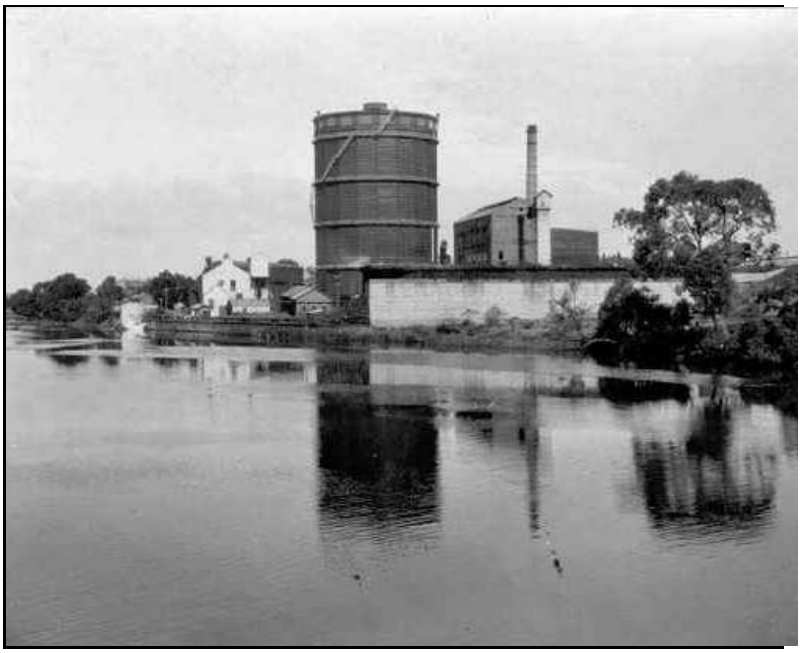


Figure 7 East Perth Gasworks c. 1933 (State Library of Western Australia 2013c. Photographer unknown).

Figure 8 Burswood and East Perth Gasworks c. 1935 (State Library of Western Australia 2013d. Photographer: Stuart Gore).

Figure 9 Aerial view of East Perth Gasworks c. 1968 (Metropolitan Redevelopment Authority 2013a).

**1990s**

Acknowledging the East Perth Gasworks site was extensively contaminated (Camp Scott Furphy and Golder Associates 1990), a proposal to remediate the area was referred to the Environmental Protection Authority (EPA) in 1990. The proponent for the project was SECWA.

In February 1992, the adjacent Claisebrook Drain and Swan Estuary were also reported as extensively contaminated by coal tar and coal tar derivatives including a broad range of carcinogenic and toxic compounds such as polycyclic aromatic hydrocarbons (PAHs) in an Environmental Assessment of the area (Bowman Bishaw Gorham 1992). In March 1992, SECWA released a Public Environmental Review document describing the extent of the contamination and proposed remediation measures (Camp Scott Furphy 1992). In October 1992, the East Perth Gasworks site and adjacent waterways were regarded as a seriously contaminated industrial site by the EPA (EPA 1992a), which released a report and recommendations on the proposal in the same month (EPA 1992b).

In the estuary, the contaminated zone (Figure 10) extended from approximately 50 m north to 250 m south of the gasworks site. The depth of the contaminated sediment was reported as greater than 2.5 m in the centre of the contaminated zone. It was noted that the distribution of the contaminated estuary sediments clearly implicated the gasworks site as the primary source of contamination (Bowman Bishaw Gorham 1993, 1992).

By 1994, the East Perth Redevelopment Authority (EPRA) had acquired the site from SECWA and become responsible for the remediation of the site and the adjacent waterways (Tingay 1994a) in accordance with the environmental conditions set for the project by the Minister for Environment (*Contamination Management Strategy for the East Perth Gasworks Site and Adjacent Areas of the Swan River, 636* – Minister for the Environment 1994) and (*East Perth project, Claisebrook Inlet, 698* – Minister for the Environment 1995).

As part of the Minister's conditions, three Environmental Management Programs (EMPs) were developed on behalf of EPRA: *Swan River Remediation East Perth Gasworks EMP* (Tingay and Associates 1994a)*; Containment Strategy East Perth Gasworks Site EMP* (Tingay and Associates 1994b); and *Remediation of Former Gasworks Site at East Perth EMP* (Camp Scott Furphy 1994).

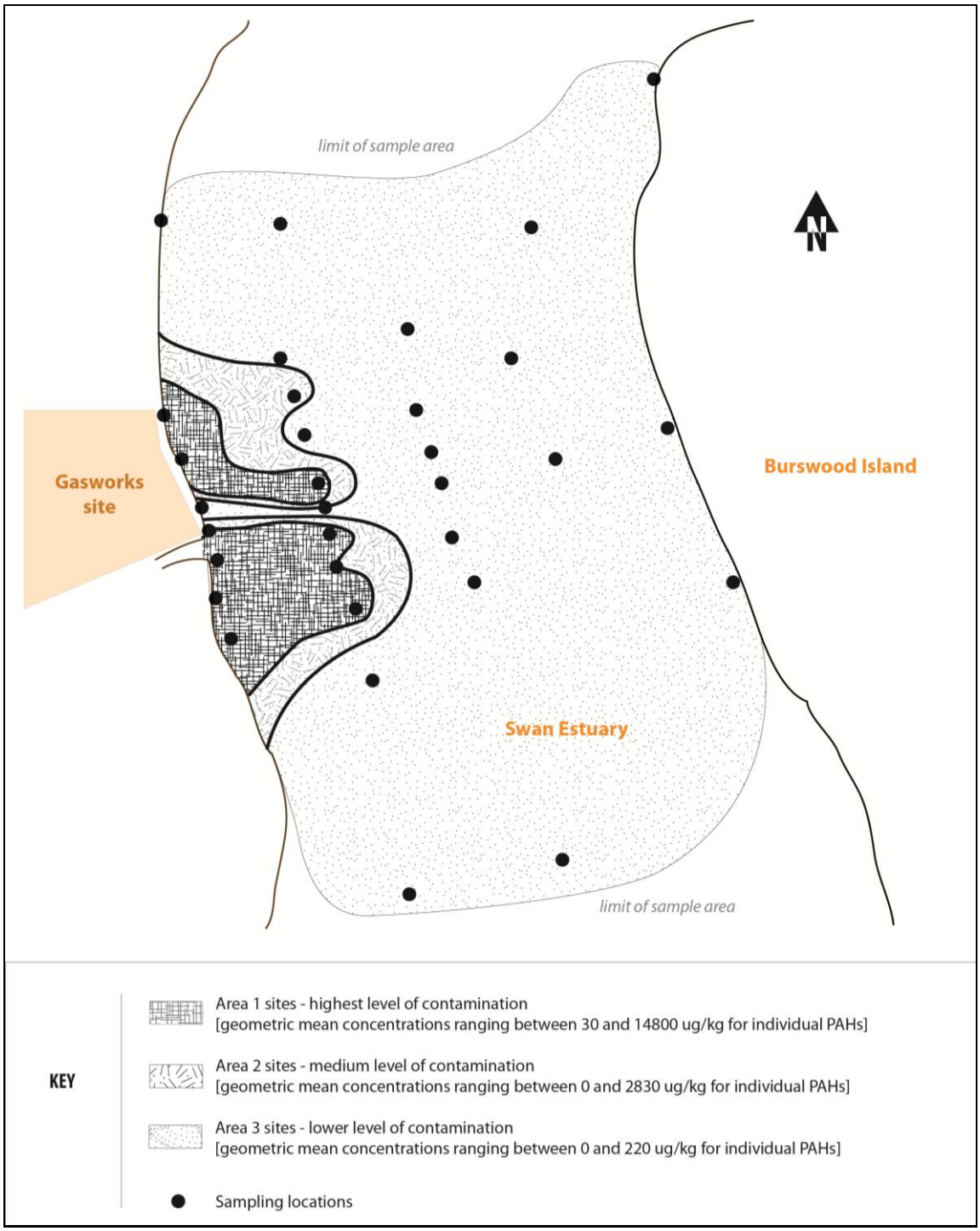



Figure 10 Distribution of PAH contamination in surface sediments of the Swan Estuary (modified from Bowman Bishaw Gorham 1992).

The EPRA conducted extensive remediation between October 1994 and July 1995. Remediation of the Swan River and containment of onsite contamination were completed in October 1994. Remediation of the gasworks site was completed in July 1995 (Camp Scott Furphy 1997). The remedial strategy is discussed in detail in Section 3.

The site was subsequently redeveloped (Figure 11) to create an artificial canal-type waterway (Claisebrook Cove) at the outlet of the Claisebrook Drain (Figure 12 and Figure 13). The resulting waterway is surrounded by Claisebrook Village (present time) comprising both domestic (1 450 homes) and retail properties (East Perth Redevelopment Authority 2009) (Figure 13).

A summary timeline of the key events in the history of Claisebrook and aerial photographs of the area between 1953 and 2013 are provided in Figure 14 and Figure 15.

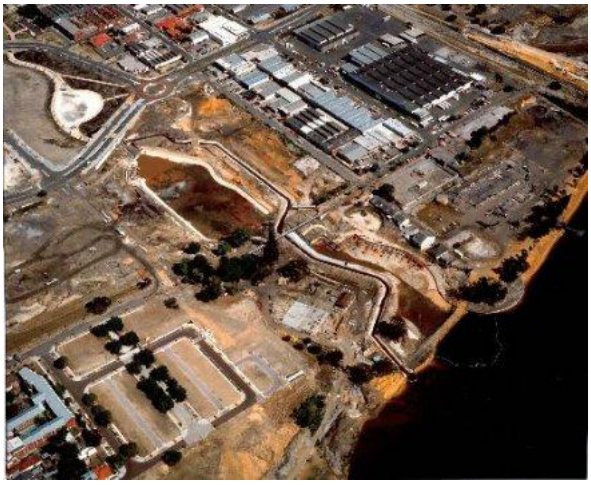


Figure 11 East Perth Gasworks site under development prior to the excavation of the Claisebrook Cove - mid 1990s (Metropolitan Redevelopment Authority 2013b).

Figure 12 East Perth Gasworks site under development post excavation of Claisebrook Cove - mid 1990s (Brookfield Multiplex 2013).

Figure 13 Claisebrook Cove and the Swan Estuary following development, 2002. (*Unpublished.* Photographer: D. Tracy, Department of Environment 2002).

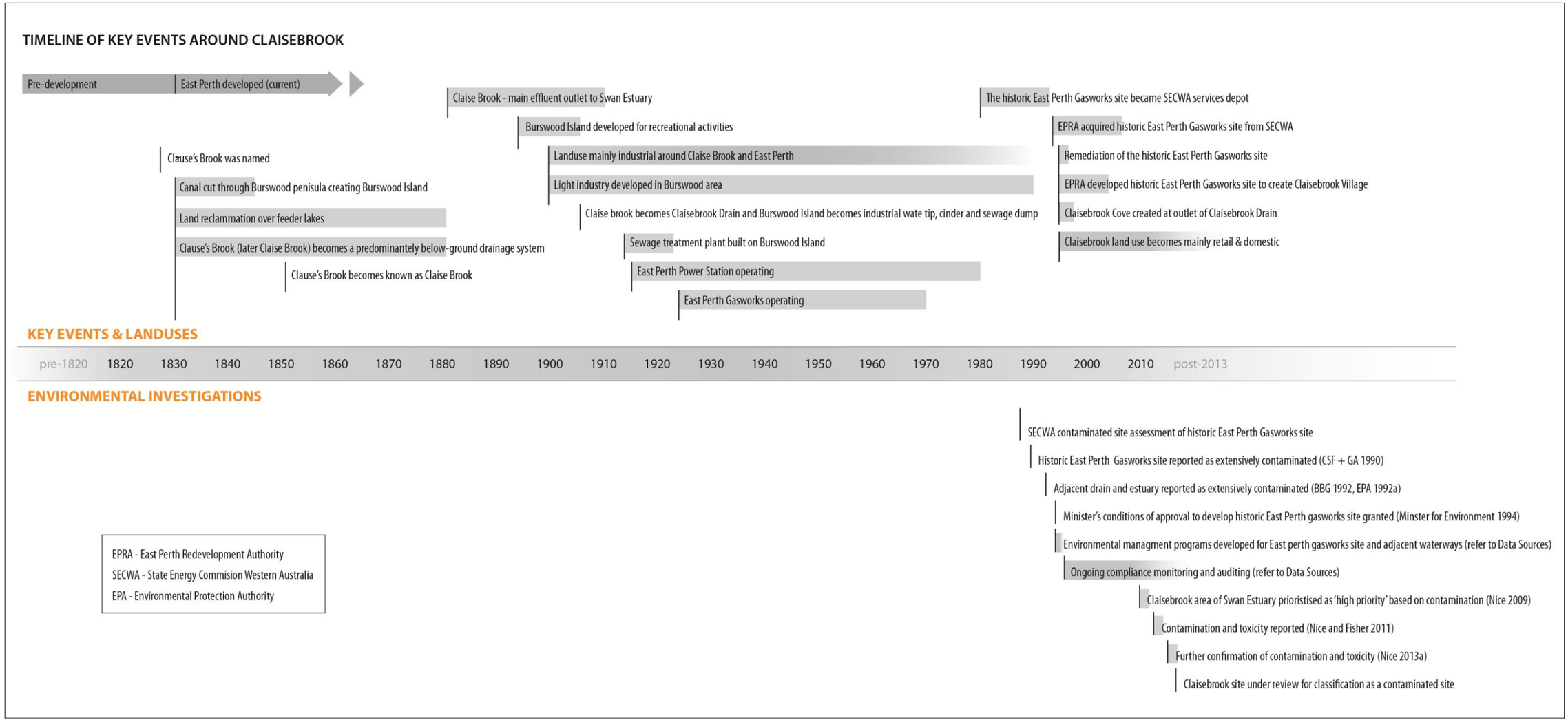



Figure 14 Timeline of key events in the Claisebrook area.

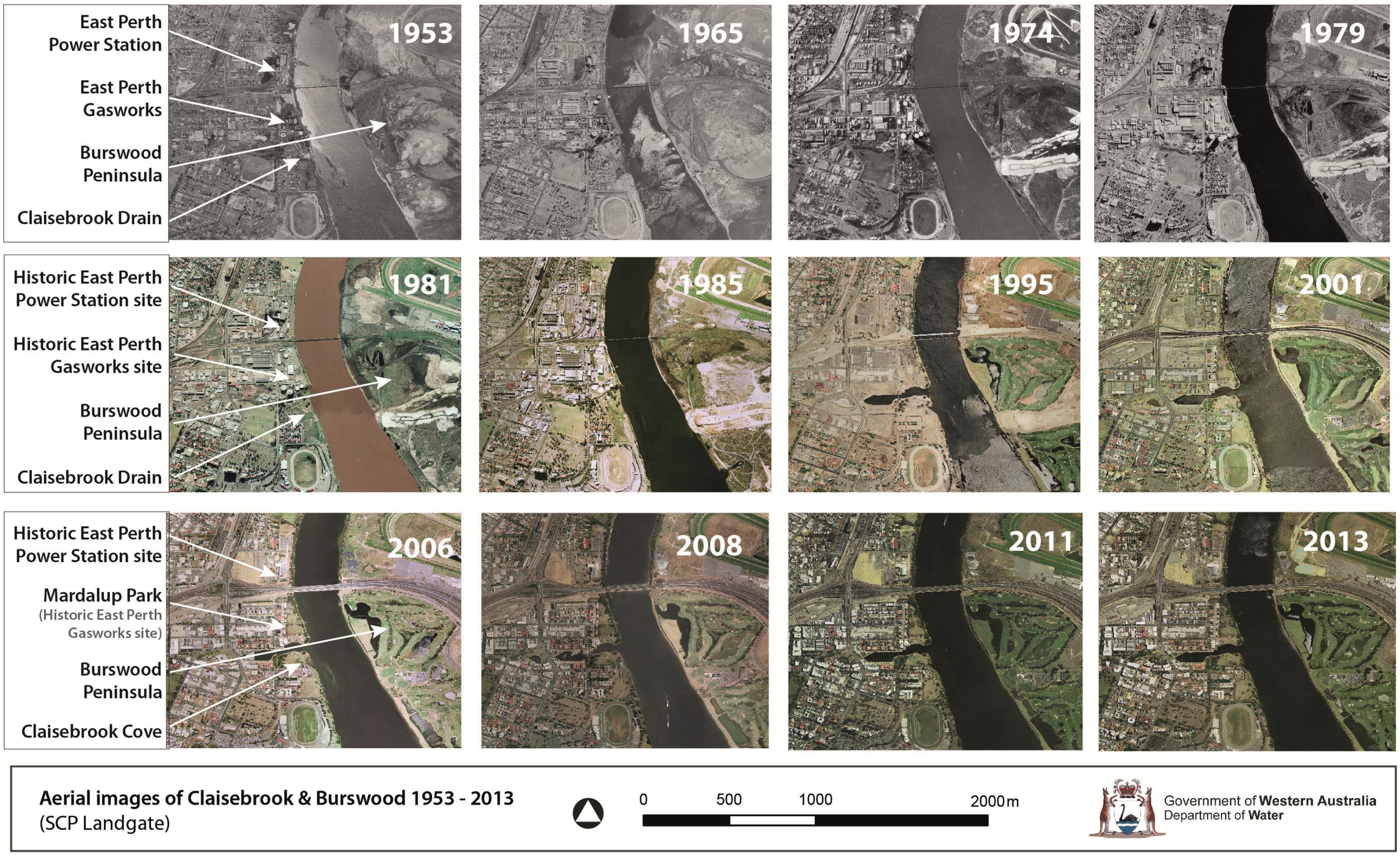



Figure 15 Aerial photographs of the Claisebrook area between 1953 and 2013.

# 3. The remedial strategy for the East Perth Gasworks site and adjacent Swan Estuary (1994 - 1995)

The remedial strategy involved the removal of contaminated material from the waterways and the containment of this and other contaminated material from the gasworks site within the site itself.

## 3.1 Removal of contaminated sediments from the Swan Estuary and Claisebrook Drain

Between April and October 1994, approximately 13 000 $m^3$ of PAH-contaminated sediment was dredged from the Swan Estuary (target depth of 1 m +/- 0.1 m below the existing estuary bed level). A further 12 000 $m^3$ (approximately) of sediment was removed from the mouth of the drain to create the entrance channel for Claisebrook Cove – the Claisebrook Inlet, with a target depth of approximately 2.5 m below the existing estuary bed level (Camp Scott Furphy 1996a). The position and extent of the remediation zone are shown in Figure 16.

Sediments were dredged using the cutter suction technique and the dredge-spoil (slurry of approximately 80% water and 20% sediment) was pumped to a series of settlement ponds located in the northern section of the gasworks site. The water from the settlement ponds was discharged to a limestone bunded area and the water passed through a silt curtain prior to discharge to the estuary to prevent the spread of contaminated sediments to the estuary. Sediments were excavated from the ponds and stored temporarily on the adjacent Public Works Department site (Figure 16). Following excavation of the gasworks site the excavated estuary and inlet sediments were spread as a continuous layer over the gasworks site as part of the installation of a capping layer (Camp Scott Furphy 1996a) discussed in detail in Section 3.2.

Contaminated sediments were also removed from the foreshore and bed of the Claisebrook Drain by excavator as part of the construction of Claisebrook Cove (Figure 17 and Figure 18). Due to the presence of high levels of contamination, a minor part of the inlet near the mouth was excavated to 1 m below its original design depth and backfilled with clean quartz sand from a Gnangara quarry to the required finished level. Clean quartz sand from Gnangara was also used to backfill the dredged area of the estuary, generally to a depth of 1 m (Camp Scott Furphy 1996a). Figure 19 shows the change in form of Claisebrook Drain before and after excavation.


Figure 16 Swan Estuary Remediation: extent of remediation zone. Recreated from information sourced in the Remedial Strategy for the East Perth Gasworks and Swan River (East Perth Redevelopment Authority 1993).

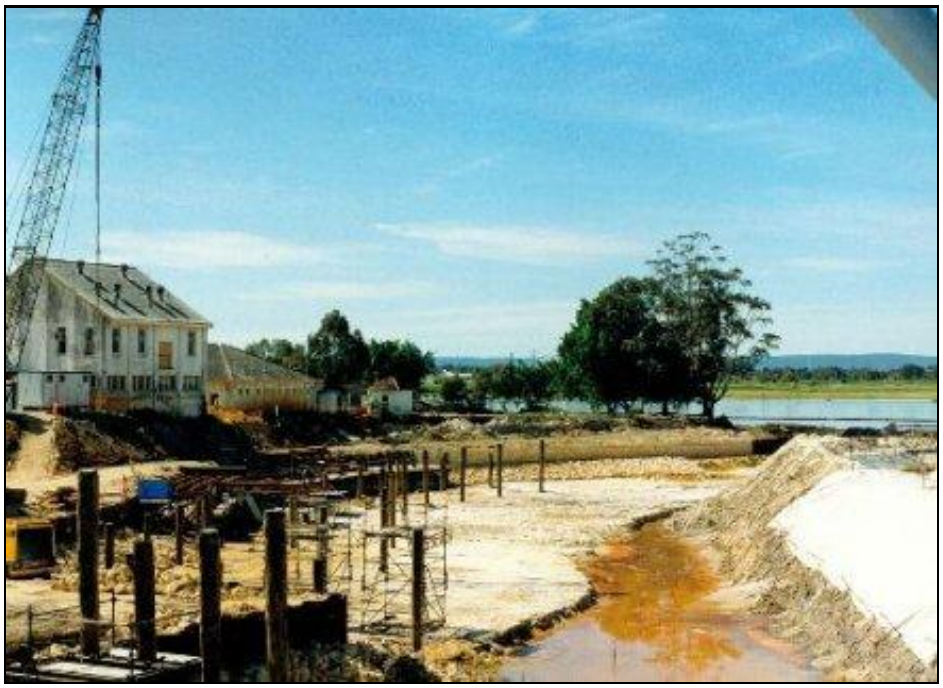


Figure 17 Excavation of sediments to create Claisebrook Cove 1994 - facing the Swan Estuary (Metropolitan Redevelopment Authority 2013c).

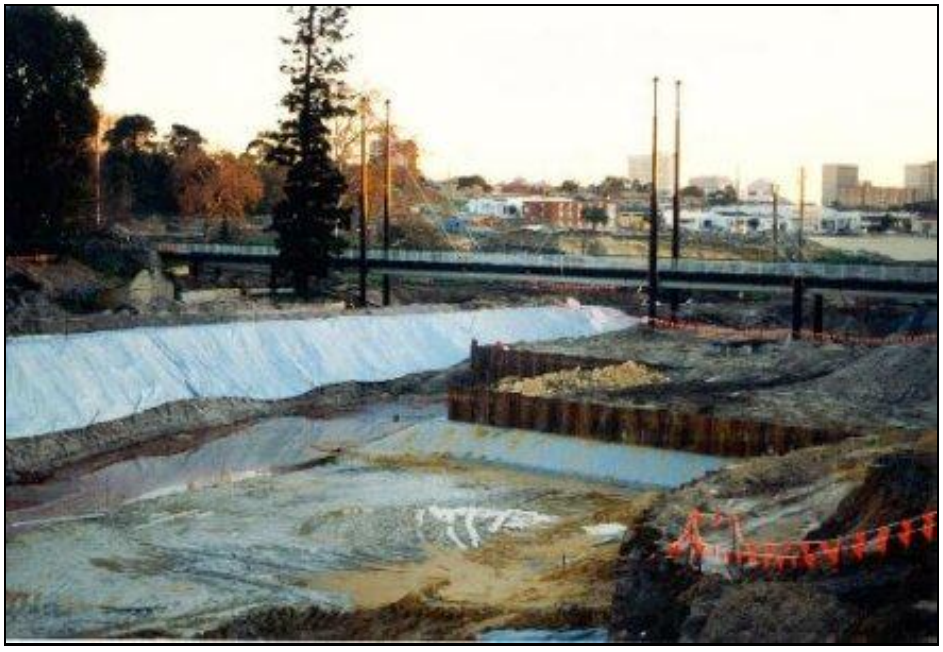


Figure 18 Excavation of sediments to create Claisebrook Cove 1994 - facing East Perth (Metropolitan Redevelopment Authority 2013d).

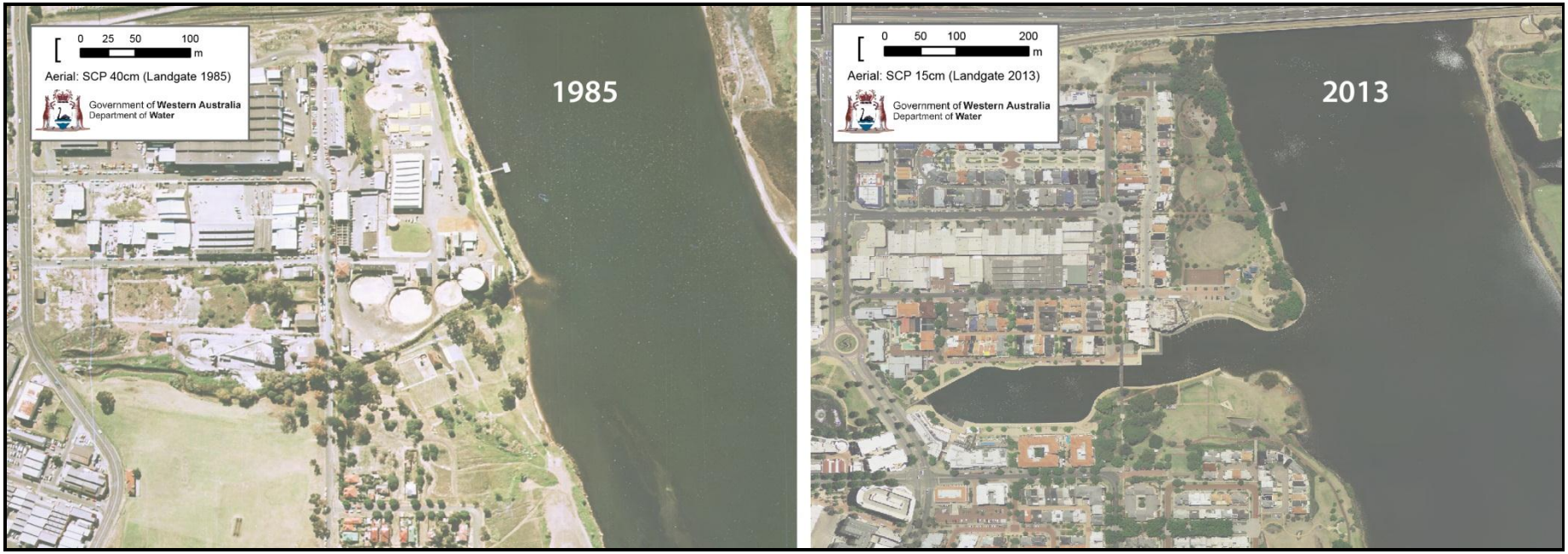



Figure 19 The change in form of Claisebrook Drain – before and after excavation.

## 3.2 Prevention of offshore migration of contaminants from the site – implementation of a 'Containment Cell'

Heavily contaminated areas containing hydrocarbons floating on the surface of the groundwater were identified within the gasworks site in the early 1990s (e.g. Bowman Bishaw Gorham 1992). In accordance with the environmental conditions (Minister for Environment 1994), a range of management actions were taken to prevent the offshore migration of such contaminants from the site. These are depicted in Figure 20 and described below.

### Installation of a plastic cut-off curtain

In order to prevent contaminated groundwater from migrating to the estuary, a shallow cut-off curtain was installed along the eastern boundary of the foreshore zone parallel to the foreshore. The curtain trench was excavated to a depth of 1 m below estuary level (understood to be Australian Height Datum). The curtain was composed of a 1 mm thick sheet of high-density polyethelene (Camp Scott Furphy 1996b; Tingay and Associates 1994b). The location of the cut-off curtain is shown (Figure 20).

### Installation of a steel cut-off wall

In order to prevent contaminated groundwater from migrating to the Cove, an inground steel cut-off wall was constructed along the southern boundary of the gasworks site (design depth of 7 m below Australian Height Datum in most places – Tingay and Associates 1994b). This was constructed prior to excavation of the Inlet to create the Cove, to minimise impacts during implementation of the gasworks project in accordance with environmental conditions (Minister for Environment 1994). The cut-off wall was composed of 10.5 mm thick steel sheet-pile (Camp Scott Furphy 1996b; Tingay and Associates 1994b). The location of the steel cut-off wall is shown (Figure 20).

### Installation of the groundwater interception drain

The groundwater interception drain (GID) is an in-ground drainage trench which was constructed beneath the western boundary of the open space zone (Mardalup Park) of the redevelopment, forming the western boundary of the containment cell. The drain has two purposes: 1) it was designed to intercept the groundwater migrating toward the contaminated site from the west, thus discharging it directly to the Swan Estuary (bypassing the contaminated gasworks site); 2) it was intended to lower the groundwater level on the site under Mardalup Park maintaining it at or below estuary level in order to prevent offsite migration of contaminated groundwater to the estuary (Axis Environmental 1996; Camp Scott Furphy 1996b). The drainage trench is V-shaped in cross section comprising a slotted pipe at the bottom situated just below mean estuary level (or 0.00 m Australian Height Datum) with granular material backfilled above the pipe to a surface level of 2.5 – 3.0 m (above Australian Height Datum) (Tingay and Associates 1994b). The location and design of the GID are shown (Figure 20 and Figure 21 respectively).

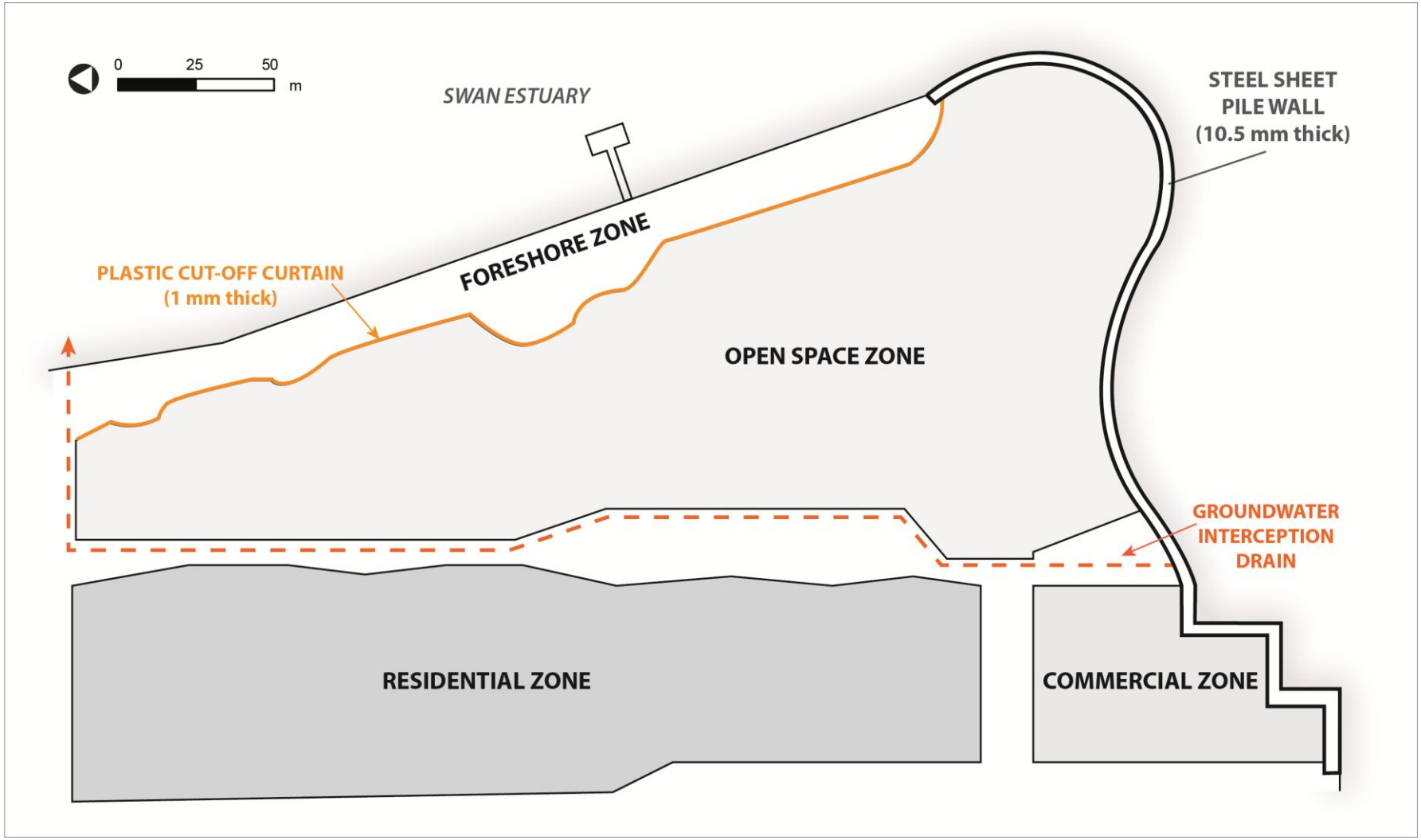



Figure 20 The containment Cell. Comprising plastic cut-off curtain, steel cut-off wall and groundwater interception drain (modified from ENV 2009).

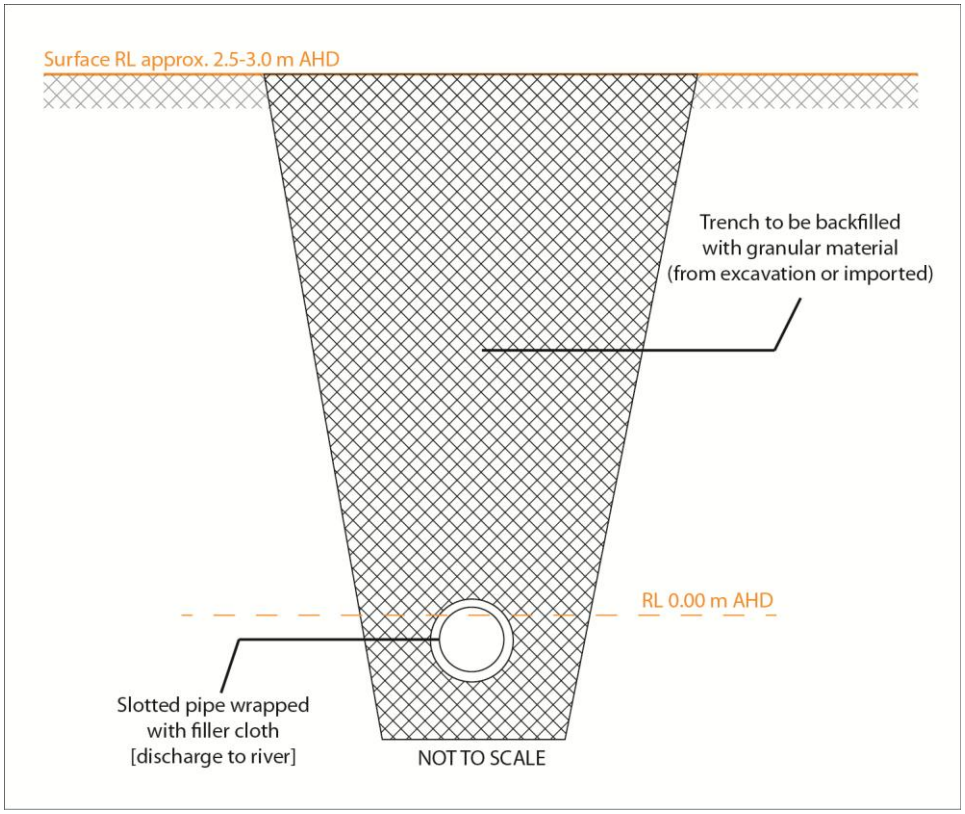



Figure 21 Groundwater interception drain (GID) in cross-section; RL: relative level; AHD: Australian Height Datum (modified from Tingay and Associates 1994b).

## Installation of a capping layer

The entire open space area (now known as Mardalup Park) including the foreshore zone was capped to prevent the percolation of rainwater (and irrigation water if applied) into the contaminated groundwater beneath. Thus preventing a head of groundwater building through replenishment, which, if allowed to occur, would result in the migration of contaminated groundwater offsite into the Swan Estuary (Camp Scott Furphy 1996b). The capping layer was created from sediments dredged from the Swan Estuary and Claisebrook Inlet (to create Claisebrook Cove). However, part way through the capping process, concerns were raised regarding the integrity of the cap, i.e. it was found to be more permeable than intended (Camp Scott Furphy 1996b). To overcome this issue a thin (10-15 mm) layer of saponite (swelling clay) was applied directly on top of the estuary sediments. This alone was considered to adequately lower the permeability to fulfil design requirements (Camp Scott Furphy 1996b). Note: the saponite layer was applied to the area covered by the original estuary sediment capping layer with the exception of the northern part of the site which was constructed to the original specification (estuary sediment cap only) prior to the introduction of saponite. The position, composition and thickness of the capping layer are shown in Figure 22.

## Establishment of subsoil drainage and vegetation

It was acknowledged that there was the potential for a perched mound of water to remain on the surface of the cap for prolonged periods, thus enabling vertical infiltration to the contaminated sediments and groundwater below (Camp Scott Furphy 1996b). However it was considered that this

issue would be overcome over time by the establishment of vegetation over the site. In the short term, strip drains were installed immediately over the cap within the coarse sand drainage layer shown in Figure 23. The cap was then covered with soil to provide a growing medium for vegetation.

### Estuary foreshore works

The foreshore was remodelled and stabilized to prevent the offshore migration of contaminants into the estuary through erosion. This included a system of groynes, beaches, soil stabilisation matting and rock spall protection work. A permanent stormwater drainage system was installed to allow the drainage of water from impervious surfaces such as roads and parking areas (Camp Scott Furphy 1996b).

### Management of irrigation

Appropriate landscape design and management was recommended to minimise the need for irrigation requirements and promote evapotranspiration (Mackie Martin – PPK 1994).

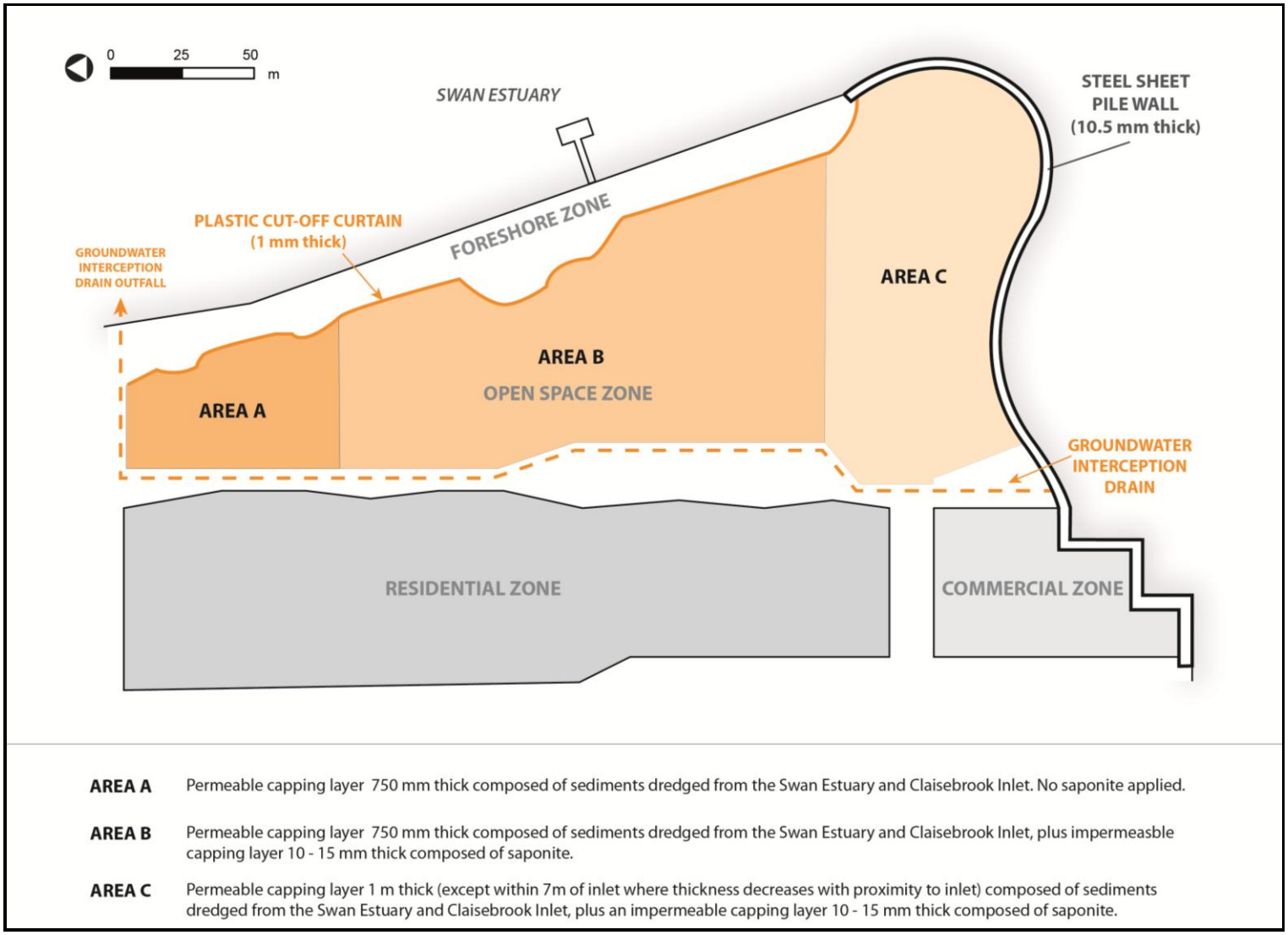



Figure 22 Capping layer composition and thickness (modified from Camp Scott Furphy 1996b).

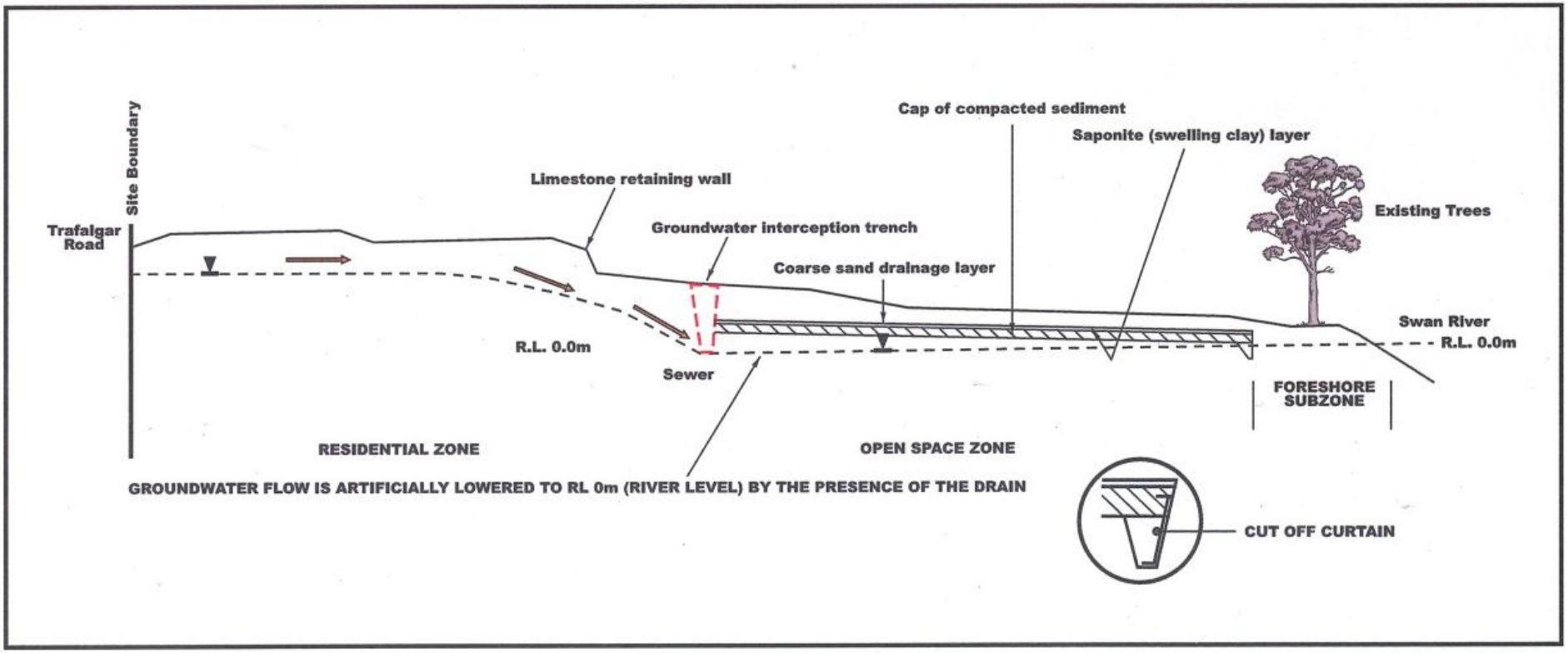



Figure 23 Schematic representation of function of containment area showing cut-off curtain, groundwater interception drain and capping layer (source: ENV 2011a).

# 4. The current environmental condition at Claisebrook – DoW contaminant investigations: 2009 - 2012

As shown, the Claise Brook (now Claisebrook drain), the Claisebrook Cove (situated at the mouth of Claisebrook Drain), and the Swan Estuary in the vicinity of Claisebrook Cove is expected to have received contamination over the years from a variety of land uses (the main ones being summarised in Section 2). Currently, it is expected that the Claisebrook Main Drain (comprising Claisebrook Drain and Claisebrook Diversion Drain outfalls) would discharge a degree of contamination given that it drains an inner-city catchment (Figure 24). For comparison, the main drains for the adjacent Maylands and Central Business District catchments, which are of similar size and current land use, have been shown to discharge contaminants such as metals and organochlorine (OC) pesticides (Nice et al. 2009).

However, when a baseline study reported a comparatively high level of contamination (refer to Figure 2) in the estuary near Claisebrook in 2009[1] (approximately 150 m from the mouth of the Claisebrook Cove), it was considered necessary to investigate further. The subsequent investigations (Figure 25) are summarized in this section.

[1] In addition to the spike in contamination that was evident at the Claisebrook site (Figure 2), environmental guidelines were exceeded for a range of the contaminants. Sediment chemistry data were compared with the Interim Sediment Quality Guideline trigger values (ISQGs) from the Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC and ARMCANZ 2000). The *low* ISQG (or trigger value – TV) represents the concentration below which, the frequency of adverse biological effects is expected to be low. The *high* ISQG represents the concentration above which, adverse biological effects are expected to occur frequently. [Refer to *A baseline study of contaminants in the sediments of the Swan and Canning estuaries* – Nice 2009].

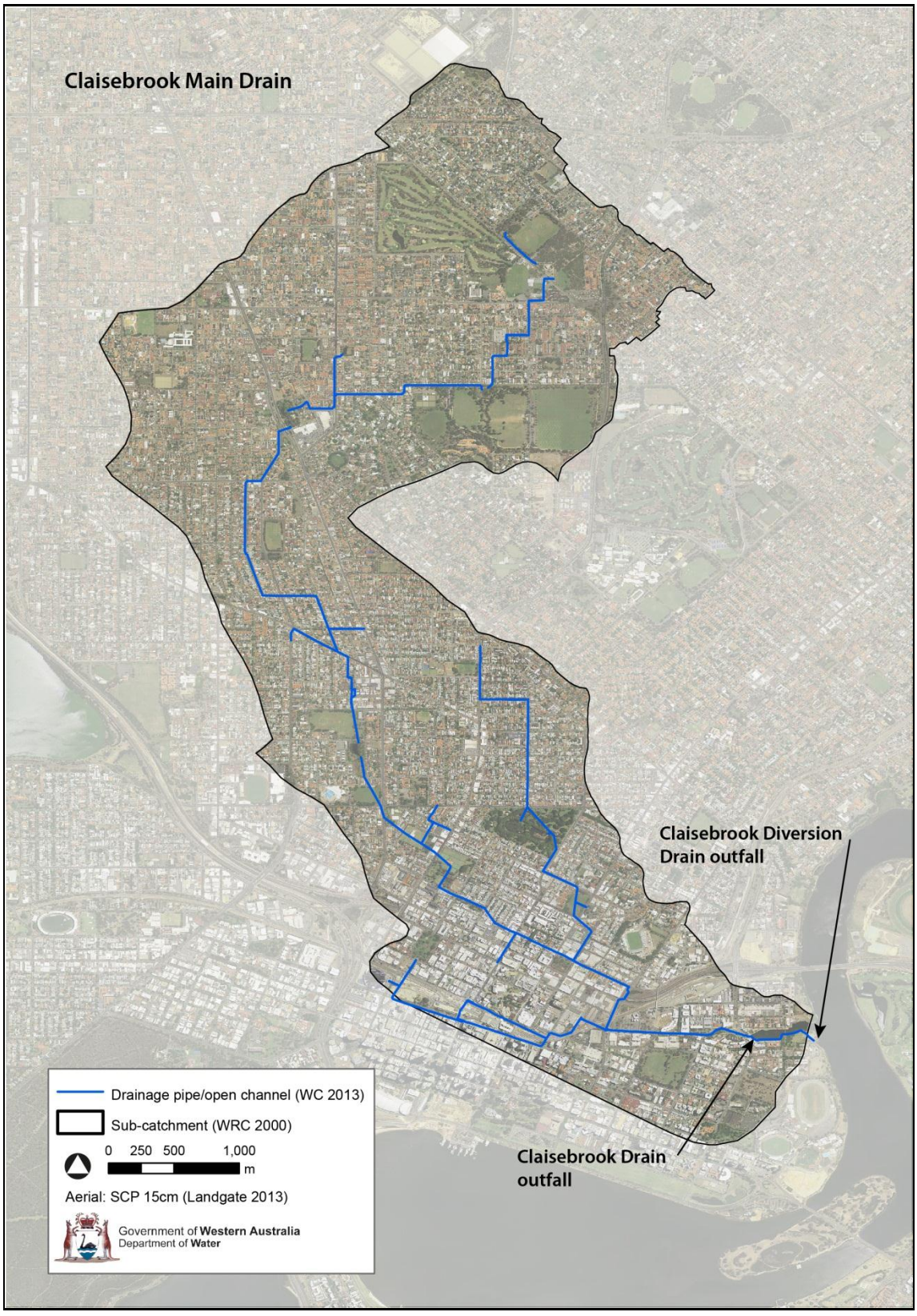
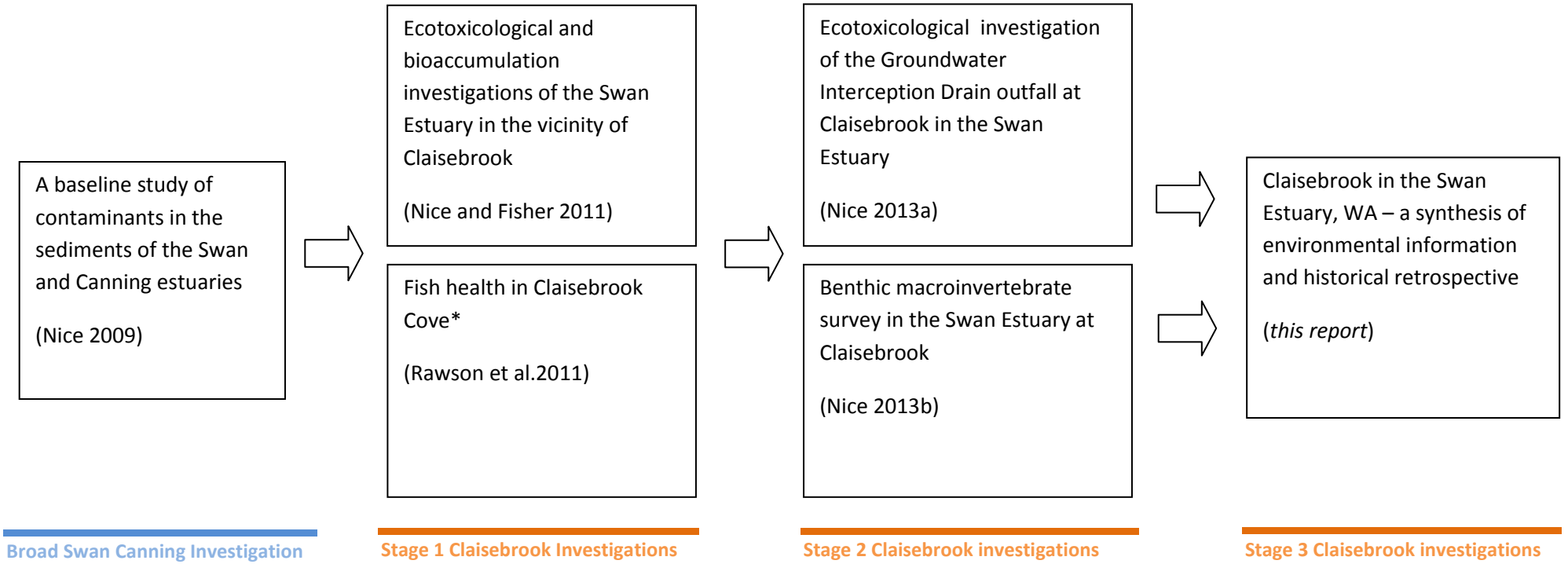



Figure 24 Drainage map of the Claisebrook Catchment.




* conducted through Curtin University on behalf of SRT

Figure 25 The sequence of DoW studies presented here (conducted on behalf of SRT) to investigate the environmental condition at Claisebrook in the Swan Estuary.

## 4.1 Stage 1 investigations – Determining the potential for environmental impact

Two investigations were conducted at this stage. These were: *Ecotoxicological and bioaccumulation investigations of the Swan Estuary in the vicinity of Claisebrook* (Nice and Fisher 2011) and *Fish health at Claisebrook Cove* (Rawson et al. 2011) investigations were conducted in 2009 – 2010. The overall objectives were to determine whether:

a) the levels of contaminants previously reported in the estuary sediments were of ecological concern, i.e. were they likely to cause toxicity?
b) the contaminants known to be present in the sediments were bioaccumulating in the mussels inhabiting the area
c) the Claisebrook Main Drain was the source of the contamination, i.e. was there evidence of a contaminant gradient from the Claisebrook Main Drain, either through the Claisebrook Drain outfall and/or the Claisebrook Diversion Drain outfall to the contaminated area in the estuary?

These investigations were designed in accordance with a *weight of evidence* approach, the underlying principle of which is that multiple lines of evidence reduce uncertainty in the assessment of environmental impact (Chapman et al. 1997). The Nice and Fisher (2011) study was conducted in 2009 in parallel with the investigation of wild-caught fish from Claisebrook Cove (Rawson et al.2011). The lines of evidence incorporated are provided in Table 1 and site locations are shown in Figure 26.

Table 1 Specific objectives and lines of evidence from Stage 1 investigations: *Ecotoxicological and bioaccumulation investigations of the Swan Estuary in the vicinity of Claisebrook* (Nice and Fisher 2011) *and Fish Health in Claisebrook Cove* (Rawson et al. 2011).

| To determine: | Line of evidence | Study |
|---|---|---|
| toxic potential of sediment collected from the estuary based on laboratory exposures of field collected sediments to laboratory animals representative of those found in the estuary | Sediment toxicity | Nice and Fisher 2011 |
| types and concentrations of contaminants present that may be responsible for any toxicity observed | Sediment chemistry | Nice and Fisher 2011 |
| whether contaminants known to be present are bioaccumulating in naturally occurring biota (mussels) | Bioaccumulation in biota | Nice and Fisher 2011 |
| whether wild-caught fish from Claisebrook Cove displayed evidence of toxicity (through biomarkers of physiological stress) | Fish health | Rawson et al. 2011 |

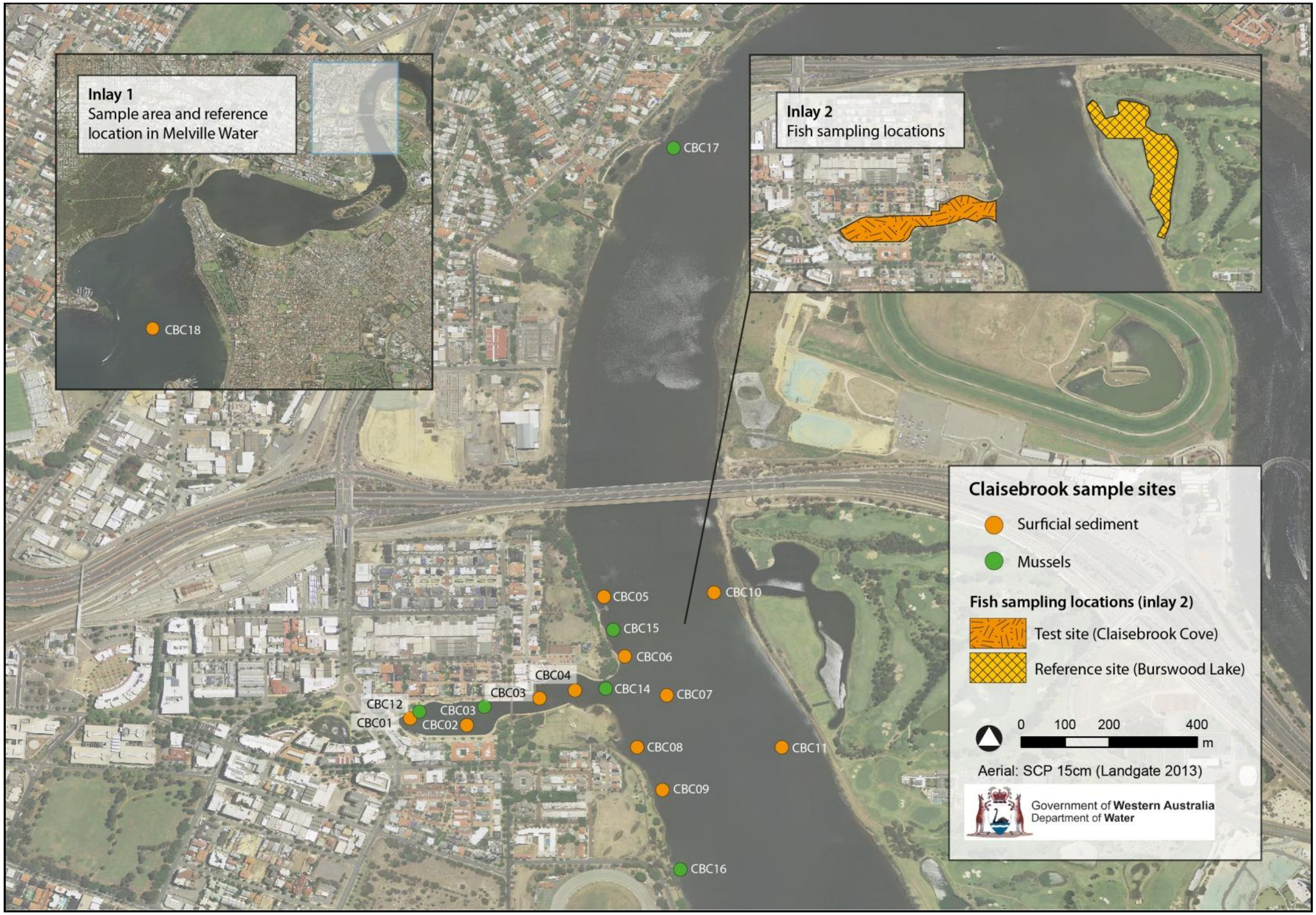



Figure 26 Site locations of Stage 1 investigations: *Ecotoxicological and bioaccumulation investigations of the Swan Estuary in the vicinity of Claisebrook* (Nice and Fisher 2011) and *Fish Health in Claisebrook Cove* (Rawson et al.2011).

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### Key findings of the Stage 1 investigations:

I. The levels of contaminants reported in the estuary sediments at some sites were considered to be of ecological concern given that toxic responses were observed (Table 2).

II. Some contaminants known to be present in the sediments were also shown to be bioaccumulating in the mussels inhabiting the area, although the resulting ecological effects of this level of bioaccumulation are currently unknown.

III. The Claisebrook Main Drain (discharging through Claisebrook Drain and Claisebrook Diversion Drain outfalls) appeared to be one source of the contamination since samples collected in the vicinity of these two outfalls resulted in the highest degree of toxicity compared with other samples. However, the spatial distribution of toxicity across sites indicates that a source(s) in addition to the Claisebrook Main Drain was likely to exist.

IV. With regard to the specific contaminant groups targeted,

- PAHs were shown to be present at concentrations of concern at several sites in the Swan Estuary including the diversion drain outfall. However, it was evident from the spatial distribution of PAH contamination that a source in addition to the two drain outfalls was responsible. There was a peak in concentrations of PAHs at the sites adjacent to Mardalup Park (Figure 27), where environmental guidelines were exceeded for every PAH for which guidelines exist (including the exceedence of several *high* ISQGs – Table 3).
- OC pesticides and metals recorded at levels of environmental concern (Table 15 and Table 16, Appendix 2) were fairly evenly distributed throughout the study area and not attributable to any one source, although the Claisebrook Drain outfall (discharging periodically within the cove) was found to be one potential source of these contaminants. These contaminants were considered to be contributing to some of the toxicity experienced by the test organisms in this study.

For detailed findings including the range of acute and chronic toxic affects reported, refer to the full reports (Nice and Fisher 2011; Rawson et al. 2011).

Table 2 Evidence of toxicity from Stage 1 investigations: *Ecotoxicological and Bioaccumulation Investigations of the Swan Estuary in the vicinity of Claisebrook* (Nice and Fisher 2011) and *Fish Health in Claisebrook Cove* (Rawson et al. 2011).

| Toxic response | Acute/chronic | Laboratory exposure / field caught | Study |
|---|---|---|---|
| Copepod mortality | Acute | Laboratory exposure | Nice and Fisher 2011 |
| Amphipod mortality | Acute | Laboratory exposure | Nice and Fisher 2011 |
| Mussel larvae abnormal development | Sub-chronic | Laboratory exposure | Nice and Fisher 2011 |
| Fish larvae abnormal development | Sub-chronic | Laboratory exposure | Nice and Fisher 2011 |
| DNA damage in mussels | Chronic | Field-collected | Rawson et al. 2011 |
| Elevated hepatic detoxification enzymes in fish | Chronic | Field-caught[2] | Rawson et al. 2011 |
| Elevated biliary PAH metabolites in fish | Chronic | Field-caught[2] | Rawson et al. 2011 |
| The intersex condition (both male and female gonad tissue present in the same individual)[3] | Chronic | Field-caught[2] | Rawson et al. 2011 |

[2] Given that fish are mobile it was not possible to attribute the chronic effects displayed in the field-caught fish to exposure to contaminants from Claisebrook sediments *per se*. Exposure of laboratory fish to field-collected sediment within a controlled laboratory environment would be required to further investigate the long-term chronic effects that the contaminants known to exist in the sediments may cause.

[3] It is possible that the existence of the intersex condition (which was observed in 2 of 15 fish in this study) may be indicative of endocrine disruption. However, given that black bream (the fish sampled in this study) are rudimentary hermaphrodites often displaying both male and female gonad tissue simultaneously (Buxton and Garatt 1990), controlled laboratory experiments would be required to confirm endocrine disruption due to contaminant exposure.

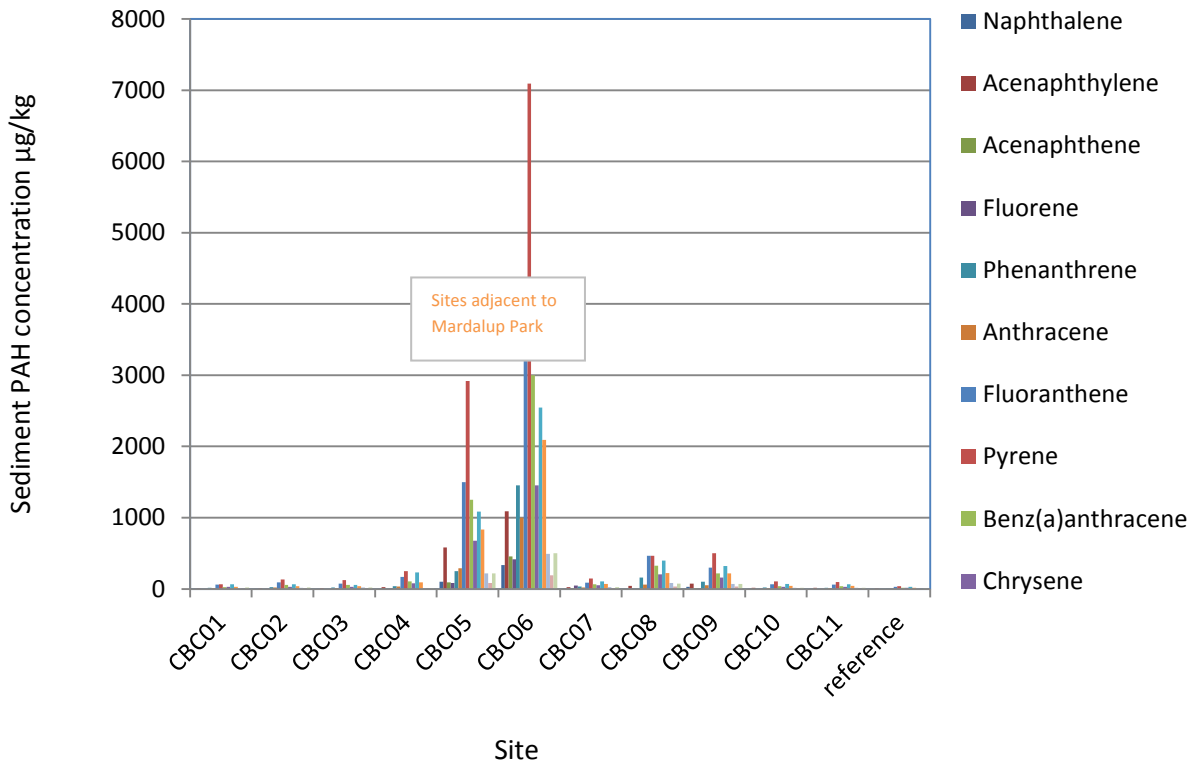


Figure 27 PAH concentrations in the surficial sediments from Stage 1 investigation: *Ecotoxicological and Bioaccumulation Investigations of the Swan Estuary in the vicinity of Claisebrook* (Nice and Fisher 2011).

Table 3 Sediment polycyclic aromatic hydrocarbon (PAH) concentrations from Stage 1 investigation: *Ecotoxicological and Bioaccumulation Investigations of the Swan Estuary in the vicinity of Claisebrook* (Nice and Fisher 2011).

| | Sediment polycyclic aromatic hydrocarbon concentrations (µg/kg) normalised to 1% organic carbon | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Naphthalene | Acenaph-thylene | Acenaph-thene | Fluorene | Phenanthrene | Anthracene | Fluoranthene | Pyrene | Benz[a]a-nthracene | Chrysene | Benzo[b]&[k]-fluoranthene | Benzo[a]-pyrene | Indeno[1,2,3-cd]pyrene | Dibenz[ah]-anthracene | Benzo(ghi)-perylene |
| Site | | | | | | | | | | | | | | | |
| CBC01 | 1.84 | 7.13 | n.d | n.d | 17.24 | 13.79 | 63.22 | 65.52 | 25.29 | 28.74 | 67.82 | 29.89 | 12.64 | 4.37 | 20.69 |
| CBC02 | 3.77 | 8.99 | n.d | 4.78 | 23.19 | 18.84 | 94.20 | 133.33 | 55.07 | 28.99 | 66.67 | 37.68 | 17.39 | 5.51 | 21.74 |
| CBC03 | 4.38 | 12.19 | n.d | n.d | 21.56 | 11.56 | 75.00 | 121.88 | 56.25 | 31.25 | 56.25 | 37.50 | 19.38 | 6.88 | 19.69 |
| CBC04 | 4.23 | 26.92 | n.d | 3.27 | 38.46 | 32.69 | 169.23 | 250.00 | 107.69 | 78.85 | 230.77 | 92.31 | 8.08 | 2.88 | 7.88 |
| CBC05 | 100.00 | 583.33 | 91.67 | 83.33 | 250.00 | 291.67 | 1500.00 | 2916.67 | 1250.00 | 675.00 | 1083.33 | 833.33 | 216.67 | 83.33 | 216.67 |
| CBC06 | 336.36 | 1090.91 | 454.55 | 418.18 | 1454.55 | 1000.00 | 3909.09 | 7090.91 | 3000.00 | 1454.55 | 2545.45 | 2090.91 | 490.91 | 190.91 | 500.00 |
| CBC07 | 8.53 | 25.88 | 5.59 | 47.06 | 32.35 | 19.71 | 88.24 | 147.06 | 64.71 | 50.00 | 105.88 | 70.59 | 26.76 | 7.94 | 26.47 |
| CBC08 | n.d | 43.10 | n.d | n.d | 162.07 | 60.34 | 465.52 | 465.52 | 327.59 | 206.90 | 396.55 | 224.14 | 82.76 | 34.48 | 74.14 |
| CBC09 | 28.00 | 74.00 | 11.40 | 13.80 | 102.00 | 52.00 | 300.00 | 500.00 | 220.00 | 158.00 | 320.00 | 220.00 | 72.00 | 32.00 | 72.00 |
| CBC10 | 6.00 | 16.00 | n.d | 4.25 | 20.00 | 13.25 | 65.00 | 107.50 | 40.00 | 30.00 | 70.00 | 42.50 | 15.75 | 5.25 | 16.75 |
| CBC11 | 4.38 | 14.69 | n.d | 3.13 | 16.25 | 10.31 | 59.38 | 96.88 | 40.63 | 31.25 | 65.63 | 43.75 | 15.00 | 4.69 | 15.94 |
| CBC18 (Ref) | n.d | 5.94 | n.d | n.d | 9.06 | 4.38 | 29.06 | 37.50 | 16.56 | 15.31 | 31.25 | 18.13 | 7.50 | n.d | 7.81 |
| ISQG Low | 160 | 44 | 16 | 19 | 240 | 85 | 600 | 665 | 261 | 384 | n.a. | 430 | n.a. | 63 | n.a. |
| ISQG High | 2100 | 640 | 500 | 540 | 1500 | 1100 | 5100 | 2600 | 1600 | 2800 | n.a. | 1600 | n.a. | 260 | n.a. |

Sites adjacent to Mardalup Park

*ISQG = Interim Sediment Quality Guideline (ANZECC & ARMCANZ 2000); blue indicates low ISQG exceeded; orange indicates high ISQG exceeded; n.a. = no ANZECC & ARMCANZ guideline available; n.d. = not detected; limit of reporting: 10 µg/kg. Samples comprised the top 2 cm of sediment. Data normalised to 1% organic carbon according to Simpson et al. 2005. Site locations are shown in Figure 26.*

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### Conclusions and outcomes of the Stage 1 investigations:

I. A significant contaminant source(s) in addition to the Claisebrook Main Drain appeared to be present in this region of the Swan Estuary.

II. The type of contaminants present (particularly the PAHs) are typical of historic gasworks sites[4]; and were shown to be present in the estuary sediments as a result of the neighbouring gasworks and migrating from the East Perth gasworks site in 1992 (Bowman Bisham Gorham 1992) (refer to Section 2 - Figure 10).

III. Despite extensive remediation (Section 2), surficial sediments collected from several sites in the remediated zone of the estuary (Figure 16) exhibited comparatively high levels of PAHs (also observed in Nice 2009).

IV. PAHs were present in forms that may indicate a recent or ongoing source of contamination to the area (discussed further in Section 5.3).

V. The groundwater interception drain (GID), which was installed as part of the remediation which took place in 1994 (location shown in Figure 20), had recently been shown to be a source of PAHs[5] (and other contaminants) to the area (ENV 2009) at concentrations high enough to be causing ecological impact.

Given these findings, it was considered necessary to conduct a subsequent set of investigations focussing specifically on the GID outfall to the estuary to determine whether it could be attributed as a source of the contaminants and toxicity reported here.

In response, Stage 2 investigations were commenced, comprising a comprehensive investigation of the Swan Estuary at Claisebrook (2011 – 2012), focussing primarily on the GID outfall to the estuary. Stage 2 investigations are summarized in the following section.

[4] The same PAHs as detected here (Nice and Fisher 2011 and previously, Nice 2009) were classified as 'contaminants of interest' for gasworks sites (DEC NSW 2005)

[5] Compliance monitoring conducted as part of the Environmental Conditions (Minister for Environment 1994)

## 4.2 Stage 2 investigations – Assessing the groundwater interception drain outfall

The overall objective of the Stage 2 investigations was to determine whether there was evidence that the groundwater interception drain (GID) outfall was impacting the receiving environment. This stage of investigation comprised a series of parallel studies incorporating the *multiple lines of evidence* approach discussed previously and following the principles of the ANZECC and ARMCANZ Guidelines (2000). The specific objectives and corresponding lines of evidence are shown in Table 4.

Table 4 Specific objectives and lines of evidence from Stage 2 investigations: *Ecotoxicological investigation of the groundwater interception drain (GID) outfall at Claisebrook in the Swan Estuary* (Nice 2013a), *Benthic Macroinvertebrate survey in the Swan Estuary at Claisebrook* (Nice 2013b) and (Fisher 2013a).

| To determine: | Line of evidence | Study |
|---|---|---|
| whether sediments collected from the receiving environment (estuary) adjacent to the GID outfall were toxic to aquatic organisms representative of those found in the estuary | Sediment toxicity | Nice 2013a |
| whether any toxicity (if experienced) could be attributable to the GID outfall | Sediment toxicity | Nice 2013a |
| types and concentrations of contaminants present in the surficial sediment that may be responsible for any toxicity observed | Sediment chemistry | Nice 2013a and Nice 2013b |
| types and concentrations of contaminants present in the surface waters of the estuary using passive sampling technology | Water chemistry | Fisher 2013a |
| whether biotic assemblages adjacent to the GID outfall were different from other sites | Benthic ecology | Nice 2013b |
| whether any differences in biotic assemblages (if observed) could be attributable to the GID outfall | Benthic ecology | Nice 2013b |
| whether differences in biotic assemblages (if observed) could be explained by sediment contaminants | Benthic ecology | Nice 2013b |

The sediment toxicity assessment (Nice 2013a) comprised a targeted sample design focussing on the GID outfall in the main channel of the estuary adjacent to the historic gasworks site with sites upstream and downstream from the GID outfall (Figure 28). The spatial design enabled determination of whether the GID outfall was a likely source of the PAH contamination and toxicity previously observed (Nice and Fisher 2011) or whether the source was likely to be upstream, downstream or across the estuary from the GID outfall. It also allowed determination of the extent of the contamination.


Figure 28 Site locations from Stage 2 investigation: *Ecotoxicological investigation of the groundwater interception drain (GID) outfall at Claisebrook in the Swan Estuary* (Nice 2013a).

### Key findings of the Stage 2 investigations:

Surficial sediments collected from the sites assessed in Nice (2013a) exhibited a range of toxic responses (Table 5) with various degrees of toxicity (Table 6) and contamination (Figure 29; Table 17 to Table 21 of Appendix 3). However, the GID outfall to the estuary (the focus of this investigation) was not found to be the major source of contamination at the time of sampling given that:

I. both sediment toxicity and sediment contaminants, although present, were comparatively low at this site compared with other sites in the investigation (toxicity was only experienced for fish) (Nice 2013a);
II. there was no evidence of either a sediment toxicity or sediment contaminant gradient emanating from the outfall (Nice 2013a);
III. the biotic assemblages adjacent to the GID outfall were not distinctly different from biotic assemblages assessed upstream of the outfall at the time of sampling (refer to Nice 2013b), indicating that any contaminants that may have been discharged intermittently (as is often the nature of drain outfalls), were not significant enough in concentration to have resulted in detectable impact to the benthic fauna – i.e. the macroinvertebrates living in the sediments;
IV. an assessment of PAH contaminants in the water column at the GID site (albeit, later in the year), indicated that during the one month investigation period, the GID was not a significant source of PAH contaminants to the water fraction of the estuary (Fisher 2013a). Although this finding is not surprising given the affinity of PAHs to bind to sediment rather than remain in the water column once in the environment.

However, at site CBE07, south of the GID outfall and adjacent to the middle section of Mardalup Park, a peak in both toxicity and contaminant concentrations was evident (Figure 29 and Figure 30); with toxicity exhibited by all test organisms and numerous guidelines exceeded (Figure 30; and Table 17 and Table 18 of Appendix 3).

Table 5 Evidence of toxicity from Stage 2 investigation: *Ecotoxicological investigation of the groundwater interception drain (GID) outfall at Claisebrook in the Swan Estuary* (Nice 2013a).

| Toxic response | Acute/chronic | Laboratory exposure / field caught | Study |
|---|---|---|---|
| Copepod mortality | Acute | Laboratory exposure | Nice 2013a |
| Amphipod mortality | Acute | Laboratory exposure | Nice 2013a |
| Mussel larvae abnormal development | Sub-chronic | Laboratory exposure | Nice 2013a |
| Fish larvae abnormal development | Sub-chronic | Laboratory exposure | Nice 2013a |

Table 6 Summary of the toxicity experienced with each test for samples collected from each site – Stage 2 investigation: *Ecotoxicological investigation of the groundwater interception drain (GID) outfall at Claisebrook in the Swan Estuary* (Nice 2013a).

| | Toxicity test | | | |
|---|---|---|---|---|
| | **Amphipod** | **Copepod** | **Mussel** | **Fish** |
| Site | | | | |
| CBE01 | | | **XX** | |
| CBE02 | | | | |
| CBE03 | | | **X** | |
| CBE04 | | | | **XX** |
| CBE05 (GID) | | | | **XX** |
| CBE06 | **X** | | | **XX** |
| CBE07 (Mardalup Park) | **X** | **XX** | **XX** | **XX** |
| CBE08 | | | | |
| CBE09 | | | | **XX** |
| CBE10 | | | | |
| CBE11 (field reference) | | | | |
| Laboratory control | | | | |

*Blank cells = no toxicity; **X** = low-level toxicity; **XX** = high-level toxicity.*

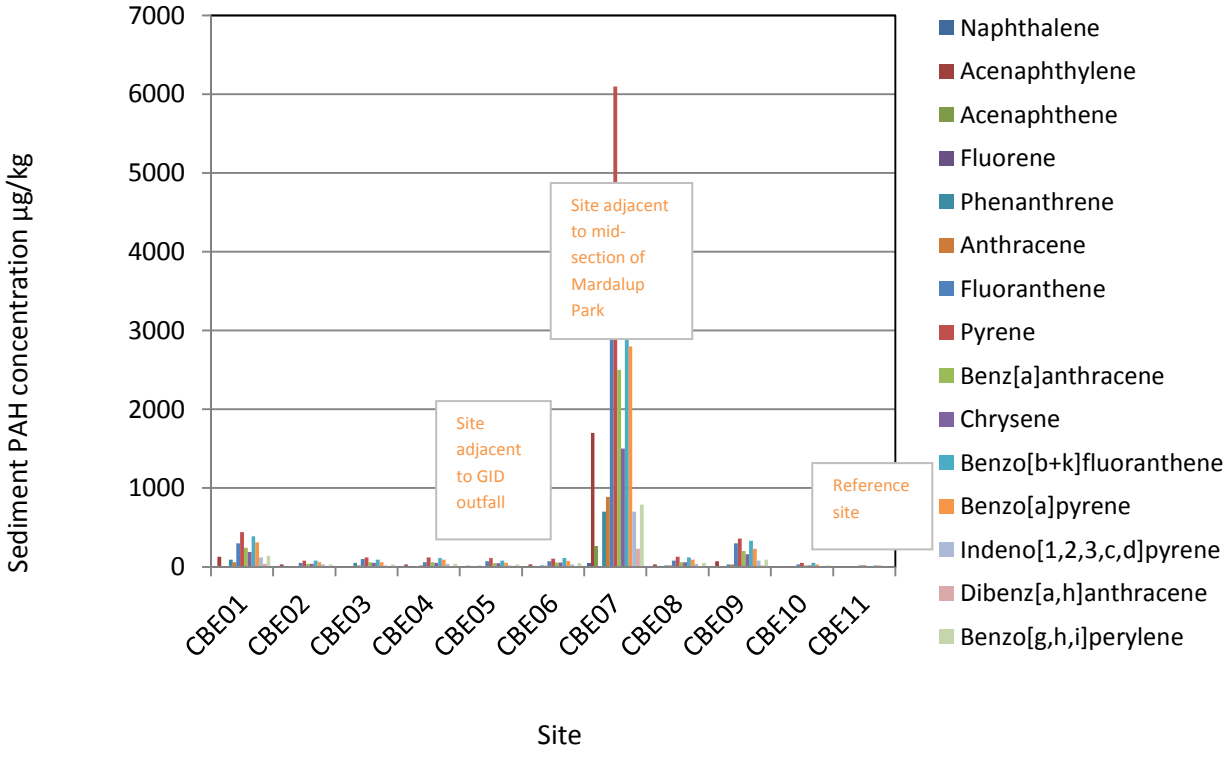


Figure 29 PAH concentrations in the surficial sediments from Stage 2 investigation: *Ecotoxicological investigation of the groundwater interception drain (GID) outfall at Claisebrook in the Swan Estuary* (Nice 2013a).

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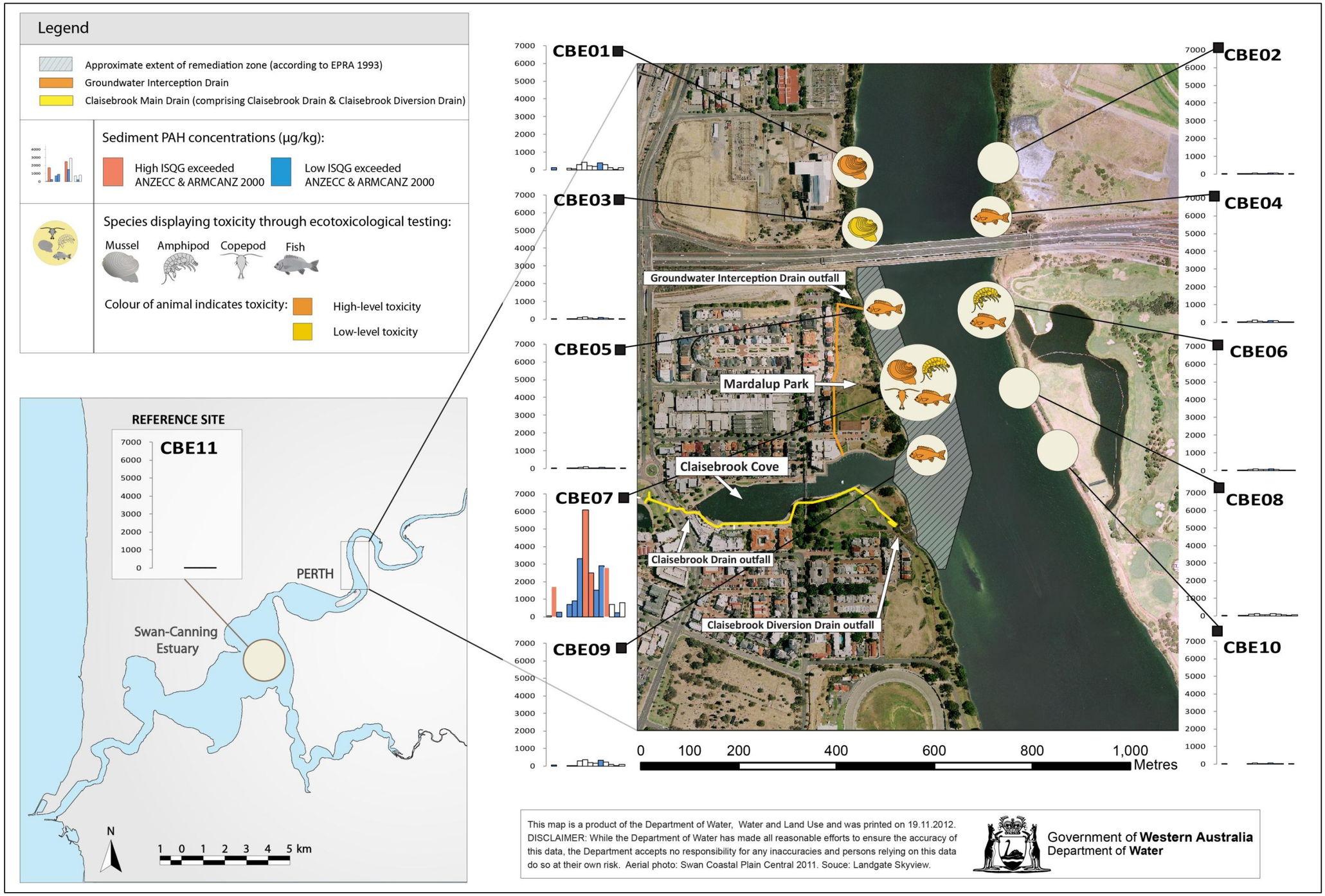


Figure 30 Spatial summary of toxicity and PAH contamination from Stage 2 investigation: *Ecotoxicological investigation of the groundwater interception drain (GID) outfall at Claisebrook in the Swan Estuary* (Nice 2013a ).

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## 4.3 Concluding the Stage 1 and 2 investigations (2009 - 2012) – identification of a *zone of interest*

In summary, information presented in the Stage 1 and 2 investigations (Nice 2013a, Nice and Fisher 2011) shows that there is a localised area of the Swan Estuary adjacent to the mid-portion of Mardalup Park where an accumulation of PAH contamination is evident in the sediments and is associated with high levels of toxicity.

The GID, while likely contributing some contamination to the estuary, is not considered to be the major source of contamination to this area (Nice 2013a and Nice 2013b)[6]. Similarly, the Claisebrook Main Drain is not considered to be the major source of contamination to this area (Nice and Fisher 2011). Potential sources for this contamination are discussed in detail in the following section; and discussion regarding historical context and current relevance is provided.

For all further discussion in this paper, this localised contaminated area shall be described as the *zone of interest* (Figure 31).

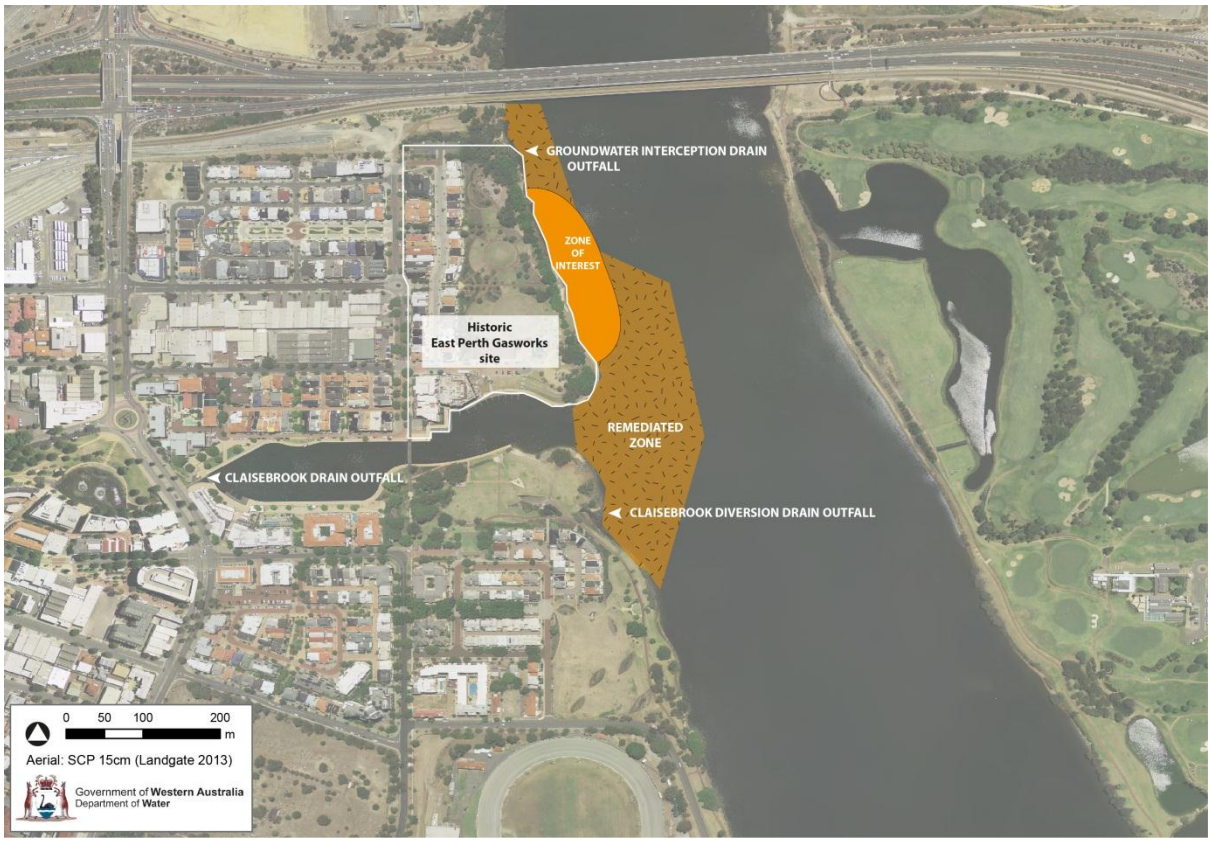



Figure 31 Contaminant hotspot – *zone of interest* identified from DoW studies (Nice 2013a, Nice 2011).

[6] While the DoW studies did not find the GID to be the *major* contaminant source in this area of the Swan Estuary, it is acknowledged that a degree of toxicity and contamination was measured at this site (Nice 2013a). This is discussed further in Section 6.2.

# 5. Placing the PAH contamination in the Swan Estuary adjacent to Mardalup Park (*zone of interest*) into context

## 5.1 How do the current sediment PAH concentrations compare with historic concentrations?

Surface sediments in the *zone of interest* (Figure 31) were shown to have the highest levels of PAH contamination in the estuary in detailed sediment surveys conducted pre-remediation in 1990 and 1992 (Bowman Bishaw Gorham 1992), refer to Section 2 – Figure 10. It is unclear how much of the current contamination in the *zone of interest* was simply not removed during the remediation that took place in 1994 (Section 3) or whether there is renewing contamination to this area.

To place the current levels of contamination in the *zone of interest* into context, total PAH concentrations in samples collected in the recent DoW studies, i.e 2009 and 2011 (sites CBC05 and CBC06 – Nice and Fisher 2011; site CBE07 – Nice 2013a) were compared to data collected immediately post-remediation in 1994 (Tingay and Associates 1994a).

Surficial sediment samples collected from the *zone of interest* in recent years (2009 and 2011) had markedly higher total PAH concentrations than samples collected in 1994 (immediately post-remediation): total PAH concentrations ranged between 12210 and 28630 µg/kg with a median of 24000 µg/kg in the recent investigations (Nice and Fisher 2011; Nice 2013a); whereas in 1994 (immediately post-remediation), total PAH concentrations ranged between 360 µg/kg and 7260 µg/kg with a median of 1520 µg/kg in the surficial sediments of the remediation zone (Tingay and Associates 1994a).

It should be noted that it is not possible to determine which of the 17 samples in the Tingay and Associates (1994a) study relates specifically to the *zone of interest*, since samples were taken throughout the greater remediation zone (Figure 16 ), which includes but is not limited to the *zone of interest*. Specific site details for each sample concentration are not provided. However, all 17 samples collected from the greater remediation zone in 1994 (some of which were from the area now defined here as the *zone of interest*) contained markedly lower total PAH concentrations than reported in *zone of interest* in 2009 and 2011. Furthermore the total PAH concentrations reported in 1994 comprised the concentrations of each of 17 separate PAH compounds. Whereas the total PAH concentrations from the latter studies comprised the concentrations of 15 PAHs. Thus the more recent total PAH concentrations may be a relative underestimation. Additionally it should be noted that many of the individual PAHs were not detected in the surficial fraction immediately post-remediation (1994) as the concentrations were below the limits of reporting (limits of reporting ranged between 1 and 100 ug/kg) , yet each of the individual PAHs were detected in the latter studies (except fluorene in Nice 2013a; limits of reporting: 10 ug/kg).

Compliance monitoring data collected in 1995, one year post-remediation (Axis Environmental 1995) also show markedly lower concentrations of total PAHs than are currently present in the *zone of interest* (Nice 2013a; Nice and Fisher 2011 ).

## 5.2 How do the current sediment PAH concentrations compare with the acceptance criteria for sediment developed specifically for the development of the site?

While current practise in Australia is to compare sediment contaminant concentrations with the trigger values provided in the ANZECC and ARMCANZ Guidelines (2000) as has been done in the DoW investigations (Section 4), monitoring conducted in relation to development and remediation of the East Perth Gasworks site used criteria developed specifically for the development of this site (according to the Ministers Conditions of Approval – Minister for the Environment 1994). These are known as the Alan Tingay and Associates (ATA) Recommended Acceptance Criteria (Tingay and Associates 1994a) and a rationale for their development is provided in Tingay and Associates (1993). Subsequent compliance monitoring associated with the site has continued to refer to the ATA Acceptance Criteria (e.g. ENV 2009). It is important to note that the ATA Acceptance Criteria for sediment are generally less conservative than ANZECC and ARMCANZ Guideline trigger values. For example, ten of the 13 individual PAHs measured have a higher ATA guideline than the ANZECC low ISQG. While the ATA Acceptance Criteria were deemed appropriate for monitoring associated with the development of the site during the 1990s (Tingay and Associates 1994a, 1993), there is some conjecture as to whether these should be applied in contemporary assessments designed to determine whether specific contaminants are present in concentrations likely to be causing environmental impact.

The ANZECC and ARMCANZ Guideline trigger values are considered the most up to date information available in Australia pertaining to the likely impact of specific contaminants. They are endorsed by the Department of Environment and Conservation (now the Department of Environment Regulation), Government of WA (and are incorporated into its Contaminated Sites Management Series – Assessment levels for Soil, Sediment and Water, February 2010). The ANZECC Guidelines were developed using toxicity information relating to a broad range of aquatic species. Accordingly, it may be argued that these are more likely to indicate the potential for ecological impact. Hence for the purpose of this investigation, the most recent sediment PAH dataset collected by DoW in 2011 (Nice 2013a), is compared to both the ATA Acceptance Criteria for Sediment and the ANZECC and ARMCANZ ISQGs (Table 7 and Table 8). Both organic carbon normalised and non-normalised data are presented because the ANZECC ISQGs generally refer to PAH concentrations that have been normalised to 1% organic carbon (Simpson et al. 2005) yet it is not clear from the historic literature (Tingay and Associates 1994a) whether this conversion was a requirement for the application of the ATA Acceptance Criteria for Sediment.

Note: Those PAH concentrations that are higher than the ATA Acceptance Criteria are shown in the following tables by a bordered cell. Concentrations that are higher than the ANZECC and ARMCANZ (2000) low and high ISQGs are shown in the following tables with blue and orange shaded cells respectively.

Table 7 Sediment polycyclic aromatic hydrocarbon (PAH) concentrations – non-normalised (*Ecotoxicological investigation of the groundwater interception drain outfall at Claisebrook in the Swan Estuary* – Nice 2013a) showing where PAH concentrations are higher than ANZECC ISQGs and ATA Acceptance Criteria.

| Sediment polycyclic aromatic hydrocarbon (PAH) concentrations (µg/kg) dry weight | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Naphthalene | Acenaphthylene | Acenaphthene | Fluorene | Phenanthrene | Anthracene | Fluoranthene | Pyrene | Benz[a]anthracene | Chrysene | Benzo[b+k]fluoranthene * | Benzo[a]pyrene | Indeno [1,2,3-cd] pyrene | Dibenz[a,h]anthracene | Benzo [g,h,i]perylene | Total PAHs |
| CBE01 | n.d. | 130 | n.d. | n.d. | 90 | 60 | 300 | 440 | 240 | 190 | 390 | 310 | 120 | 40 | 140 | 2400 |
| CBE02 | n.d. | 30 | n.d. | n.d. | 10 | 10 | 50 | 80 | 40 | 40 | 80 | 60 | 30 | n.d. | 30 | 470 |
| CBE03 | n.d. | 10 | n.d. | n.d. | 50 | 20 | 100 | 120 | 60 | 50 | 90 | 60 | 20 | n.d. | 30 | 620 |
| CBE04 | n.d. | 30 | n.d. | n.d. | 10 | 20 | 60 | 120 | 60 | 50 | 110 | 90 | 40 | 10 | 40 | 630 |
| CBE05 | n.d. | 15 | n.d. | n.d. | 15 | 10 | 70 | 110 | 45 | 45 | 80 | 50 | 20 | n.d. | 30 | 310 |
| CBE06 | n.d. | 30 | n.d. | n.d. | 20 | 15 | 70 | 105 | 55 | 55 | 110 | 75 | 30 | 7.5 | 45 | 520 |
| CBE07 | 40 | 1700 | 260 | n.d. | 700 | 890 | 3300 | 6100 | 2500 | 1500 | 2900 | 2800 | 700 | 230 | 790 | 24000 |
| CBE08 | n.d. | 30 | n.d. | n.d. | 20 | 20 | 80 | 130 | 60 | 60 | 120 | 90 | 40 | 10 | 50 | 710 |
| CBE09 | n.d. | 70 | n.d. | n.d. | 30 | 30 | 300 | 360 | 200 | 160 | 330 | 230 | 80 | 20 | 90 | 1900 |
| CBE10 | n.d. | 10 | n.d. | n.d. | n.d. | n.d. | 30 | 50 | 20 | 20 | 50 | 30 | 10 | n.d. | 20 | 240 |
| CBE11(ref) | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 20 | 20 | 10 | 10 | 20 | 20 | n.d. | n.d. | n.d. | n.d. |
| ISQG Low | 160 | 44 | 16 | 19 | 240 | 85 | 600 | 665 | 261 | 384 | n.a. | 430 | n.a. | 63 | n.a. | 4000 |
| ISQG High | 2100 | 640 | 500 | 540 | 1500 | 1100 | 5100 | 2600 | 1600 | 2800 | n.a. | 1600 | n.a. | 260 | n.a. | 45000 |
| ATA Criteria | 600 | 40 | 200 | 40 | 400 | 180 | 800 | 2000 | 200 | 800 | 800** | 1000 | 120 | 120 | 120 | 6000 |

*Red border indicates site within the zone of interest. ISQG = Interim Sediment Quality Guideline (ANZECC & ARMCANZ 2000); single black border indicates concentration higher than ATA Acceptance Criteria, double black border indicates concentration higher than 10xATA Acceptance Criteria); blue indicates concentration higher than low ISQG; orange indicates concentration higher than high ISQG; n.a. = no ANZECC & ARMCANZ guideline available; * alternative guidelines for benzo[b+k]fluoranthene of 240 and 1340000 µg/kg (Ontario Sediment Quality Guidelines 1993 lowest effect level and severe effect level respectively). ** is the ATA Criteria for each of benzo[b]fluoranthene and benzo[k]fluoranthene separately. N.d. = not detected; limit of reporting: 10 µg/kg. Samples comprised the top 2 cm of sediment. Data not normalised to 1% OC. Site locations are shown in Figure 28.*

Table 8 Sediment polycyclic aromatic hydrocarbon (PAH) concentrations – normalised to 1% organic carbon (*Ecotoxicological investigation of the groundwater interception drain outfall at Claisebrook in the Swan Estuary* – Nice 2013a) showing where PAH concentrations are higher than ANZECC ISQGs and ATA Acceptance Criteria.

| Sediment polycyclic aromatic hydrocarbon (PAH) concentrations (µg/kg) dry weight, normalised to 1% organic carbon | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Naphthalene | Acenaphthylene | Acenaphthene | Fluorene | Phenanthrene | Anthracene | Fluoranthene | Pyrene | Benz[a]anthracene | Chrysene | Benzo[b+k]fluoranthene * | Benzo[a]pyrene | Indeno[1,2,3,c,d]pyrene | Dibenz[a,h]anthracene | Benzo[g,h,i]perylene | Total PAHs |
| CBE01 | n.d. | 6.6 | n.d. | n.d. | 4.5 | 3.0 | 15.2 | 22.2 | 12.1 | 9.6 | 19.7 | 15.7 | 6.1 | 2.0 | 7.1 | 121.2 |
| CBE02 | n.d. | 7.0 | n.d. | n.d. | 2.3 | 2.3 | 11.6 | 18.6 | 9.3 | 9.3 | 18.6 | 14.0 | 7.0 | n.d. | 7.0 | 109.3 |
| CBE03 | n.d. | 2.8 | n.d. | n.d. | 13.9 | 5.6 | 27.8 | 33.3 | 16.7 | 13.9 | 25.0 | 16.7 | 5.6 | n.d. | 8.3 | 172.2 |
| CBE04 | n.d. | 10.3 | n.d. | n.d. | 3.4 | 6.9 | 20.7 | 41.4 | 20.7 | 17.2 | 37.9 | 31.0 | 13.8 | 3.4 | 13.8 | 217.2 |
| CBE05 | n.d. | 12.5 | n.d. | n.d. | 12.5 | 8.3 | 58.3 | 91.7 | 37.5 | 37.5 | 66.7 | 41.7 | 16.7 | 0.0 | 25.0 | 258.3 |
| CBE06 | n.d. | 10.3 | n.d. | n.d. | 6.9 | 5.2 | 24.1 | 36.2 | 19.0 | 19.0 | 37.9 | 25.9 | 10.3 | 2.6 | 15.5 | 179.3 |
| CBE07 | 17.4 | 739.1 | 113.0 | n.d. | 304.3 | 387.0 | 1434.8 | 2652.2 | 1087.0 | 652.2 | 1260.9 | 1217.4 | 304.3 | 100.0 | 343.5 | 10434.8 |
| CBE08 | n.d. | 8.6 | n.d. | n.d. | 5.7 | 5.7 | 22.9 | 37.1 | 17.1 | 17.1 | 34.3 | 25.7 | 11.4 | 2.9 | 14.3 | 202.9 |
| CBE09 | n.d. | 97.2 | n.d. | n.d. | 41.7 | 41.7 | 416.7 | 500.0 | 277.8 | 222.2 | 458.3 | 319.4 | 111.1 | 27.8 | 125.0 | 2638.9 |
| CBE10 | n.d. | 2.4 | n.d. | n.d. | n.d. | n.d. | 7.3 | 12.2 | 4.9 | 4.9 | 12.2 | 7.3 | 2.4 | n.d. | 4.9 | 58.5 |
| CBE11(ref) | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 7.7 | 7.7 | 3.8 | 3.8 | 7.7 | 7.7 | n.d. | n.d. | n.d. | n.d. |
| ISQG Low | 160 | 44 | 16 | 19 | 240 | 85 | 600 | 665 | 261 | 384 | n.a. | 430 | n.a. | 63 | n.a. | 4000 |
| ISQG High | 2100 | 640 | 500 | 540 | 1500 | 1100 | 5100 | 2600 | 1600 | 2800 | n.a. | 1600 | n.a. | 260 | n.a. | 45000* |
| ATA Criteria | 600 | 40 | 200 | 40 | 400 | 180 | 800 | 2000 | 200 | 800 | 800** | 1000 | 120 | 120 | 120 | 6000 |

*Red border indicates site within the zone of interest. ISQG = Interim Sediment Quality Guideline (ANZECC & ARMCANZ 2000); single black border indicates concentration higher than ATA Acceptance Criteria, double black border indicates concentration higher than 10xATA Acceptance Criteria); blue indicates concentration higher than low ISQG; orange indicates concentration higher than high ISQG; n.a. = no ANZECC & ARMCANZ guideline available; * alternative guidelines for benzo[b+k]fluoranthene of 240 and 1340000 µg/kg (Ontario Sediment Quality Guidelines 1993 lowest effect level and severe effect level respectively). ** is the ATA Criteria for each of benzo[b]fluoranthene and benzo[k]fluoranthene separately. N.d. = not detected; limit of reporting: 10 µg/kg. Samples comprised the top 2 cm of sediment. Data normalised to 1% OC. Site locations are shown in Figure 28.*

This demonstrates that the current PAH concentrations (Nice 2013a) within the *zone of interest* are higher than both the ANZECC ISQGs and the ATA Acceptance Criteria for sediment for almost all PAHs for which ISQGs and ATA Criteria exist (for both normalised and non-normalised datasets).

It may be argued that it is not appropriate to compare the current data to the ATA Criteria given that the ATA Criteria were intended for comparison with average concentrations for a domain of interest over depths of 0.5 and 1 m (Tingay and Associates 1994a) and the data from Nice 2013a were obtained from individual composited surficial samples at specific sites. However, acknowledging that sediments are typically heterogeneous in nature which in turn tends to result in an unsystematic distribution of contaminant concentrations, the ATA Criteria state that:

*'…it is conceivable that an aberrant high value may occur in the midst of a field of low values of concentration so that the average concentrations is acceptable. To guard against the slight possibility that such a value might be unacceptably high itself, a screening threshold of ten times the acceptance criterion for average concentrations has been established.'*

This means that individual sample concentrations should not exceed ten times the ATA Criteria. When applying the 'ten times the ATA Criteria' conversion to current individual sample concentration data from Nice 2013a, concentrations of acenapthylene and benzo[a]anthracene, in the *zone of interest* also exceeded the altered ATA Criteria for the non-normalised dataset; and acenapthylene exceeded the altered ATA Criteria for the normalised dataset (Table 7 and Table 8), indicated by the double bordered cells.

## 5.3 Is there evidence to suggest the source of the contamination is a renewing or recent source?

The range of PAHs detected in the recent DoW studies includes many of the low-molecular-weight PAHs, which break down relatively rapidly in the environment (Volkering and Breure 2003; Wilson and Jones 1993). Degradation is exacerbated in relatively high-energy environments such as the middle Swan Estuary in the Claisebrook area, where the surficial sediments are likely to be subject to agitation and suspension from waves, tidal action and boat activity. This coupled with processes such as bioturbation (Simpson et al. 2005) and biodegradation (Herbes and Schwall 1978) would likely accelerate the breakdown of such contaminants. Thus, their presence may suggest the potential for a renewing or recent source.

Further, the ratio of low-molecular-weight PAHs to high-molecular-weight PAHs in a sample provides a measure of its "freshness" (Bowman Bishaw Gorham 1993). The Freshness Index is calculated as the ratio between [naphthalene+acenaphthalene] : [Benzo(b)+(k) fluoranthene], and the higher the index, the fresher the PAH contamination. Freshness indices are presented (Table 9) for a range of sites sampled in 2011 (Nice 2013a). While it is not possible to determine exactly how 'fresh' or recent this contamination is, the sediment collected from the site located within the *zone of interest* (CBE07 – Nice 2013a) had the highest freshness index indicating the contamination in this area is likely to be fresher (more recent) than at the other sites examined in this study.

This observation was supported for data sourced from Nice and Fisher (2011) for sites located within the *zone of interest* (CBC05 and CBC06) (Table 10).

Table 9 Freshness indices for sites assessed in 2011 (Nice 2013a).

| Sediment polycyclic aromatic hydrocarbon (PAH) concentrations (µg/kg) dry weight | | | |
|---|---|---|---|
| Site | Naphthalene + Acenaphthalene | Benzo[b+k]fluoranthene | freshness index |
| CBE01 | 130 | 390 | 0.33 |
| CBE02 | 30 | 80 | 0.38 |
| CBE03 | 10 | 90 | 0.11 |
| CBE04 | 30 | 110 | 0.27 |
| CBE05 | 15 | 80 | 0.19 |
| CBE06 | 30 | 110 | 0.27 |
| CBE07 | 1740 | 2900 | 0.60 |
| CBE08 | 30 | 120 | 0.25 |
| CBE09 | 70 | 330 | 0.21 |
| CBE10 | 10 | 50 | 0.20 |
| CBE11 (reference site) | 0 | 20 | 0 |

Data not normalised to 1% organic carbon. Red border indicates site located within *zone of interest*.

Table 10 Freshness indices for sites assessed in 2009 (Nice and Fisher 2011).

| Sediment polycyclic aromatic hydrocarbon (PAH) concentrations (µg/kg) dry weight | | | |
|---|---|---|---|
| Site | Naphthalene + Acenaphthalene | Benzo[b+k]fluoranthene | freshness index |
| CBC01 | 78 | 590 | 0.13 |
| CBC02 | 88 | 460 | 0.19 |
| CBC03 | 53 | 180 | 0.29 |
| CBC04 | 162 | 1200 | 0.14 |
| CBC05 | 820 | 1300 | 0.63 |
| CBC06 | 1570 | 2800 | 0.56 |
| CBC07 | 117 | 360 | 0.33 |
| CBC08 | 25 | 230 | 0.11 |
| CBC09 | 510 | 1600 | 0.32 |
| CBC10 | 88 | 280 | 0.31 |
| CBC11 | 61 | 210 | 0.29 |
| CBC18 (reference site) | 19 | 100 | 0.19 |

Data not normalised to 1% organic carbon. Red border indicates sites located within the *zone of interest*.

In summary, although it is not possible to establish the precise timing the contamination occurred in the *zone of interest*, there is evidence to suggest the concentrations have increased since remediation occurred in 1994, indicating a source more recent than 1994 (refer to Section 5.1); and given that relatively high concentrations (exceeding ISQGs) of these low-molecular-weight PAHs have been measured in the area over a period of four years in the DoW studies (2007 - 2011), a recent or current source of PAH contamination to the area should be considered. Furthermore, the PAH contamination measured specifically within the *zone of interest* in 2009 and 2011 (Nice and Fisher 2011; Nice 2013a respectively) is likely to be more recent contamination than at other sites assessed in the same studies demonstrated here (freshness indices).

## 5.4 Is the current PAH contaminant signature representative of that associated with the contaminated site prior to remediation?

The investigation of the East Perth Gasworks Site conducted in 1990 prior to remediation (Camp Scott Furphy 1990) concluded that the signature (composition) of PAHs in the highly contaminated sediments of Claisebrook Drain and the Swan Estuary could be used as a tracer (fingerprint) for the principal PAHs emanating from the gasworks site.

Figure 32 shows the distribution of PAH contamination in surface sediments prior to remediation (Bowman Bishaw Gorham 1992). Figure 33 and Figure 34. show the PAH signature (composition) in the surface sediments of the remediation zone prior to remediation (Bowman Bishaw Gorham 1992) and in recent studies (Nice 2013a, Nice and Fisher 2011 and Nice 2009) respectively.

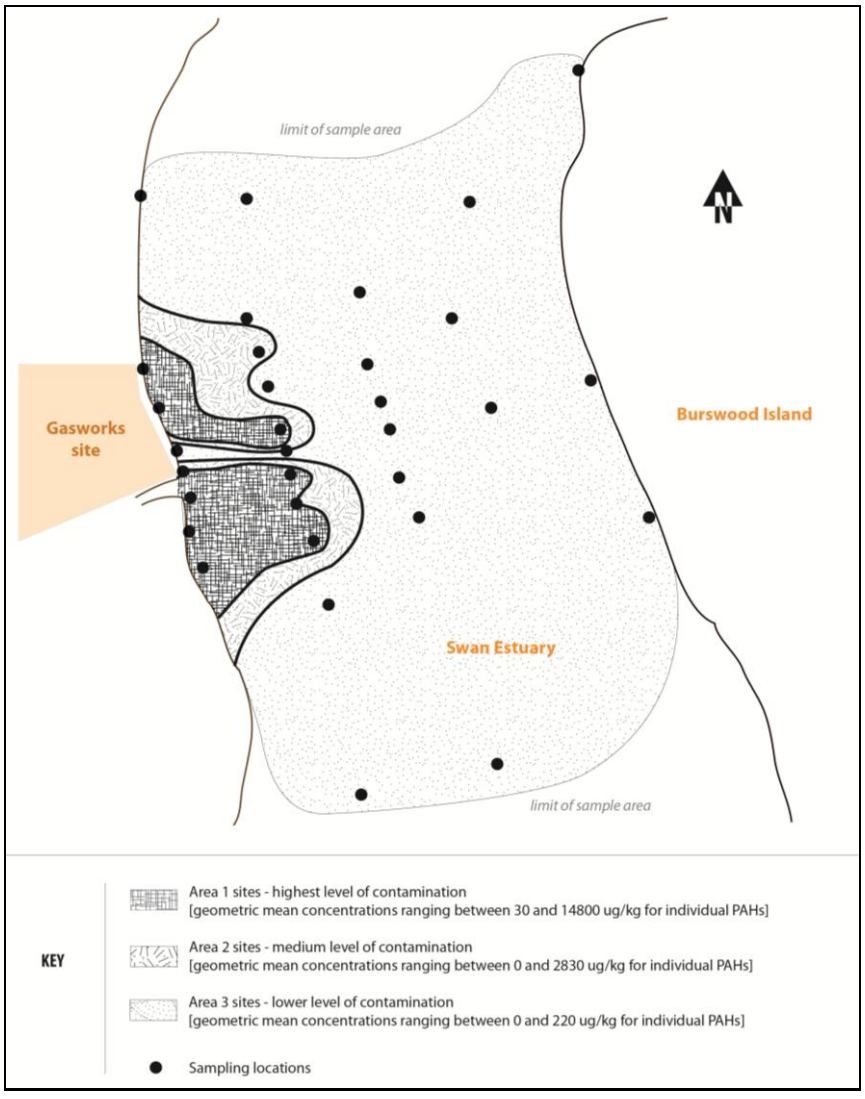


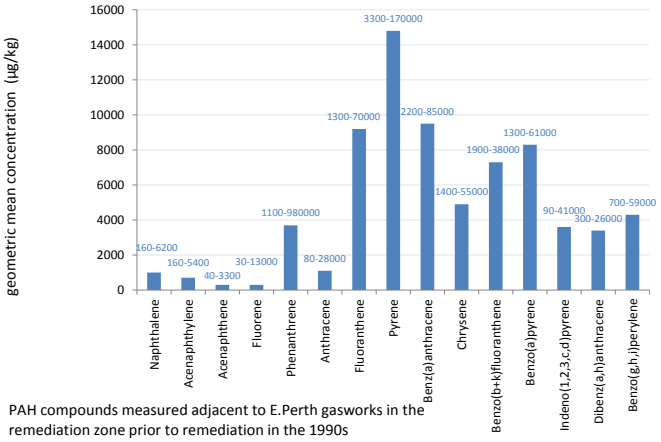

Figure 32 Distribution of PAH contamination in surface sediments of the Swan Estuary (modified from Bowman Bishaw Gorham 1992).

Figure 35 shows the PAH signature (composition) in the surface sediments for sites located specifically in the *zone of interest* (2009-2011) based on concentrations provided in Nice and Fisher (2011) and Nice (2013a).

Given that the historic signature (composition) of PAHs in the highly contaminated sediments of the Swan Estuary (shown in Figure 33) can be used as a tracer (fingerprint) for the principal PAHs emanating from the gasworks site (according to Camp Scott Furphy 1990), and the profile is similar to that generated from the recent studies (Figure 34 and Figure 35), it is likely that the contamination measured recently also emanated from the gasworks site.

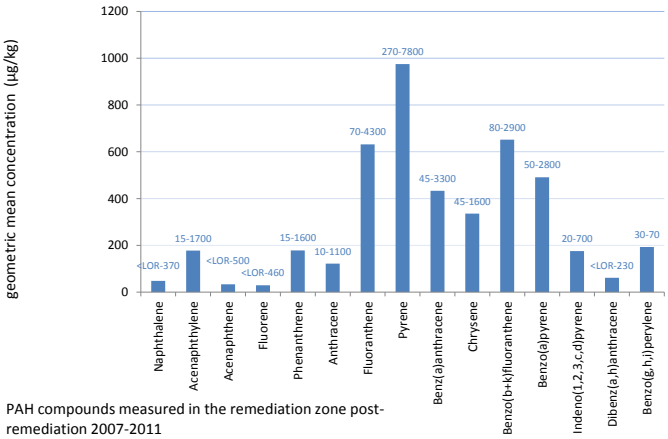
For comparison, Figure 36, Figure 37 and Figure 38 show the PAH profiles of sediments collected from three drains discharging to the Swan-Canning system in 2006 (data from Nice et al. 2009); and Figure 39 and Figure 40 show the PAH profiles of sediments collected from elsewhere in the Swan Estuary in 2007 (data from Nice 2009). Subtle differences in the profiles exist between those samples collected from adjacent to the historic East Perth Gasworks site (blue graphs) and those collected in the wider environment (green graphs). For example, benzo[b+k]fluoranthene is present in the highest concentrations in samples collected from the wider environment (estuary and drains) (Figure 36 to Figure 40), whereas pyrene is present in the highest concentrations in sediments adjacent to the historic gasworks site (Figure 33 to Figure 35). Furthermore the ratios of fluoranthene to pyrene are notably different between sediments collected from adjacent to the gasworks site and those collected from the wider environment (both estuary and drain sites, Nice 2009, Nice et al. 2009).

In summary, the PAH contaminant signature in the *zone of interest* is representative of that associated with the contaminated site prior to remediation.



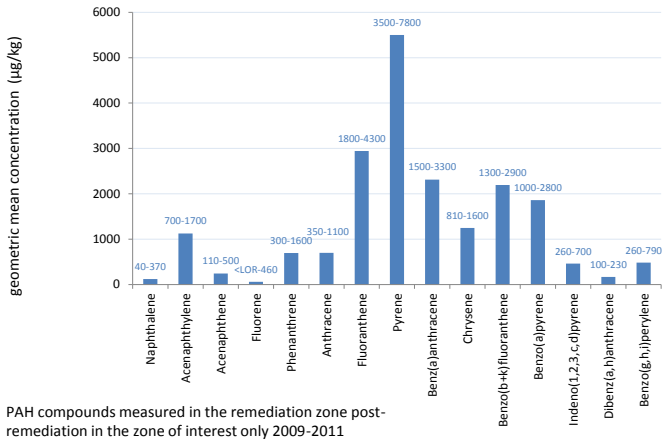

PAH compounds measured adjacent to E.Perth gasworks in the remediation zone prior to remediation in the 1990s

Figure 33 PAH signature in the estuary sediments pre-remediation. Data range provided above bars. [data sourced from Bowman Bishaw Gorham 1992].



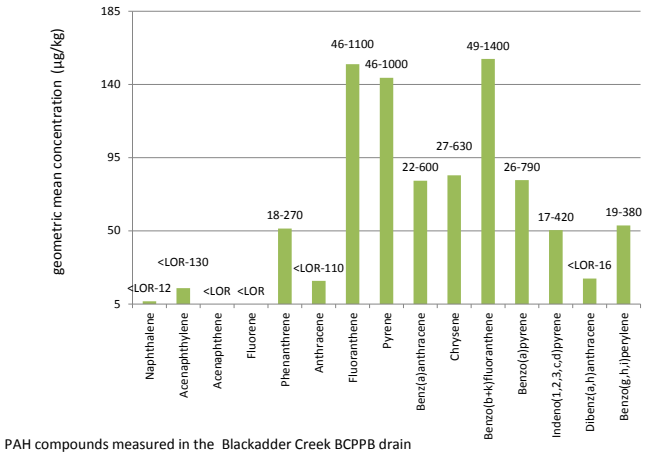

PAH compounds measured in the remediation zone post-remediation 2007-2011

Figure 34 PAH signature in the estuary sediments at sites located in the remediation zone 2007-2011. Data range provided above bars. [data sourced from Nice 2013a, Nice and Fisher 2011 and Nice 2009].



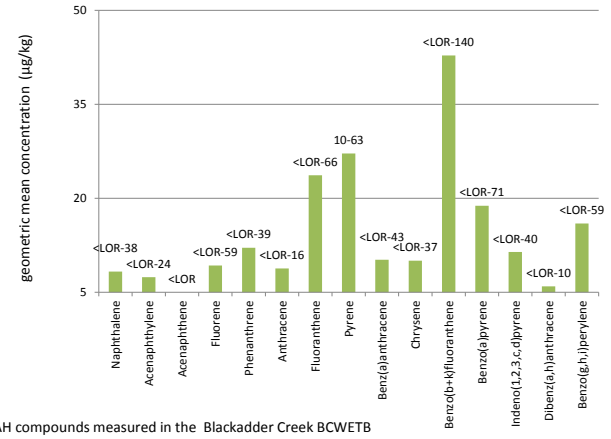

PAH compounds measured in the remediation zone post-remediation in the zone of interest only 2009-2011

Figure 35 PAH signature in the estuary sediments at sites located in the *zone of interest* 2009-2011. Data range provided above bars. [data sourced from Nice 2013a and Nice and Fisher 2011].



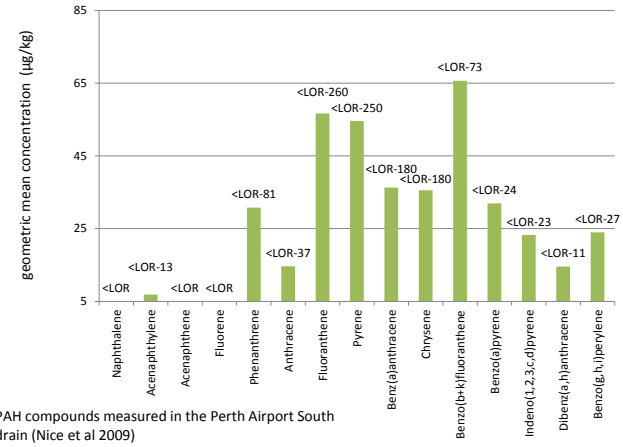

PAH compounds measured in the Blackadder Creek BCPPB drain (Nice et al 2009)

Figure 36 PAH signature in the Blackadder Creek sediments at drain BCPPB. Data range provided above bars. [data sourced from Nice et al. 2009].



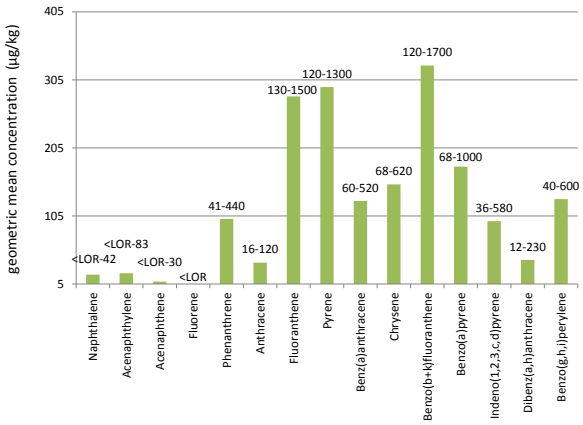

PAH compounds measured in the Blackadder Creek BCWETB drain (Nice et al 2009)

Figure 37 PAH signature in the Blackadder Creek sediments at drain BCWETB. Data range provided above bars. [data sourced from Nice et al. 2009].



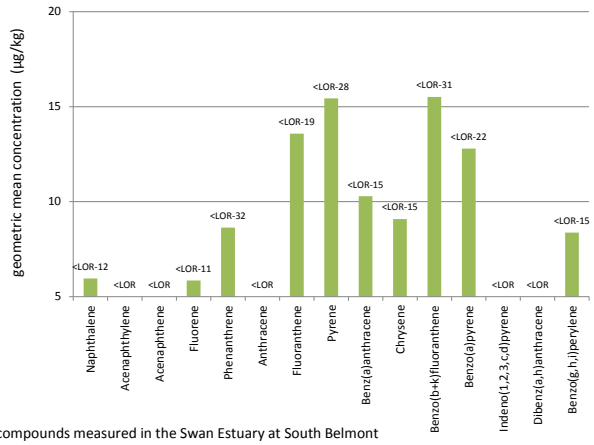

PAH compounds measured in the Perth Airport South drain (Nice et al 2009)

Figure 38 PAH signature in the Perth Airport South Drain sediments. Data range provided above bars. [data sourced from Nice et al. 2009].




PAH compounds measured in the Swan Estuary ajacent to Central Business District (Nice 2009)

Figure 39 PAH signature in the Swan Estuary sediments adjacent to the Central Business District. Data range provided above bars. [data sourced from Nice 2009].




PAH compounds measured in the Swan Estuary at South Belmont (Nice 2009)

Figure 40 PAH signature in the Swan Estuary sediments adjacent to South Belmont. Data range provided above bars. [data sourced from Nice 2009].

## 5.5 Are the PAH concentrations of enough concern to prompt further management action? – Application of the Weight of Evidence Decision Matrix.

Since the release of the Australian ISQGs (within the ANZECC and ARMCANZ Guidelines – 2000), changes to the assessment framework have been recommended to incorporate multiple lines of evidence (chemistry, ecotoxicology, bioaccumulation and ecology) in an improved *weight of evidence* assessment protocol (e.g. Batley and Simpson 2008). The revised framework (due to be released in 2014) provides an extension to the existing approach of simple comparisons with guideline trigger values and provides greater certainty in impact assessment where guideline trigger values are exceeded.

Here, in order to determine whether the contamination in the *zone of interest* is significant enough to prompt further management action (e.g. to reduce the levels of existing contamination and/or to set up measures to prevent further contamination to the area), the weight of evidence framework has been applied and scores have been allocated (according to Batley and Simpson, 2008) (Table 11).

Scores of 1, 2 or 3 are based on the significance of the difference to control or reference conditions (1 representing no difference). The final line of evidence score listed within each line of evidence category is the highest scoring assessment in that category.

An overall *weight of evidence* score of 1 suggests adverse effects are unlikely, an overall *weight of evidence* score of 2 suggests adverse effects are possible; and an overall *weight of evidence* score of 3 suggests adverse effects are likely.

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Table 11 Weight of Evidence Decision Matrix (modified from Batley and Simpson 2008) for the *zone of interest* in the estuary adjacent to Mardalup Park.

| Lines of evidence | | | | Line of Evidence score | Explanation | Data source |
|---|---|---|---|---|---|---|
| **1. Chemistry Line of Evidence**[1] | | | | | | |
| **Comparison with sediment Trigger Values (TV**[2]**)** | | | | | | |
| >TV<ISQG-high | >ISQG-high | Bioavailability consideration | | | | |
| PAHS:<br>acenapthene<br>phenanthrene<br>anthracene<br>fluoranthene<br>benzo[a]anthracene<br>chrysene<br>benzo[a]pyrene<br>dibenz[a,h]anthracene<br><br>OC pesticide:<br>p,p'-DDE<br><br>Metals:<br>lead<br>zinc<br><br>Score: 2 | PAHs:<br>acenapthylene<br>pyrene<br><br>Score: 3 | PAH concentrations were normalised to 1% organic carbon<br><br>OC pesticide concentrations were normalised to 1% organic carbon<br><br>Metal concentrations were determined using *bioavailable metals* methods[3] | | Score: 3 | ISQG-high exceeded for acenapthylene and pyrene.<br><br>Sediment TV exceeded for eight additional PAHs, one OC pesticide; and two metals.<br><br>[Similar sediment chemistry results were reported for sites located within the *zone of interest* in an earlier study and would also result in a LOE score of 3.] | Nice 2013a<br><br>Nice and Fisher 2011 |
| **2. Toxicity Line of Evidence**[4] | | | | | | |
| Whole-sediment tests | Elutriate tests | | | | | |
| Amphipod 10-d survival<br>20-50% effect<br><br>Score: 2 | Copepod 48-hr survival<br>100% effect<br><br>Score: 3 | Mussel 48-hr larval development<br>20-50% effect<br><br>Score: 2 | Fish 96-hr larval development test<br>100% effect<br><br>Score: 3 | Score: 3 | High toxicity in copepod and fish tests. Moderate toxicity in amphipod and mussel tests.<br>[Similar sediment toxicity results were reported for a site located within the *zone of interest* in an earlier study and would also result in a LOE score of 3.] | Nice 2013a<br><br>Nice and Fisher 2011 |
| **3. Bioaccumulation Line of Evidence** | | | | | | |
| Field-collected mussels | | | | | | |
| Bioaccumulation of metals, OC pesticides and PAHs not significant.<br><br>Score: 1 | | | | Score: 1 | Bioaccumulation of metals, OC pesticides and PAHs not significant compared to upstream and downstream reference sites (most OC pesticides and all PAHs not actually detected at limits of reporting of 0.001 and 0.01 mg/kg respectively). | Nice and Fisher 2011 |
| **4. Biomarkers of physiological stress Line of Evidence** | | | | | | |
| Field-collected fish and mussels | | | | | | |
| Intersex condition[5] in fish.<br><br>Score: 1-2 | Elevated hepatic detoxification enzymes in fish.<br><br>Score: 2 | Elevated biliary PAH metabolites in fish.<br><br>Score: 2 | DNA damage in mussels<br><br>Score: 1 | Score: 2 | Intersex condition, elevated hepatic detoxification enzymes and elevated biliary PAH metabolites (indicators of physiological stress) were reported for fish occupying the general Claisebrook area compared to reference site fish. The effects were significant. However, a moderate score of 2 (rather than 3) has been allocated to this line of evidence because given that fish are mobile, it was not possible to attribute the effects to contamination in the *zone of interest per se.* DNA damage in mussels was not significant compared to upstream reference site. | Rawson et al. 2011 |
| Weight of evidence Assessment of Lines of Evidence | | | | | | |
| Chemistry | Toxicity | Bioaccumulation | Biomarkers of physiological stress | **Weight of Evidence score** | **Assessment Decision** | |
| 3 | 3 | 1 | 2 | **3** | **Adverse effects likely** | |

[1]An additional component to the chemistry line of evidence that may be considered when applying the weight of evidence decision matrix for assessment of lines of evidence is the porewater concentrations versus aqueous TV. This was not calculated here because these data were not available. However this would not alter the score, given that the final line of evidence score listed in each line of evidence category is the highest scoring assessment in that category. Based on TVs, the highest score (3) has already been allotted to the chemistry line of evidence.

[2]TV = ISQG low

[3]Bioavailability consideration: Acid volatile sulphide data were not available. However, the concentrations of metals presented here were determined through cold dilute acid extraction, considered to provide an approximation of the metals that are biologically available (Simpson et al. 2005).

[4]An additional component of the toxicity line of evidence that may be considered is porewater toxicity. Porewater toxicity data were not available. However this would not alter the resulting score, given that a score of 3 had already been allotted to this line of evidence from the results of the elutriate toxicity testing.

[5]It is possible that the existence of the intersex condition may be indicative of endocrine disruption. However, given that the black bream (the fish sampled in this study) are rudimentary hermaphrodites often displaying both male and female gonad tissue simultaneously (Buxton and Garatt 1990), controlled laboratory experiments would be required to confirm endocrine disruption due to contaminant exposure. Thus a low to moderate score of 1-2 has been allocated.

Note: the Benthic Macroinvertebrate Survey, while providing an additional line of evidence to the DoW (2013) investigations, did not have a site within the *zone of interest* as classified in this report, since it targeted the GID and wider spatial scales predetermined by a historic study (Trayler and McKernan 1997). As such, this ecological dataset has not been considered in the WoE matrix.

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### Findings of the Weight of Evidence Decision Matrix

In summary, the Weight of Evidence Decision Matrix demonstrates that the contamination within the *zone of interest* is likely to result in adverse impacts. Thus, it is considered that further management action is necessary.

In order to manage the contamination in the *zone of interest*, the source(s) needs to be determined. The following section provides discussion on the numerous potential sources in the area and their likely contribution.

# 6. Determining the source of the current PAH contamination in the *zone of interest* of the Swan Estuary

There are numerous potential sources for the PAH contamination present in the *zone of interest*. These may be divided into historic (legacy) and/or current. The *zone of interest* is located in the area that underwent extensive remediation of PAH-contaminated sediments in 1994 (Camp Scott and Furphy 1996a) as described in Sections 2 and 3, thus the current high concentrations in the surficial sediments suggest the site was either not adequately remediated or that the PAH contamination seen in this study is more recent than 1994. Given that a recent or current source to the estuary is possible (Section 5.3), both renewing and legacy sources will be considered in this section.

## 6.1 East Perth Power Station and Burswood Peninsula

East Perth Power Station (located upstream) and Burswood Peninsula (located upstream and on the opposite banks) to the *zone of interest* are both currently classified as *possibly contaminated – investigation required* (Contaminated Sites Register, DEC – data retrieved 2013).

The distribution of sediment PAH concentrations (Figure 30) show that the major source for the PAH contamination in the *zone of interest* is unlikely due to current or recent sources located upstream or on the opposite side of the estuary.

Although potential sources such as the East Perth Power Station (upstream) and the Burswood (upstream and opposite) sites could be contributing to the sediment contaminants observed in the *zone of interest*, any contribution is likely to be minor since sites closer to these potential sources had markedly lower sediment PAH concentrations and sediments with similar binding capacity (Nice 2013a, sites: CBE01, CBE02, CBE04, CBE06, CBE08 and CBE10). That is, there was no indication of a PAH contaminant gradient emanating from either of these historic contaminated sites, or from upstream generally.

It is possible that PAH contaminated sediment particles are being carried from an upstream source and settling out upon reaching the *zone of interest*, but unlikely, given that the *zone of interest* is not a site of major deposition (estuary morphology: straight and uniform depth adjacent to Mardalup Park). Further, sediment deposition is not evident in the aerial photographs taken over time compared with other sites (Figure 15).

## 6.2 The Groundwater Interception Drain (GID)

The GID outfall (located upstream of the *zone of interest*) may be the source of *some* PAH contamination to the *zone of interest*, given that compliance monitoring in recent years (ENV 2011a, 2009) has demonstrated that PAHs (and other contaminants) have been shown to be present within the discharge water (ENV 2011a, 2009; Fisher 2013b). However there is no evidence in the DoW studies that suggest the GID is the *major* current or recent source of the PAH contamination in the *zone of interest* downstream, given that relatively low concentrations of PAHs were measured in the sediments (Nice 2013a; 2013b) and water (Fisher 2013a) adjacent to the GID outfall to the estuary and relatively low levels of toxicity were recorded (Nice 2013a). Furthermore, there was no

measurable impact to macroinvertebrate communities that was attributable to the GID (Nice 2013b).

It may be possible that PAHs in solution are carried from the GID outfall to the estuary downstream to the *zone of interest* where the sediment is more favourable for binding (i.e. has higher concentrations of organic carbon and has a higher proportion of finer particles – Nice 2013a). However, this is unlikely since the contaminants would need to remain in the dissolved phase over a distance of approximately 200 m before partitioning out; and PAHs typically bind rapidly to particulate matter once in the environment. Alternatively, in the event that PAHs are being discharged from the GID outfall already bound to sediment particles, it is unlikely that they are being carried downstream before settling given that the *zone of interest* is unlikely to be a site of major deposition, given the estuary morphology at this location (relatively straight with approximately uniform depth) as discussed in Section 6.1.

## 6.3 The Claisebrook Main Drain

The Claisebrook Main Drain discharging through the Claisebrook Drain and the Claisebrook Diversion Drain outfalls immediately downstream[7] from the *zone of interest* is also unlikely to be the *major* source of the PAHs in the *zone of interest*, given that relatively low PAH concentrations were measured in the drainage water of the Claisebrook Main Drain during 2011 using passive sampling technology (Fisher 2013b).

PAH contamination was reported in the sub-surface sediments adjacent to the Claisebrook Diversion Drain outfall (Nice and Fisher 2011) with concentrations of 9 individual PAHs exceeding the low ISQGs. However, there was no evidence of a contamination gradient emanating from this outfall leading towards the *zone of interest*, given that concentrations at sites within the *zone of interest* were markedly higher than adjacent to the outfall in that study. There was also no evidence of a gradient in PAH contamination originating from the Claisebrook Drain outfall located within the cove.

Additionally, there was no evidence of a PAH gradient originating from any downstream site (including the general cove area) (Nice and Fisher 2011).

## 6.4 Brown Street Drain

The Brown Street Drain outfall discharges to the Swan Estuary within the *zone of interest*. However, its catchment is small (0.018 $km^2$) comprising the localised hardstand and park area shown (Figure 41). The hardstand area (limited parking, pavement and sports court) would be unlikely to contain extensive PAH contamination.

The drain (closed pipe according to ENV 2011b) appears to pass through Mardalup Park. However, assuming the integrity of the pipe has been maintained, it is not expected to be carrying contaminated water from Mardalup Park. Furthermore, its placement appears to be above the capping layer described in Section 3 (ENV 2011b).

[7] Local downstream sources were considered because given that this area of the Swan Estuary is tidal, it is possible (although unlikely) that the contamination is coming from downstream.


Figure 41 Catchment and discharge point of Brown Street Drain.

## 6.5 Contaminated groundwater at Mardalup Park

Mardalup Park is located adjacent to the *zone of interest.* Heavily contaminated areas containing hydrocarbons floating on the surface of the groundwater were located within the gasworks site (much of which is now Mardalup Park) in the early 1990s (e.g. Bowman Bishaw Gorham 1992). It was considered acceptable for the contaminated groundwater to remain on site provided it was prevented from migrating offshore (to the estuary and cove) by the implementation of a 'containment cell' in accordance with the Environmental Conditions for the development of the site (Minister for Environment 1994). One of the strategies for the effective operation of the containment cell was for the groundwater level onsite (beneath Mardalup Park) to be maintained at or below estuary level (understood to be mean surface level or Australian Height Datum), thus preventing the migration of contaminated groundwater to the estuary (Axis Environmental 1996; Camp Scott Furphy Ltd 1996b). This was to be achieved by a number of strategies discussed in detail in Section 3.

However, concerns were raised in recent years by the Department of Environment and Conservation (refer to Appendix A of ENV 2007) that the containment cell has not been working effectively, resulting in the passage of contaminants from the East Perth Gasworks site into the Swan Estuary. These concerns were based on compliance monitoring data (e.g. ENV 2003) conducted as part of the Environmental Conditions (Minister for Environment 1994).

In response, a detailed investigation of effective operation of the containment system at Mardalup Park was conducted in 2008 – 2009 (ENV 2009). The authors of this investigation concluded that a groundwater mound existed in the lower middle section of the containment area (i.e. adjacent to the *zone of interest*). This resulted in the groundwater levels in the containment area generally being above the estuary level, giving rise to the potential for 'contained' groundwater to discharge from the site into the Swan Estuary (i.e. no longer be contained onsite); and that PAHs (and other contaminants) were present in this groundwater. Groundwater level contours and flow direction are indicated in Figure 42.

Similarly, the most recent compliance monitoring (available at the time of writing this report) of the containment management strategy (ENV 2011a) demonstrated that groundwater levels in the containment area were again mostly above or equal to the estuary level in July, September and December 2010 (Figure 43). The report notes that the levels observed within the containment area indicate that the flow of groundwater is away from the containment area, including to the interception drain on the western and northern boundaries of Mardalup Park (discussed previously) and to the Swan Estuary on the eastern and southern boundaries (ENV 2011a). This report does not indicate a specific point of entry for the groundwater to the estuary. However, the integrity of the 1 mm thick plastic cut-off curtain on the eastern boundary and the 10.5 mm sheet pile wall on the southern boundary (Figure 20) is currently unknown and may warrant investigation.

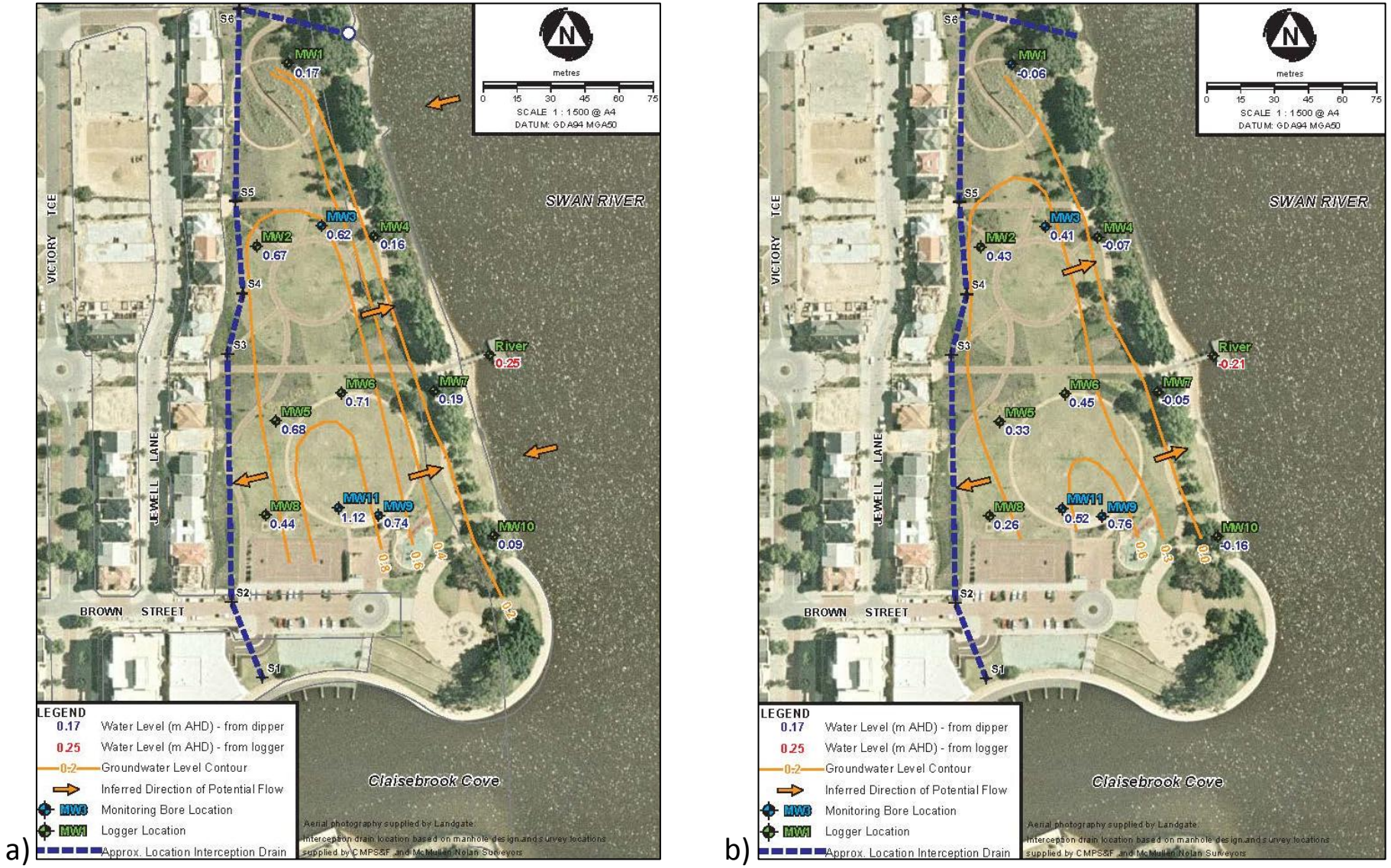


Figure 42 Groundwater level contours and flow direction at Mardalup Park, a) 25/11/2008; b) 06/02/2009 (Source: ENV 2009).

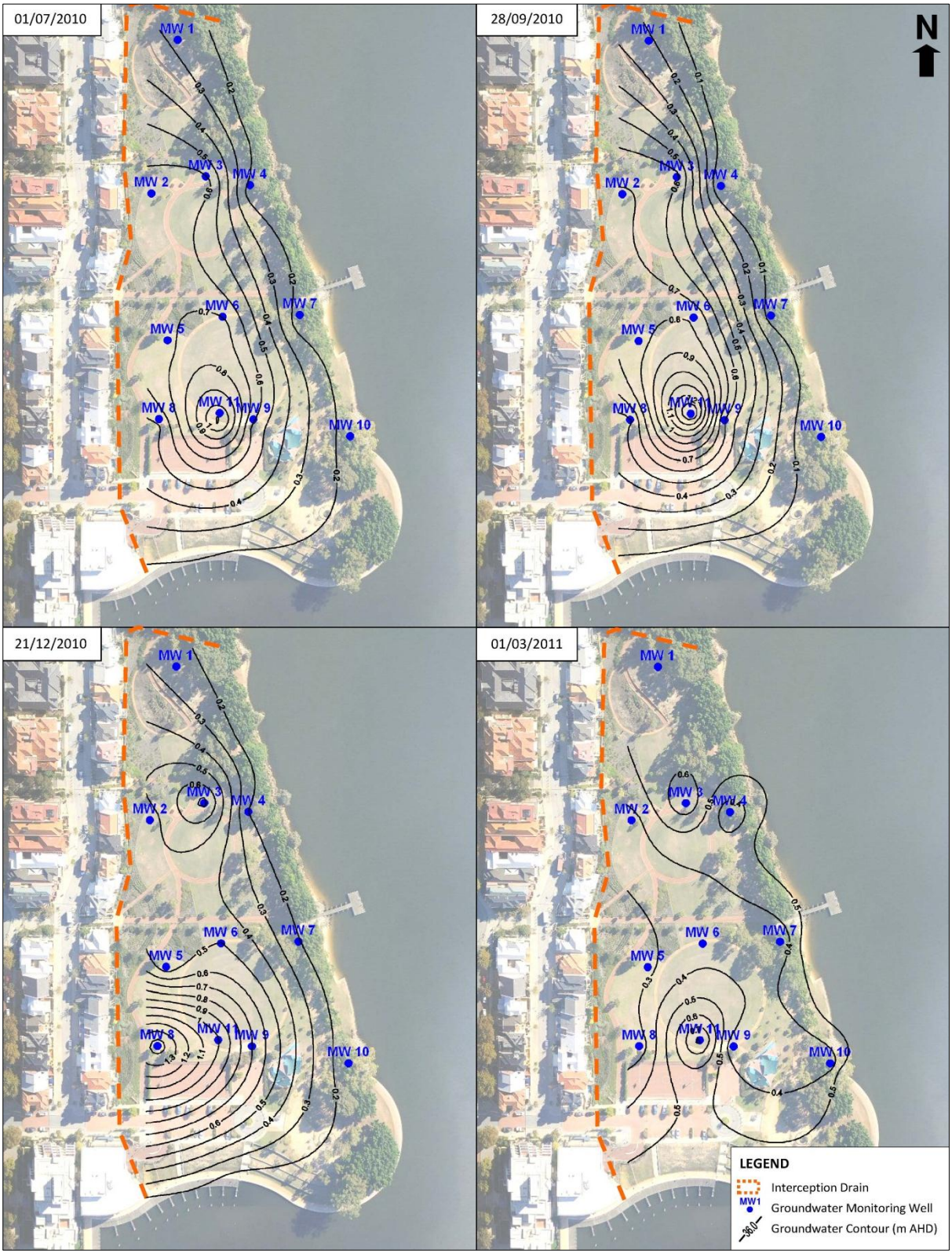


Figure 43 Groundwater contours at Mardalup Park 01/07/2010, 28/09/2010, 21/12/2010 and 01/03/2011. Scale: 1:2800 m (Source: ENV 2011a).

A specific feature of the 'containment cell' for maintaining the groundwater level onsite at or below estuary level (in accordance with the Environmental Conditions – Minister for the Environment 1994) was the installation of a capping layer over the entire open space area (Mardalup Park). The purpose of the capping layer was to prevent the percolation of rainwater into the contaminated groundwater beneath, which, if allowed to happen, would result in a head of groundwater being created through replenishment, resulting in the migration of contaminated groundwater offsite (Camp Scott Furphy 1996b). However, the marked variation in groundwater levels over an 8 month period (shown by the variation in contour patterns in Figure 43), suggests infiltration to the 'contained' area from the surface, resulting in recharge of the groundwater below. This in turn, suggests the integrity of the capping layer may be compromised. Further, it was acknowledged in 1996 that the saponite (swelling clay) capping layer that was applied to the site as an impermeable barrier during the remediation process (refer to Section 3), was not applied to the entire site. The northern portion of the site (shown in Figure 22) remained capped only with sediment sourced from the estuary and found to be more permeable than design requirements had specified (Camp Scott Furphy 1996b).

Additionally, in 2007 monitoring bores were constructed in Mardalup Park to monitor groundwater levels and quality within the containment cell (ENV 2007). However, there was no clear evidence of the saponite layer (or any continuous clay layer) in the monitoring bore construction logs provided (ENV 2008 – Appendix B)

Percolation of water from above the capping layer (resulting in groundwater recharge) may have been exacerbated over the years by the fact that fewer trees were planted than were outlined in the original design specifications for effective operation of the containment cell (Tingay and Associates 1994b), the implication being that less water that falls on the surface will be taken up by evapo-transpiration (ENV 2007). Concerns have also been raised regarding 'over-irrigation' of Mardalup Park also resulting in groundwater recharge (ENV 2007). However, these factors should only become issues if the capping layer integrity is compromised, thus allowing infiltration.

In summary,

- groundwater in the 'contained area' is contaminated with PAHs (e.g. ENV 2009, EPA 1992a; Camp Scott Furphy 1992; Camp Scott Furphy and Golder Associates 1990);
- the direction of groundwater flow suggests offshore migration of this contaminated groundwater, despite attempts to contain it (ENV 2011a, ENV 2009);
- the integrity of the cap appears to be compromised, given a) lack of evidence of saponite layer (bore logs provided in ENV 2008) and b) the saponite layer was not applied to the entire site during remediation (Camp Scott Furphy 1996b); and
- the signature (compositions) currently present in the estuary sediments adjacent to Mardalup Park reflect those in the estuary sediments that had originated from the gasworks site pre-remediation (Section 5.4).

Each of these factors supports the potential for contaminated groundwater at the gasworks site to be a current or recent contributor to the contamination that currently exists in the estuary (*zone of interest*) (Nice 2013a, Nice and Fisher 2011).

## 6.6 Residual estuary sediment contamination not removed in 1994

The estuary sediments adjacent to the East Perth Gasworks site were reported as extensively contaminated by coal tar and coal tar derivatives, including PAHs, in 1992 (Bowman Bishaw Gorham 1992, EPA 1992a). The contaminated zone extended from approximately 50 m north to 250 m south of the gasworks site, including the western half of the Swan Estuary to sediment depths greater than 2.5 m (Bowman Bishaw Gorham 1993, 1992).

Remediation of this area of the Swan Estuary was conducted in 1994 in accordance with the Environmental Conditions (Minister for the Environment 1994). Approximately 13 000 $m^3$ was dredged from the Swan Estuary with a target depth of 1 m $\pm$ 0.1 m below the existing estuary bed level (refer to Figure 16 for the extent of the dredged zone). The dredged area of the estuary was backfilled generally to a depth of 1 m with clean quartz sand from a Gnangara quarry (Camp Scott Furphy 1996a). Further details are provided in Section 3.

The rationale for the remediation of the Swan Estuary was based on the information provided in Box 1, which also acknowledges that some highly contaminated sediments remained in the estuary upon completion of remediation.

**Box 1 Excerpt from Swan River Remediation – East Perth Gasworks – Environmental Management Program, Section 4.3.2, Tingay and Associates (1994a)**

*'…..the risk that erosion of sediments more than 1.0 m below the river bed is negligible. The Swan River Trust also will ensure that future dredging (after remediation) will be managed so as not to excavate the remediated river bed after remediation.*

*In these circumstances, and given that the depth of interest for benthic organisms is 0.6 m below river bed level at any time, the risks of exposure to chemicals more than 1.0 m below river bed is negligible.*

*It is explicitly recognised that this will leave some highly contaminated locations below 1 m depth…'*

Given that sediments highly contaminated with PAHs from the gasworks site remained in the estuary post-remediation (Tingay and Associates 1994a), in the same area (Bowman Bishaw Gorham 1993) as the current *zone of interest*, albeit with approximately 1 m of clean quartz sand placed on top, it is possible that the 'clean' layer has been disturbed or displaced in the intervening 19 years and at least some of the contamination currently reported in the surficial sediments in the *zone of interest* is residual. That is, the contamination is present in the surficial sediments of the estuary today as part of the historic signature from the extensive contamination associated with the operation of the East Perth Gasworks during the 1900s. This is supported by the PAH profiles (Section 5.4), which show that the current PAH contamination is representative of that measured during the 1990s as emanating from the gasworks site (Bowman Bishaw Gorham 1993, 1992).

Furthermore, the current particle size distribution in the *zone of interest* is predominantly fine sediment (0.02 – 250 µm – e.g. Nice 2013a), whereas one would expect a predominance of coarser particles if the area had remained covered with the clean quartz sand applied during remediation.

That is, it is possible that at least partial erosion of the coarse grain sand layer has occurred, which may have resulted in exposure of the legacy sediments below.

It is also possible that a proportion of the finer sediments (present today) have been carried from upstream sources (as discussed in Sections 6.1 and 6.2). However, this is not considered a major factor given lack of evidence to support a major deposition zone adjacent to the mid-portion of Mardalup Park as discussed previously.

## 6.7 Potential diffuse sources

A proportion of the PAH contamination in the *zone of interest* may be attributable to sources such as fuel from boating activity, illegal dumping or general runoff from the catchment (e.g. road and railway related). However, such a high accumulation of PAHs from these sources is unlikely, particularly at this specific site in the estuary. Furthermore, the profile of PAHs from activities such as these would not necessarily match that found to have originated from the gasworks site and shown in section 5.4.

## 6.8 Summary and ranking of potential sources

A summary and ranking of potential sources is provided in Table 12 and a conceptual diagram of potential sources is provided in Figure 44.

Table 12 Summary and ranking of potential sources of the PAH contamination in the *zone of interest.*

| Potential source | Likely level of contribution: negligible/low/moderate/high | Rationale | Rank |
|---|---|---|---|
| Contaminated groundwater at Mardalup Park | high | 1. Groundwater at Mardalup Park is contaminated with PAH compounds (e.g. ENV 2009; EPA 1992a; Camp Scott Furphy and Golder Associates 1990; Sections 2 and 6.5 of this report).<br>2. The direction of groundwater flow suggests offshore migration of contaminated groundwater despite attempts to contain it (ENV 2011a; ENV 2009; Section 6.5 of this report).<br>3. The integrity of the cap appears to be compromised:<br>a) lack of evidence of saponite layer (bore logs provided in ENV 2008)<br>b) saponite layer was not applied to entire area (Camp Scott Furphy 1996b; (refer to Figure 22 –Section 3 of this report)<br>c) groundwater mounding onsite (ENV 2011a; ENV 2009; Section 6.5 of this report).<br>4. The PAH profiles currently present in the estuary sediments are representative of those considered to have emanated from the gasworks site pre-remediation (Section 5.4 of this report).<br>5. Spatial distribution of PAH contamination in DoW studies showing a peak in the *zone of interest* and an absence of a contaminant gradient from other potential sources (Nice 2013a; Nice and Fisher 2011; Section 4 of this report) indicating a localized source.<br>6. Evidence to suggest a recent or renewing source is possible:<br>a) freshness indices were highest in *zone of interest* indicating contamination more recent here than at other sites (Section 5.3 of this report)<br>b) low molecular weight PAH compounds present which breakdown relatively rapidly (Section 5.3 of this report). | 1 |
| Residual contamination remaining in the estuary upon completion of remediation in 1994 | high | 1. Highly contaminated sediments remained in estuary (under a clean quartz sand layer) once remediation was complete (Tingay and Associates 1994a; Section 6.6 of this report).<br>2. Recent particle size distributions in the *zone of interest* do not represent those of a continuous clean quartz sand layer, suggesting this layer may have been displaced or eroded exposing the contaminated sediments beneath (Section 6.6 of this report).<br>3. The PAH profiles currently present in the estuary sediments are representative of those found in this part of the estuary (1992), which were considered to have emanated from the gasworks site pre-remediation (Section 5.4 of this report).<br>4. Spatial distribution of PAH contamination in DoW studies showing a peak in the *zone of interest* and an absence of a contaminant gradient from other potential sources (Nice 2013a; Nice and Fisher 2011; Section 3 of this report) indicating a localized source. | 1 |
| GID outfall | Low to moderate | 1. PAH compounds were present in the GID drainage water (ENV 2011a; ENV 2009; Fisher 2013b; Section 6.2 of this report).<br>2. No evidence in DoW studies (Nice 2013a; Nice 2013b; Fisher 2013a; Fisher 2013b) that suggest it as a *major* current or recent source:<br>a) relatively low concentrations in sediments (Nice 2013a, Nice 2013b) and water column (Fisher 2013a) adjacent to GID outfall<br>b) relatively low levels of toxicity from sediment adjacent to GID outfall (Nice 2013a)<br>c) no measurable impact to macroinvertebrate communities in situ (Nice 2013b).<br>3. The GID may be contributing a *degree* of PAH contamination to the *zone of interest* but is not considered to be a major contributor. | 2 |
| East Perth Power Station (currently classified as *possibly contaminated, investigation required*, DEC 2013) located upstream | Low | 1. It is possible that a *degree* of PAH contamination in the *zone of interest* could be attributable to the historic East Perth Power Station site, especially given that PAH contamination is often associated with coal fire power stations (e.g. Maliszewska-Kordybach 1999). However, there is no evidence in DoW studies (Nice 2013a; Fisher 2013a) that suggest the historic East Perth Power Station site is a *major* contributor (Section 6.1 of this report):<br>a) no evidence of a toxicity or contaminant gradient emanating from the historic East Perth Power Station site<br>b) comparatively low PAH concentrations were recorded in sediments adjacent to historic East Perth Power Station site<br>c) it is possible that contaminated sediments are carried downstream to the *zone of interest* from the historic East Perth Power Station site, but | 3 |

| | | | |
|---|---|---|---|
| | | this is unlikely given the *zone of interest* not considered to be a site of major deposition. | |
| Burswood Peninsula (currently classified as *possibly contaminated*, *investigation required*, DEC 2013) located upstream and on opposite bank of the estuary | low | 1. It is possible that a *degree* of PAH contamination in the *zone of interest* could be attributable to Burswood Peninsula. However, there is no evidence in the DoW studies (Nice 2013a; Nice and Fisher 2011) that suggest the Burswood Peninsula is a *major* contributor (Section 6.1 of this report):<br>a) no evidence of a toxicity or PAH contaminant gradient emanating from the Burswood Peninsula<br>b) comparatively low PAH concentrations were recorded in sediments adjacent to Burswood Peninsula<br>c) it is possible that contaminated sediments are carried across the estuary or downstream to the *zone of interest* from the Burswood Peninsula, but this is unlikely given the *zone of interest* is not considered to be a site of major deposition. | 4 |
| Brown St drain outfall | low | 1. Brown St drain outfall discharges directly to the *zone of interest.* However, its catchment is small (Section 6.4), collecting stormwater from a hardstand and park area of approximately 0.018 $km^2$. The stormwater is unlikely to contain significant concentrations of PAHs, given the landuse in its catchment.<br>2. The drain is a closed pipe that passes through Mardalup Park. There is currently no evidence to suggest the integrity of the pipe has been compromised. However, if this was the case, it is likely that the drain would provide a conduit for PAH contamination present in the groundwater at Mardalup Park (ENV 2011a; ENV 2009) to the *zone of interest.* | 4 |
| Claisebrook Main Drain | negligible | 1. PAH contamination has been detected in the sediments adjacent to both outfalls of the Claisebrook Main Drain (Nice and Fisher 2011; Section 6.3 of this report). However this drain is unlikely to be a *major* contributor to the contamination in the *zone of interest* given that:<br>a) The outfalls are located downstream from the *zone of interest*<br>b) There is no evidence of a contaminant or toxicity gradient emanating from either outfall towards the *zone of interest* (Nice and Fisher 2011)<br>c) Relatively low concentrations of PAH contaminants were measured in the drainage water during 2011 (Fisher 2013b). | 5 |
| Diffuse sources such as fuel from boating activity, illegal dumping or general runoff from the catchment | negligible | 1. A *degree* of PAH contamination is likely to be attributable to a range of diffuse sources (Section 6.7 of this report). However, these sources are unlikely to be *major* contributors to the PAH contamination in the *zone of interest* given that:<br>a) The *zone of interest* is unlikely to be a major deposition zone of the estuary<br>b) The profile of PAHs from such activities would not necessarily match that associated with the gasworks site (Section 5.4). | 5 |

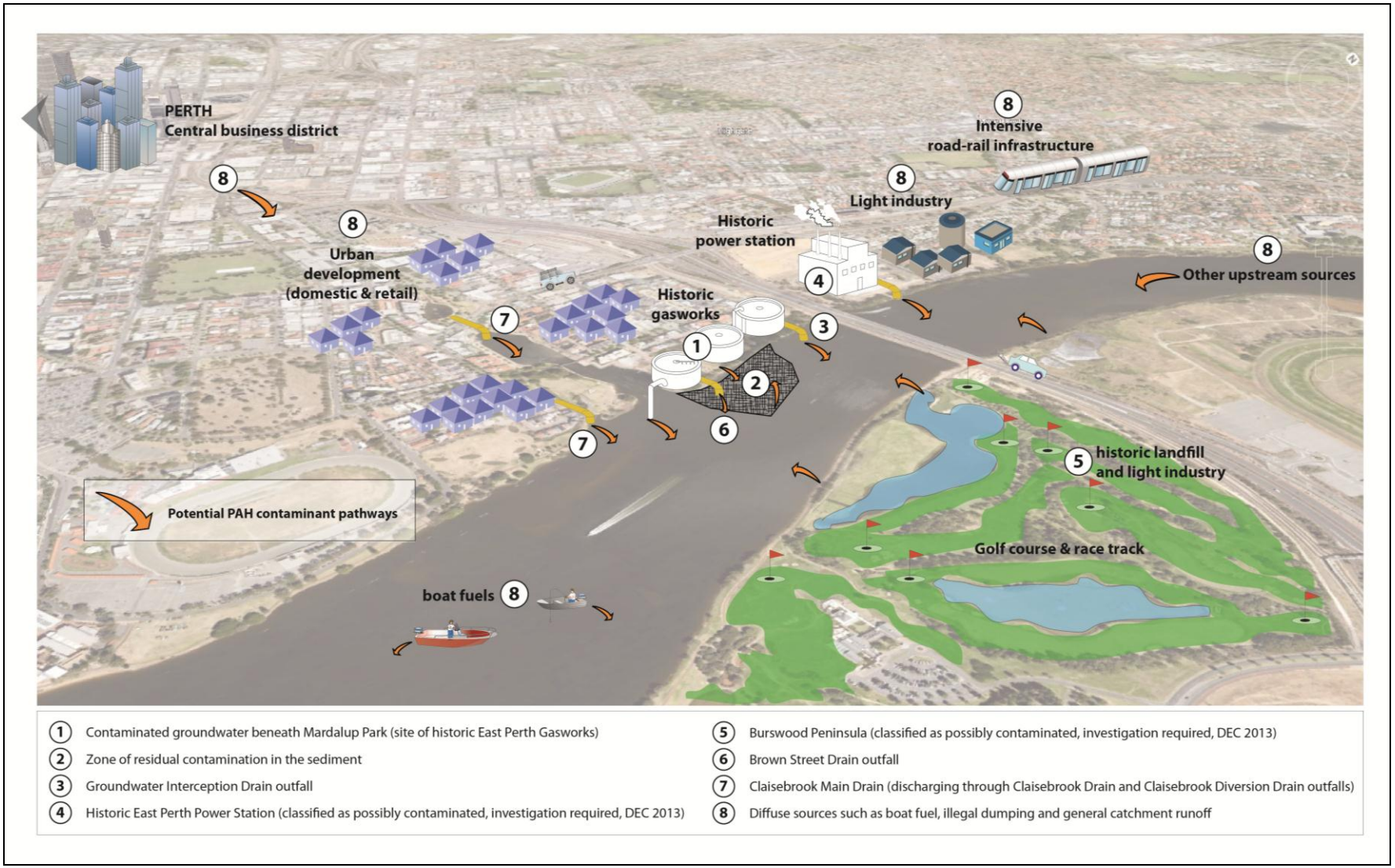


Figure 44 Conceptual diagram of the potential sources likely to be contributing PAH contamination to the *zone of interest.*

# 7. Conclusions

A *zone of interest* exists in the Swan Estuary adjacent to the historic East Perth Gasworks site where the level of contamination associated with the estuary sediments is likely to be deleterious to ecosystem health. When the information presented in the DoW studies (Nice 2013a; Nice and Fisher 2011; Nice 2009) was considered in conjunction with the historic information relating to the surrounding area (refer to Table 13 – Data sources), it was concluded that the primary source of the current PAH contamination in the *zone of interest* is most likely the historic East Perth Gasworks site.

The historic East Perth Gasworks site is considered to be the primary source, either a) through residual contamination of estuarine sediments due to incomplete removal during 1994; or b) through PAH-contaminated groundwater that exists at Mardalup Park (ENV 20011a; ENV 2009); or, most likely a combination of both (Table 12 and Figure 44).

In order to prevent further contamination of the surficial sediments within the *zone of interest*, both the potential future disturbance of residual contaminated sediments in the estuary; and the pathway of contaminated groundwater from Mardalup Park to the estuary require consideration.

# 8. Recommendations

In the context of this report, and in consultation with the Department of Water (DoW), the Swan River Trust (the Trust) makes the following recommendations:

- That the Mardalup Park site be considered for classification under the *Contaminated Sites Act 2003* by the Department of Environment Regulation (DER) and that key stakeholders including the Metropolitan Redevelopment Authority (MRA), Office of the Environmental Protection Authority (OEPA), Department of Health (DoH), DoW and the Trust are informed of and, where appropriate, involved in the classification process.

- That the integrity of the containment cell at Mardalup Park and potential pathways of contaminants from the cell to the Swan River be investigated.

- That an ecological risk assessment be conducted to determine appropriate future management of residual contamination in the Swan River with a particular focus on current and/or future disturbance of these sediments.

- That this information is noted by regulatory and managing authorities such as DER, OEPA and MRA and, where appropriate, used to help inform future management of other known or potentially contaminated sites abutting the Swan and Canning rivers, particularly if a site is to be developed.

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# 10. Appendices

## Appendix 1 – Data sources relating specifically to the development of Claisebrook and ongoing compliance monitoring.

Table 13 Data sources relating to the development of the site and ongoing compliance monitoring.

| Pre-remediation | Post-remediation |
|---|---|
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Tingay & Associates 1994a. Swan River Remediation – East Perth Gasworks – Environmental Management Program – East Perth Redevelopment Authority. January 1994. Report no: 93/86.

Tingay & Associates 1994b. Containment Management Strategy East Perth Gasworks Site – Environmental Management Program – East Perth Redevelopment Authority. February 1994. Report no: 93/84.

for East Perth Redevelopment Authority. ENV Australia Pty Ltd. May 2007.

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ENV 2011b. Environmental Management Plan – 11 Brown Street East Perth. Prepared for Spandau Pty Ltd by ENV Australia Pty Ltd. March 2011.

# Appendix 2 – Contaminant data sourced from Ecotoxicological and bioaccumulation investigations of the Swan Estuary in the vicinity of Claisebrook – Nice and Fisher 2011

Table 14 Sediment polycyclic aromatic hydrocarbon (PAH) concentrations.

| | Sediment polycyclic aromatic hydrocarbon concentrations (µg/kg) normalised to 1% organic carbon* | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Naphthalene | Acenaph-thylene | Acenaph-thene | Fluorene | Phenanthrene | Anthracene | Fluoranthene | Pyrene | Benz[a]a-nthracene | Chrysene | Benzo[b]&[k]-fluoranthene | Benzo[a]-pyrene | Indeno[1,2,3-cd]pyrene | Dibenz[ah]-anthracene | Benzo(ghi)-perylene |
| Site adjacent to Claisebrook Drain outfall | | | | | | | | | | | | | | | |
| CBC01 | 1.84 | 7.13 | n.d | n.d | 17.24 | 13.79 | 63.22 | 65.52 | 25.29 | 28.74 | 67.82 | 29.89 | 12.64 | 4.37 | 20.69 |
| CBC02 | 3.77 | 8.99 | n.d | 4.78 | 23.19 | 18.84 | 94.20 | 133.33 | 55.07 | 28.99 | 66.67 | 37.68 | 17.39 | 5.51 | 21.74 |
| CBC03 | 4.38 | 12.19 | n.d | n.d | 21.56 | 11.56 | 75.00 | 121.88 | 56.25 | 31.25 | 56.25 | 37.50 | 19.38 | 6.88 | 19.69 |
| CBC04 | 4.23 | 26.92 | n.d | 3.27 | 38.46 | 32.69 | 169.23 | 250.00 | 107.69 | 78.85 | 230.77 | 92.31 | 8.08 | 2.88 | 7.88 |
| Sites adjacent to Mardalup Park | | | | | | | | | | | | | | | |
| CBC05 | 100.00 | 583.33 | 91.67 | 83.33 | 250.00 | 291.67 | 1500.00 | 2916.67 | 1250.00 | 675.00 | 1083.33 | 833.33 | 216.67 | 83.33 | 216.67 |
| CBC06 | 336.36 | 1090.91 | 454.55 | 418.18 | 1454.55 | 1000.00 | 3909.09 | 7090.91 | 3000.00 | 1454.55 | 2545.45 | 2090.91 | 490.91 | 190.91 | 500.00 |
| CBC07 | 8.53 | 25.88 | 5.59 | 47.06 | 32.35 | 19.71 | 88.24 | 147.06 | 64.71 | 50.00 | 105.88 | 70.59 | 26.76 | 7.94 | 26.47 |
| Site adjacent to Claisebrook Diversion Drain outfall | | | | | | | | | | | | | | | |
| CBC08 | n.d | 43.10 | n.d | n.d | 162.07 | 60.34 | 465.52 | 465.52 | 327.59 | 206.90 | 396.55 | 224.14 | 82.76 | 34.48 | 74.14 |
| CBC09 | 28.00 | 74.00 | 11.40 | 13.80 | 102.00 | 52.00 | 300.00 | 500.00 | 220.00 | 158.00 | 320.00 | 220.00 | 72.00 | 32.00 | 72.00 |
| CBC10 | 6.00 | 16.00 | n.d | 4.25 | 20.00 | 13.25 | 65.00 | 107.50 | 40.00 | 30.00 | 70.00 | 42.50 | 15.75 | 5.25 | 16.75 |
| CBC11 | 4.38 | 14.69 | n.d | 3.13 | 16.25 | 10.31 | 59.38 | 96.88 | 40.63 | 31.25 | 65.63 | 43.75 | 15.00 | 4.69 | 15.94 |
| CBC18 (Reference) | n.d | 5.94 | n.d | n.d | 9.06 | 4.38 | 29.06 | 37.50 | 16.56 | 15.31 | 31.25 | 18.13 | 7.50 | n.d | 7.81 |
| ISQG Low | 160 | 44 | 16 | 19 | 240 | 85 | 600 | 665 | 261 | 384 | n.a. | 430 | n.a. | 63 | n.a. |
| ISQG High | 2100 | 640 | 500 | 540 | 1500 | 1100 | 5100 | 2600 | 1600 | 2800 | n.a. | 1600 | n.a. | 260 | n.a. |

**Data normalised to 1% organic carbon according to Simpson et al. 2005. ISQG = Interim Sediment Quality Guidline (ANZECC & ARMCANZ 2000). Limit of reporting: 10 µg/kg; n.d. = not detected in concentrations greater than the limit of reporting; n.a. = ISQG not available. Samples comprised the top 2 cm of sediment.*

Table 15 Sediment organochlorine (OC) pesticide concentrations.

| | Sediment organochlorine pesticide concentrations (µg/kg) normalised to 1% organic carbon* | | |
|---|---|---|---|
| | trans-chlordane | dieldrin | p,p'-DDE |
| **Site** | | | |
| Site adjacent to Claisebrook Drain outfall: CBC01 | n.d | 4.94 | 4.25 |
| CBC02 | n.d | 3.04 | 4.20 |
| CBC03 | n.d | n.d | n.d |
| CBC04 | n.d | n.d | 4.23 |
| Sites adjacent to Mardalup Park: CBC05 | n.d | n.d | 14.17 |
| CBC06 | n.d | n.d | 24.55 |
| CBC07 | n.d | n.d | 3.53 |
| Site adjacent to Claisebrook Diversion Drain outfall: CBC08 | n.d | n.d | n.d |
| CBC09 | n.d | 2.40 | 9.80 |
| CBC10 | n.d | n.d | 2.50 |
| CBC11 | n.d | n.d | n.d |
| CBC18 (Reference) | n.d | n.d | n.d |
| ISQG – LOW | 0.50 | 0.02 | 2.20 |
| ISQG – HIGH | 6.00 | 8.00 | 27.00 |

**Data normalised to 1% organic carbon according to Simpson et al. 2005. ISQG = Interim Sediment Quality Guidline (ANZECC & ARMCANZ 2000). Only OC pesticides that were present in concentrations greater than the limit of reporting are presented. Limit of reporting: 10 µg/kg; n.d. = not detected in concentrations greater than the limit of reporting. Samples comprised the top 2 cm of sediment.*

Table 16 Sediment metal concentrations (bioavailable).

| | Sediment metal concentrations (bioavailable) mg/kg | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aluminium | Arsenic | Cadmium | Chromium | Cobalt* | Copper | Lead | Manganese* | Mercury | Nickel | Selenium* | Zinc |
| **Site** | | | | | | | | | | | | |
| Site adjacent to Claisebrook Drain outfall | | | | | | | | | | | | |
| CBC01 | 2620 | 0.7 | 0.8 | 11.0 | 2.2 | 14.0 | 120.0 | 35.0 | n.d. | 5.1 | 0.8 | 740.0 |
| CBC02 | 3900 | 3.4 | 0.7 | 16.0 | 5.0 | 72.0 | 130.0 | 110.0 | n.d. | 6.1 | 0.9 | 660.0 |
| CBC03 | 1360 | 2.0 | n.d. | 5.0 | 2.5 | 22.0 | 42.0 | 65.0 | n.d. | 2.0 | n.d. | 180.0 |
| CBC04 | 3370 | 9.6 | n.d. | 13.0 | 6.4 | 62.0 | 100.0 | 210.0 | n.d. | 4.8 | 0.9 | 430.0 |
| Sites adjacent to Mardalup Park | | | | | | | | | | | | |
| CBC05 | 3220 | 3.5 | n.d. | 11.0 | 5.5 | 36.0 | 87.0 | 170.0 | n.d. | 3.5 | 0.5 | 360.0 |
| CBC06 | 3070 | 3.9 | n.d. | 10.0 | 5.1 | 35.0 | 81.0 | 160.0 | n.d. | 3.4 | 0.6 | 340.0 |
| CBC07 | 2640 | 2.0 | n.d. | 8.7 | 4.0 | 29.0 | 67.0 | 110.0 | n.d. | 3.0 | n.d. | 300.0 |
| Site adjacent to Claisebrook Diversion Drain outfall | | | | | | | | | | | | |
| CBC08 | 170 | 0.7 | n.d. | 0.8 | n.d. | 6.9 | 10.0 | 39.0 | n.d. | n.d. | n.d. | 50.0 |
| CBC09 | 2690 | 4.6 | 0.7 | 11 | 4.6 | 59.0 | 110.0 | 200.0 | n.d. | 4.1 | 0.6 | 460.0 |
| CBC10 | 3400 | 3.0 | n.d. | 12 | 5.3 | 27.0 | 72.0 | 290.0 | n.d. | 3.4 | 0.6 | 330.0 |
| CBC11 | 2690 | 2.2 | n.d. | 8.6 | 4.1 | 25.0 | 54.0 | 170.0 | n.d. | 3.1 | n.d. | 260.0 |
| $CBC18_{reference}$ | 3180 | 6.4 | n.d. | 11 | 7.0 | 50.0 | 66.0 | 460.0 | n.d. | 3.5 | n.d. | 310.0 |
| ISQG Low | n.a. | 20.0 | 1.5 | 80.0 | n.a. | 65.0 | 50.0 | n.a. | 0.15 | 21.0 | n.a. | 200.0 |
| ISQG High | n.a. | 70.0 | 10.0 | 370.0 | n.a. | 270.0 | 220.0 | n.a. | 1.0 | 52.0 | n.a. | 410.0 |

*ISQG = Interim Sediment Quality Guidline (ANZECC & ARMCANZ 2000). Limits of reporting for all metals except mercury: 0.5 mg/kg; limit of reporting for mercury: 0.1 mg/kg. n.d. = not detected in concentrations greater than the limit of reporting; n.a. = ISQG not available; * alternative guidelines for cobalt, manganese and selenium of 50, 1100 and 2 mg/kg respectively (Ontario Sediment Quality Guidelines 1993 & Lemly 1996) were also not exceeded. Samples comprised the top 2 cm of sediment.*

# Appendix 3 – Contaminant data sourced from Ecotoxicological investigation of the groundwater interception drain at Claisebrook in the Swan Estuary – Nice 2013a

Concentrations of organic contaminants such as PAHs and OC pesticides presented here are typically normalised to 1% organic carbon for comparison with the ISQGs (Simpson *et al.* 2005). There is some conjecture as to whether normalising to 1% organic carbon is appropriate where organic carbon concentrations are considered to be high. That is, in instances where total organic carbon concentrations have been increased above normal concentrations due to organic contamination (such as petroleum compounds), the organic carbon normalised values may be inappropriately low and may not exceed ISQGs even though adverse biological effects may occur (Michelsen 1992). As such, both normalised and non-normalised PAH and OC pesticide data are presented at this stage of the investigation in the following tables.

Table 17 Sediment polycyclic aromatic hydrocarbon (PAH) concentrations

| Sediment polycyclic aromatic hydrocarbon (PAH) concentrations (µg/kg) dry weight | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Naphthalene | Acenaphthylene | Acenaphthene | Fluorene | Phenanthrene | Anthracene | Fluoranthene | Pyrene | Benz[a]anthracene | Chrysene | Benzo[b+k]fluoranthene * | Benzo[a]pyrene | Indeno [1,2,3-cd] pyrene | Dibenz[a,h]anthracene | Benzo [g,h,i]perylene | Total PAHs |
| CBE01 | n.d. | 130 | n.d. | n.d. | 90 | 60 | 300 | 440 | 240 | 190 | 390 | 310 | 120 | 40 | 140 | 2400 |
| CBE02 | n.d. | 30 | n.d. | n.d. | 10 | 10 | 50 | 80 | 40 | 40 | 80 | 60 | 30 | n.d. | 30 | 470 |
| CBE03 | n.d. | 10 | n.d. | n.d. | 50 | 20 | 100 | 120 | 60 | 50 | 90 | 60 | 20 | n.d. | 30 | 620 |
| CBE04 | n.d. | 30 | n.d. | n.d. | 10 | 20 | 60 | 120 | 60 | 50 | 110 | 90 | 40 | 10 | 40 | 630 |
| CBE05 | n.d. | 15 | n.d. | n.d. | 15 | 10 | 70 | 110 | 45 | 45 | 80 | 50 | 20 | n.d. | 30 | 310 |
| CBE06 | n.d. | 30 | n.d. | n.d. | 20 | 15 | 70 | 105 | 55 | 55 | 110 | 75 | 30 | 7.5 | 45 | 520 |
| CBE07 | 40 | 1700 | 260 | n.d. | 700 | 890 | 3300 | 6100 | 2500 | 1500 | 2900 | 2800 | 700 | 230 | 790 | 24000 |
| CBE08 | n.d. | 30 | n.d. | n.d. | 20 | 20 | 80 | 130 | 60 | 60 | 120 | 90 | 40 | 10 | 50 | 710 |
| CBE09 | n.d. | 70 | n.d. | n.d. | 30 | 30 | 300 | 360 | 200 | 160 | 330 | 230 | 80 | 20 | 90 | 1900 |
| CBE10 | n.d. | 10 | n.d. | n.d. | n.d. | n.d. | 30 | 50 | 20 | 20 | 50 | 30 | 10 | n.d. | 20 | 240 |
| CBE11 (ref) | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 20 | 20 | 10 | 10 | 20 | 20 | n.d. | n.d. | n.d. | n.d. |
| ISQG Low | 160 | 44 | 16 | 19 | 240 | 85 | 600 | 665 | 261 | 384 | n.a. | 430 | n.a. | 63 | n.a. | 4000 |
| ISQG High | 2100 | 640 | 500 | 540 | 1500 | 1100 | 5100 | 2600 | 1600 | 2800 | n.a. | 1600 | n.a. | 260 | n.a. | 45000 |

Site adjacent to GID

Site adjacent to mid-section of Mardalup Park

*ISQG = Interim Sediment Quality Guideline (ANZECC & ARMCANZ 2000); blue indicates low ISQG exceeded; orange indicates high ISQG exceeded; n.a. = no ANZECC & ARMCANZ guideline available; * alternative guidelines for benzo[b+k] fluoranthene of 240 and 1340000 µg/kg (Ontario Sediment Quality Guidelines 1993 lowest effect level and severe effect level respectively). N.d. = not detected; limit of reporting: 10 µg/kg. Samples comprised the top 2 cm of sediment. Data not normalised to 1% OC.*

Table 18 Sediment polycyclic aromatic hydrocarbon (PAH) concentrations normalised to 1% organic carbon

| Sediment polycyclic aromatic hydrocarbon (PAH) concentrations (µg/kg) dry weight, normalised to 1% organic carbon | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Naphthalene | Acenaphthylene | Acenaphthene | Fluorene | Phenanthrene | Anthracene | Fluoranthene | Pyrene | Benz[a]anthracene | Chrysene | Benzo[b+k]fluoranthene * | Benzo[a]pyrene | Indeno[1,2,3,c,d]pyrene | Dibenz[a,h]anthracene | Benzo[g,h,i]perylene | Total PAHs |
| CBE01 | n.d. | 6.6 | n.d. | n.d. | 4.5 | 3.0 | 15.2 | 22.2 | 12.1 | 9.6 | 19.7 | 15.7 | 6.1 | 2.0 | 7.1 | 121.2 |
| CBE02 | n.d. | 7.0 | n.d. | n.d. | 2.3 | 2.3 | 11.6 | 18.6 | 9.3 | 9.3 | 18.6 | 14.0 | 7.0 | n.d. | 7.0 | 109.3 |
| CBE03 | n.d. | 2.8 | n.d. | n.d. | 13.9 | 5.6 | 27.8 | 33.3 | 16.7 | 13.9 | 25.0 | 16.7 | 5.6 | n.d. | 8.3 | 172.2 |
| CBE04 | n.d. | 10.3 | n.d. | n.d. | 3.4 | 6.9 | 20.7 | 41.4 | 20.7 | 17.2 | 37.9 | 31.0 | 13.8 | 3.4 | 13.8 | 217.2 |
| CBE05 | n.d. | 12.5 | n.d. | n.d. | 12.5 | 8.3 | 58.3 | 91.7 | 37.5 | 37.5 | 66.7 | 41.7 | 16.7 | 0.0 | 25.0 | 258.3 |
| CBE06 | n.d. | 10.3 | n.d. | n.d. | 6.9 | 5.2 | 24.1 | 36.2 | 19.0 | 19.0 | 37.9 | 25.9 | 10.3 | 2.6 | 15.5 | 179.3 |
| CBE07 | 17.4 | 739.1 | 113.0 | n.d. | 304.3 | 387.0 | 1434.8 | 2652.2 | 1087.0 | 652.2 | 1260.9 | 1217.4 | 304.3 | 100.0 | 343.5 | 10434.8 |
| CBE08 | n.d. | 8.6 | n.d. | n.d. | 5.7 | 5.7 | 22.9 | 37.1 | 17.1 | 17.1 | 34.3 | 25.7 | 11.4 | 2.9 | 14.3 | 202.9 |
| CBE09 | n.d. | 97.2 | n.d. | n.d. | 41.7 | 41.7 | 416.7 | 500.0 | 277.8 | 222.2 | 458.3 | 319.4 | 111.1 | 27.8 | 125.0 | 2638.9 |
| CBE10 | n.d. | 2.4 | n.d. | n.d. | n.d. | n.d. | 7.3 | 12.2 | 4.9 | 4.9 | 12.2 | 7.3 | 2.4 | n.d. | 4.9 | 58.5 |
| CBE11 (ref) | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 7.7 | 7.7 | 3.8 | 3.8 | 7.7 | 7.7 | n.d. | n.d. | n.d. | n.d. |
| ISQG Low | 160 | 44 | 16 | 19 | 240 | 85 | 600 | 665 | 261 | 384 | n.a. | 430 | n.a. | 63 | n.a. | 4000 |
| ISQG High | 2100 | 640 | 500 | 540 | 1500 | 1100 | 5100 | 2600 | 1600 | 2800 | n.a. | 1600 | n.a. | 260 | n.a. | 45000* |

Site adjacent to GID

Site adjacent to mid-section of Mardalup Park

*ISQG = Interim Sediment Quality Guideline (ANZECC & ARMCANZ 2000); blue indicates low ISQG exceeded; orange indicates high ISQG exceeded; n.a. = no ANZECC & ARMCANZ guideline available; * alternative guidelines for benzo[b+k] fluoranthene of 240 and 1340000 µg/kg (Ontario Sediment Quality Guidelines 1993 lowest effect level and severe effect level respectively). N.d. = not detected; limit of reporting: 10 µg/kg. Samples comprised the top 2 cm of sediment. Data normalised to 1% OC.*

Table 19 Sediment organochlorine (OC) pesticide concentrations

| Sediment organochlorine (OC) pesticide concentrations (µg/kg) dry weight | | | | | |
|---|---|---|---|---|---|
| Site | trans-Chlordane | Dieldrin | p,p'-DDT | p,p'-DDE | p,p'-DDD |
| CBE01 | 4.2 | n.d. | 2 | 13 | 7.8 |
| CBE02 | 1.1 | 3.9 | 1.1 | 13 | 4.8 |
| CBE03 | 2 | 8.7 | n.d. | 5.6 | 3.7 |
| CBE04 | n.d. | 3.9 | 1.4 | 18 | 7.5 |
| CBE05 | n.d. | 2.9 | n.d. | 1.7 | n.d. |
| CBE06 | n.d. | 2.9 | 1.7 | 9.7 | 3.1 |
| CBE07 | n.d. | n.d. | n.d. | 15 | n.d. |
| CBE08 | 1.2 | 4.6 | 1.5 | 16 | 4.8 |
| CBE09 | n.d. | n.d. | n.d. | 2.2 | 1.2 |
| CBE10 | 1.2 | 4.1 | 1.2 | 13 | 4.2 |
| CBE11(ref) | n.d. | n.d. | n.d. | 3 | n.d. |
| ISQG – low | 0.5* | 0.02 | 1.6** | 2.2 | 2*** |
| ISQG – high | 6* | 8 | 46** | 27 | 20*** |

Site adjacent to GID

Site adjacent to mid-section of Mardalup Park

*Note: Only those parameters detected are shown in this table. ISQG = Interim Sediment Quality Guideline (ANZECC & ARMCANZ 2000); blue indicates low ISQG exceeded; orange indicates high ISQG exceeded. * denotes the ISQG for chlordane (trans-chlordane is one constituent of chlordane). ** denotes the ISQG for total DDT (only p,p'-DDT was measured in this study). *** denotes the ISQG for p,p'-DDD plus o,p'-DDD (only p,p'-DDD was measured in this study). N.d. = not detected; limit of reporting: 1 µg/kg. Samples comprised the top 2 cm of sediment. Data not normalised to 1% organic carbon.*

Table 20 Sediment organochlorine (OC) pesticide concentrations normalised to 1% organic carbon

| | Sediment organochlorine pesticide (OC) concentrations (µg/kg) dry weight, normalised to 1% organic carbon | | | | |
|---|---|---|---|---|---|
| Site | trans-Chlordane | Dieldrin | p,p'-DDT | p,p'-DDE | p,p'-DDD |
| CBE01 | 0.2 | n.d. | 0.1 | 0.7 | 0.4 |
| CBE02 | 0.3 | 0.9 | 0.3 | 3.0 | 1.1 |
| CBE03 | 0.6 | 2.4 | n.d. | 1.6 | 1.0 |
| CBE04 | n.d. | 1.3 | 0.5 | 6.2 | 2.6 |
| CBE05 | n.d. | 2.4 | n.d. | 1.4 | n.d. |
| CBE06 | n.d. | 1.0 | 0.6 | 3.3 | 1.1 |
| CBE07 | n.d. | n.d. | n.d. | 6.5 | n.d. |
| CBE08 | 0.3 | 1.3 | 0.4 | 4.6 | 1.4 |
| CBE09 | n.d. | n.d. | n.d. | 3.1 | 1.7 |
| CBE10 | 0.3 | 1.0 | 0.3 | 3.2 | 1.0 |
| CBE11(ref) | n.d. | n.d. | n.d. | 1.2 | n.d. |
| ISQG – low | 0.5* | 0.02 | 1.6** | 2.2 | 2*** |
| ISQG – high | 6* | 8 | 46** | 27 | 20*** |

Site adjacent to GID

Site adjacent to mid-section of Mardalup Park

*Note: Only those parameters detected are shown in this table. ISQG = Interim Sediment Quality Guideline (ANZECC & ARMCANZ 2000). * denotes the ISQG for chlordane (trans-chlordane is one constituent of chlordane). ** denotes the ISQG for total DDT (only p,p'-DDT was measured in this study). *** denotes the ISQG for p,p'-DDD plus o,p'-DDD (only p,p'-DDD was measured in this study). Blue indicates low ISQG exceeded; orange indicates high ISQG exceeded. N.d. = not detected; limit of reporting: 1 µg/kg. Samples comprised the top 2 cm of the sediment. Data normalised to 1% organic carbon.*

Table 21 Sediment metal concentrations (bioavailable)

| Sediment metal concentrations (bioavailable) mg/kg dry weight | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **Arsenic** | **Cadmium** | **Chromium** | **Cobalt*** | **Copper** | **Lead** | **Manganese*** | **Mercury** | **Nickel** | **Selenium*** | **Zinc** |
| CBE01 | 2.1 | n.d. | 8.3 | 3.9 | 32 | 95 | 170 | n.d. | 5.3 | 0.64 | 270 |
| CBE02 | 1.5 | n.d. | 9.9 | 4.9 | 36 | 82 | 110 | n.d. | 3.7 | n.d. | 230 |
| CBE03 | 1.8 | n.d. | 4.1 | 2.9 | 26 | 37 | 140 | n.d. | 3.3 | n.d. | 120 |
| CBE04 | 1.9 | n.d. | 5.9 | 3.1 | 30 | 50 | 100 | n.d. | 2.4 | n.d. | 180 |
| CBE05 | 0.68 | n.d. | 2.4 | 1.3 | 6.9 | 14 | 92 | n.d. | 1.0 | n.d. | 43 |
| CBE06 | 3.3 | n.d. | 11 | 4.7 | 39 | 74 | 170 | n.d. | 3.7 | 0.76 | 290 |
| CBE07 | 2.0 | n.d. | 8.2 | 3.3 | 30 | 66 | 180 | n.d. | 2.9 | n.d. | 260 |
| CBE08 | 3.8 | n.d. | 12 | 5.5 | 43 | 80 | 190 | n.d. | 3.9 | 0.89 | 320 |
| CBE09 | 0.64 | n.d. | 2.5 | 1.1 | 8.9 | 17 | 54 | n.d. | 0.94 | n.d. | 62 |
| CBE10 | 3.2 | n.d. | 12 | 5.4 | 41 | 83 | 150 | n.d. | 4.1 | 0.93 | 330 |
| CBE11 (ref) | 5.8 | n.d. | 14 | 6.9 | 54 | 82 | 300 | n.d. | 4.5 | 0.66 | 330 |
| ISQG Low | 20 | 1.5 | 80 | n.a. | 65 | 50 | n.a. | 0.15 | 21 | n.a. | 200 |
| ISQG High | 70 | 10 | 370 | n.a. | 270 | 220 | n.a. | 1 | 52 | n.a. | 410 |

Site adjacent to GID

Site adjacent to mid-section of Mardalup Park

*ISQG = Interim Sediment Quality Guideline (ANZECC & ARMCANZ 2000); blue indicates low ISQG exceeded; orange indicates high ISQG exceeded; n.a. = no ANZECC & ARMCANZ guideline available; * alternative guidelines for cobalt, manganese and selenium of 50, 1100 and 2 mg/kg respectively (Ontario Sediment Quality Guidelines 1993 lowest effect level; Lemly 1996) were also not exceeded. N.d. = not detected; limit of reporting for mercury: 0.5 mg/kg; limit of reporting for other metals: 0.1 mg/kg. Samples comprised the top 2 cm of sediment.*

# Appendix 4 – Glossary and shortened forms

| | |
|---|---|
| Acute effect | Typically develops relatively rapidly in response to a relatively short exposure period. Often results in mortality within a short timeframe after exposure. [compare sub-chronic and chronic effects]. |
| ANZECC | Australia and New Zealand Environment and Conservation Council. |
| ARMCANZ | Agriculture and Resource Management Council of Australia and New Zealand. |
| Chronic effect | Typically develops relatively slowly in response to a relatively long exposure period; or has a long-lasting effect that does not result in mortality in the short term. [compare acute and sub-chronic effects]. |
| COP | City of Perth |
| DDD | Dichlorodiphenyldichloroethane. |
| DDE | Dichlorodiphenyldichloroethylene. |
| DDT | Dichlorodiphenyltrichloroethane. |
| Ecotoxicology | The integration of toxicology and ecology. Ecotoxicology aims to quantify the effects of stressors on natural populations, communities or ecosystems. |
| EPA | Environmental Protection Authority. |
| EPRA | East Perth Redevelopment Authority. |
| GID | Groundwater Interception Drain. |
| High-level toxicity | Statistically significant effect (statistically significant difference from the control organisms; $p<0.05$); and when subsequent dilution-series testing was performed, the statistically significant effect was observed with < 50% sediment elutriate concentration. [Definition determined for this study]. |
| ISQGs | Interim Sediment Quality Guidelines (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand – ANZECC & ARMCANZ 2000). The *low* ISQG is the concentration below which the frequency of adverse biological effects is expected to be low. The *high* ISQG is the concentration above which adverse biological effects are expected to occur more frequently. |
| Limit of reporting | The lowest concentration at which an analyte will be reported after taking into account interferences and instrumental limits of detection. |
| Low-level toxicity | Statistically significant effect (statistically significant difference from the control organisms; $p<0.05$) observed with undiluted sediment elutriate concentration but there was no such effect when subsequent dilution-series testing was performed. [Definition determined for this study]. |
| No toxicity | No statistically significant effect (i.e. no statistically significant difference in response by the test organisms from the control organisms; $p > 0.05$). |

| | |
|---|---|
| OC | Organochlorine. |
| PAH | Polycylic aromatic hydrocarbon. |
| Pesticide | Substance or mixture of substances intended for preventing, destroying, repelling or mitigating pests such as insects. |
| SECWA | State Energy Commission of Western Australia. |
| SRT | Swan River Trust. |
| Sub-chronic effect | A non-lethal effect that typically develops in response to a relatively short exposure period. May result in mortality in the long-term. |
| Toxicity | The degree to which a substance or combination of substances is able to damage an exposed organism. In this study, different endpoints were employed for different test organisms to represent toxic effects:<br>– mussel 72-hour larval development test: developmental abnormalities or developmental delays were used as a measure of toxicity.<br>– copepod 48-hour survival test: mortality was used as a measure of toxicity.<br>– amphipod 10-day whole-sediment survival test: mortality was used as a measure of toxicity.<br>– fish 96-hour larval imbalance test: imbalance (fish unable to maintain upright position in water column) was used as a measure of toxicity. |
| WC | Water Corporation |
| WRC | Water and Rivers Commission |

## Appendix 5 – Map disclaimer and data acknowledgements

The maps in this publication were produced by the Department of Water with the intent that they be used as illustrations in this report, *Claisebrook in the Swan Estuary, Western Australia – a synthesis of environmental information and historical retrospective*. While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, it accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

The Department of Water acknowledges the following datasets and custodians in the analysis of data and production of the maps:

| Dataset name | Custodian | Metadata year |
|---|---|---|
| Subcatchments of the Swan Canning Estuary | WRC | 2000 |
| Drainage pipe / open channel (WCORP – 003) | WC | 2013 |
| Pipes | COP | 2013 |
| Pits | COP | 2013 |
| Drainage subcatchments | COP | 2013 |
| Swan Coastal Plain 30 cm | Landgate | 1953 |
| Swan Coastal Plain 30 cm | Landgate | 1965 |
| Swan Coastal Plain 50 cm | Landgate | 1974 |
| Swan Coastal Plain 80 cm | Landgate | 1979 |
| Swan Coastal Plain 20 cm | Landgate | 1981 |
| Swan Coastal Plain 40 cm | Landgate | 1985 |
| Swan Coastal Plain 40cm | Landgate | 1995 |
| Swan Coastal Plain 40 cm | Landgate | 2001 |
| Swan Coastal Plain Central 20 cm | Landgate | 2006 |
| Swan Coastal Plain Central 15 cm | Landgate | 2008 |
| Swan Coastal Plain West 15 cm | Landgate | 2011 |
| Swan Coastal Plain Central 15 cm | Landgate | 2013 |

The maps have been produced using the following data and projection information:
**Vertical Datum:** AHD (Australian Height Datum)
**Horizontal Datum:** GDA 94 (Geocentric Datum of Australia 1994)
**Projection System:** GDA 94 (Geocentric Datum of Australia 1994)
Original ArcMap documents (*.mxd): J:\gisprojects\Project\B_series\B5050\004_Claisebrook_2013

**Swan River Trust**

Level 1 Fortescue Centre | 20 Terrace Road | East Perth | Western Australia 6004

PO Box 6829 | East Perth | Western Australia 6892

Telephone (08) 9278 0900 | Facsimile (08) 9325 7149

info@swanrivertrust.wa.gov.au

www.swanrivertrust.wa.gov.au

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