Tier 1 Environmental Health Risk Assessment

Orica Botany Independent Review – Stage 3

Prepared for:

NSW Environment Protection Authority

Level 13, 10 Valentine Ave

Parramatta NSW 2124

24 February 2016

Distribution

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Orica Botany Independent Review – Stage 3

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Executive Summary

Due to the historical use of elemental mercury at the Orica former chlor-alkali plant (FCAP), which operated from 1945 to 2002 in the Botany Industrial Park (BIP) south of Sydney, releases of mercury to the local environment have occurred. In response to community concerns regarding the potential for mercury contamination to impact on community health, the NSW Environment Protection Authority (EPA) commissioned an independent review into all information around historical mercury emissions from the FCAP, located in the suburb of Banksmeadow within the City of Botany Bay.

Senversa Pty Ltd was engaged by the EPA to undertake an environmental health risk assessment (EHRA) of these mercury impacts. The objective of this EHRA was to assess the potential risks to the community associated with exposures to reported concentrations of mercury in soil, vapour, sediment and fish in the assessment area in proximity to the Orica FCAP site.

Prior to the EHRA commencing, two stages of investigation were completed (by others) as part of the independent review. These comprised:

- Stage 1 – Data and information collection and review.
- Stage 2 – Environmental sampling program.

Based on the information collected within Stage 1 and Stage 2, this EHRA provides a human health focused evaluation of the available information. The assessment considered receptors within approximately 1.5 km of the FCAP, including nearby residents and users of Penrhyn Estuary.

This report was developed as a Tier 1, or screening level, risk assessment. A Tier 1 risk assessment compares known site data to relevant and appropriate risk-based screening criteria published by Australian and international regulatory agencies. This provides a conservative review of the data to determine whether further investigation or a more detailed (Tier 2) risk assessment is required.

A review of the available information indicated that dispersion of mercury in the air from the FCAP was a key exposure pathway to assess. Additionally, residual impacts in soil, sediment, and fish may contribute to community exposures.

The investigation results from Stage 2 indicated that mercury was detected in all environmental media investigated, however at concentrations below adopted screening criteria. Limited spatial correlation was observable in the mercury data, and results were consistent with concentrations reported due to background urban sources in cities within Australia and internationally.

With consideration to the community concerns which prompted the independent review, the overall conclusions of the Tier 1 EHRA were the following:

- The quantity and quality of data collected during Stages 1 and 2 of the independent review were considered adequate to undertake an environmental health risk assessment, i.e. were adequate to characterise levels of mercury in the environment to which the community may be exposed.
- Health risks to the community due to identified levels of mercury in the environment are classified as acceptable in accordance with Australian and international regulatory guidance, and are not discernibly higher than that expected for the general public in urban areas of NSW.

In addition to the above, specific findings of the Tier 1 EHRA included the following:

- The data were considered to have reasonably characterised the area for mercury contamination and were of acceptable quality to use in the decision making process.
- One residence was found to have anomalously high mercury contamination within a narrow plant bed in a back garden area, at a depth of 0.4 metres. It was considered that this was most likely associated with residential waste or uncontrolled importation of fill/soil, rather than from emissions associated with the FCAP. It is understood that the contaminated soil will be managed by the EPA.

- This environmental health risk assessment was based on a conservative screening level assessment, whereby screening criteria published by Australian and international regulators were compared against the upper limits of reported concentrations. All sampling locations (excluding the anomalously high mercury levels reported in one garden bed) were found to have mercury and other contaminant concentrations less than the relevant screening criteria, and concentrations were consistent with those reported elsewhere in urban areas.
- Concentrations of other potential contaminants (lead, chromium, polychlorinated biphenyls and polycyclic aromatic hydrocarbons), which were included in the soil sampling program in selected locations, were also reported to be less than relevant health-based screening criteria.

On the basis of these findings, public health risks to the community due to mercury contamination from the FCAP and/or from other background sources of mercury are classified as acceptable in accordance with Australian and international regulatory guidance, and are not discernibly higher than that expected for the general public in urban areas of NSW.

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List of Acronyms

Acronym	Definition
ADI	Acceptable Daily Intake
AS	Australian Standard
bgl	below ground level
BH	Borehole
BIP	Botany Industrial Park
COC	Chain of custody
CSM	Conceptual site model
DPI	Department of Primary Industries
EHRA	Environmental Health Risk Assessment
EPA	Environment Protection Authority
FCAP	Former Chlor-Alkali Plant
FSANZ	Food Standards Australia New Zealand
HI	Hazard Index
HIL	Health-based investigation level
HQ	Hazard Quotient
HSL	Health screening level
m	Metre
m^3	Cubic metres
mg/kg	Milligrams per kilogram
mg/L	Milligrams per litre
NATA	National Association of Testing Authorities
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observed Adverse Effect Level
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated Biphenyl
QA	Quality assurance

Acronym	Definition
QC	Quality control
RfD	Reference Dose
RPD	Relative percentage difference
SAQP	Sampling and Analysis Quality Plan
SEPP	State Environment Planning Policy
TDI	Tolerable Daily Intake
µg/kg	Micrograms per kilogram
µg/L	Micrograms per litre
WHO	World Health Organisation

1.0 Introduction

Senversa Pty Ltd was engaged by the NSW Environment Protection Authority (EPA) to undertake an environmental health risk assessment (EHRA) of the residential area around Orica's former chlor-alkali plant (FCAP) at the Botany Industrial Park (BIP).

This assessment was undertaken as part of the ongoing NSW EPA Orica Botany Independent Review. The assessment area is located to the east of Sydney airport approximately 11 km south of the Sydney Central Business District, and includes lands and waters within approximately 1.5 km of the FCAP, and some public lands such as parks beyond this.

Figure 1a depicts the location of the Orica FCAP site and the surrounding assessment area.

1.1 Background

Elemental mercury was used at the FCAP from 1944 until 2002, as part of the chlor-alkali process to produce chlorine, hydrogen and caustic soda from saline water. This process resulted in historic releases of mercury to the environment on- and off-site. Remediation of on-site source areas commenced in 2011 and is scheduled for completion in 2016; however, mercury has been detected across off-site areas in air, soil, and groundwater, and within fish in Penrhyn Estuary (Golder, 2011; enRiskS, 2013; Golder, 2015; WSP, 2015b; WSP, 2015c).

In response to community concerns regarding the potential for mercury contamination to impact on community health, the EPA announced in January 2013 that it would conduct an independent review of available information around historical mercury emissions at Botany (NSW EPA, 2015). A stated aim of the independent review was to assess the potential for health risks to the adjacent community, including recreational fishers within Penrhyn Estuary, associated with mercury emissions from the FCAP.

Prior to the EHRA commencing, two stages of investigation were completed as part of the independent review. These comprised:

- Stage 1 – Data and information collection and review (CDM Smith, 2014).
- Stage 2 – Environmental sampling program (WSP, 2015a; WSP, 2015b; WSP, 2015c).

Stage 1 provided a review of site data and historical records and conducted community consultation to identify potential issues associated with mercury and the assessment area. Stage 1 presented a comprehensive conceptual site model (CSM), which provided information on sources and releases of mercury, hydrogeology, mercury fate and transport, and potential community exposure pathways. The report also presented an assessment of on-site activities and mass-balance calculations to estimate potential mercury releases.

Stage 2 measured levels of mercury in soil, vapour, sediment and fish within the assessment area. The concentrations reported were above limits of reporting but below those health-based screening criteria adopted by WSP.

Based on the information collected within Stage 1 and Stage 2, this EHRA was conducted to provide a more rigorous and comprehensive human health focused evaluation of the available information.

1.2 Objective and Scope

This EHRA was conducted to assess the potential risks to the community associated with mercury emissions from the former Orica FCAP site, based on available data collected and reported during the Stage 1 and Stage 2 investigations.

This report was developed as a Tier 1, or screening level, risk assessment, incorporating:

- A review of Stage 1 findings and Stage 2 environmental sampling data and analysis;
- An overview of the site specific conceptual site model, outlining the pathways whereby adjacent communities may come into contact with mercury;
- A review of the basis for derivation of available published screening criteria, for assessing human health exposures to mercury in the environment; and
- An assessment of the community risk profile, based on a comparison of available analytical data against published screening criteria.

1.3 Methodology

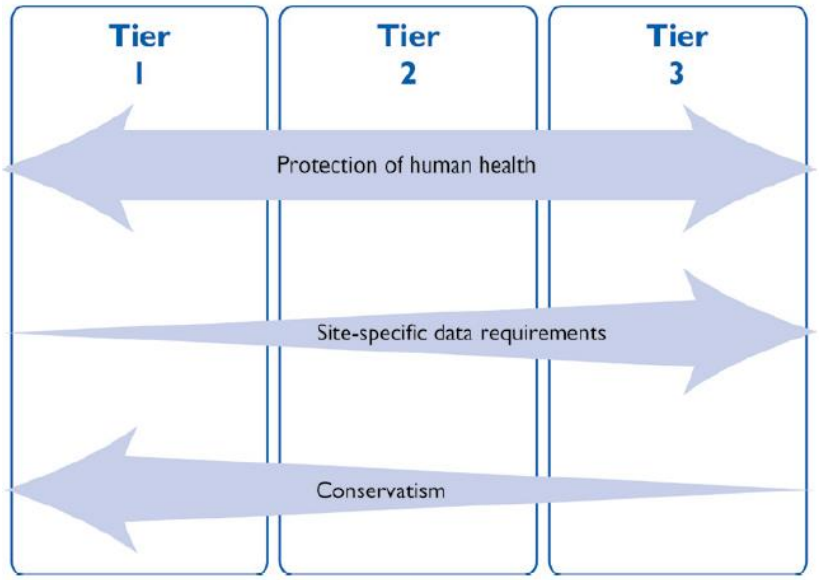
1.3.1 Relevant Guidance

This EHRA was undertaken in accordance with the following relevant Australian guidance:

- *Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards* (enHealth, 2012a).
- *National Environment Protection (Assessment of Land Contamination) Amendment Measure 2013 (No. 1) (the 'NEPM')* (NEPC, 2013). Incorporating:
  - Schedule B4, Guideline on Site-Specific Health Risk Assessment Methodology.
  - Schedule B7, Guideline on Derivation of Health-Based Investigation Levels.
  - Schedule B7, Appendix A: The Derivation of HILs for Metals and Inorganics [mercury toxicity profile].

The above documents recommend a tiered approach to environmental health risk assessment, with the simplest approach (Tier 1) comprising initial screening of risks based on comparison of data to published health-based guidelines which were derived using conservative default exposure assumptions. A risk assessment progresses from Tier 1 to Tier 2 when the Tier 1 assessment indicates potentially unacceptable risk, or to Tier 3 where Tier 2 risk estimates are potentially unacceptable. At each progressive tier of assessment, additional site-specific data and information is incorporated in order to further refine risk estimates.

The diagram below (enHealth, 2012a) represents the elements of the tiered approach to risk assessment. The diagram demonstrates that all three Tiers of risk assessment achieve a similar level of human health protection, however the Tier 1 assessment utilises a higher level of conservatism than subsequent tiers. This is because the Tier 1 evaluation is based on conservative default assumptions regarding exposure, and does not consider site-specific data which may allow refinement of these assumptions.



1.3.2 Tier 1 EHRA

The risk assessment methodology, as outlined in the guidance above, is applied by government agencies to develop generic, chemical specific, screening criteria. These criteria are then compared against environmental data as a Tier 1 screening assessment of potential health risks.

Criteria used for Tier 1 EHRA screening are generally developed to be highly conservative and represent concentrations at or below which adverse health effects on the general population, including sensitive individuals or sub-populations, are not expected to occur. The presence of chemicals in the environment at concentrations above these generic screening criteria does not necessarily indicate the potential for unacceptable risks to health; rather, that further site specific assessment, such as a Tier 2 or Tier 3 risk assessment, is required. This approach is widely adopted internationally (Meek et al., 2014), and the available Australian guidance and criteria are considered to be current and well accepted nationally.

For the purposes of this EHRA, screening criteria for assessment of mercury were selected from the following sources:

- *National Environment Protection (Assessment of Land Contamination) Amendment Measure 2013 (No. 1)* (NEPC, 2013).
- *Food Standards Code 1.4.1, Contaminants and Natural Toxicants* (FSANZ, 2015).
- *Concise International Chemical Assessment Document 50: Elemental mercury and inorganic mercury compounds: human health aspects. Geneva, World Health Organization, International Programme on Chemical Safety* (WHO, 2003).

2.0 Project and Site Background

This section presents an overview of environmental, historical, and land use factors that were of relevance to this Tier 1 EHRA.

2.1 Information Reviewed

In undertaking the EHRA, Senversa relied primarily upon the following references from Stages 1 and 2 for obtaining site specific environmental information across the assessment area:

- *Orica Botany Mercury Independent Review: Stage 1 – Data and Information Collection and Review*, CDM Smith Australia Pty Ltd, 6 February 2014 (CDM Smith, 2014).
- *Sampling and Analysis Quality Plan, Orica Botany Mercury Independent Review: Stage 2 – Environmental Testing Regime*, WSP Environmental Pty Ltd, 20 January 2015 (WSP, 2015a).
- *Interim Summary of Results for Orica Mercury Independent Review: Stage 2 Environmental Testing Regime*, WSP Environmental Pty Ltd, 24 April 2015 (WSP, 2015b).
- *Summary of Results for Orica Mercury Independent Review: Stage 2 Environmental Testing Regime – Private Lands Testing*, WSP Environmental Pty Ltd, 24 November 2015 (WSP, 2015c).

In addition, the following information was reviewed to assess the nature and extent of mercury related impacts in the source area:

- *2010 Conceptual Site Model – Botany*, Golder Associates, Report Number: 07623162_001_R_Rev0, 31 January 2011 (Golder, 2011).
- *Former ChlorAlkali Plant, Human Health and Environmental Risk Assessment – 2013*, enRiskS. 20 June 2013 (enRiskS, 2013).
- *Former ChlorAlkali Plant Groundwater Monitoring Program. Annual Groundwater Monitoring Event: December 2014,* Golder Associates, Report Number: 1418921-001-R-Rev0, 31 March 2015 (Golder, 2015).
- *Environmental Monitoring Data, FCAP (Mercury) Remediation Project*, Orica Australia Pty Ltd, December 2014 – November 2015 (Orica, 2015a).

2.2 Project Assessment Area

The location and key site features of the FCAP and surrounding assessment area are shown on **Figure 1a**.

2.2.1 FCAP Site Details

The FCAP site details are summarised within Error! Reference source not found. below.

Table 1: FCAP Site Details

Item	Detail
FCAP Site Address	16-20 Beauchamp Road, Matraville
Local Government Authority	Botany Bay City Council
Current Zoning	General Industrial (IN1)

Item	Detail
Planning Policy	State Environmental Planning Policy (Three Ports) 2013
Site Setting	Located at the southern end of the Botany Industrial Park (BIP) within the Orica facility.

2.2.2 EPA Independent Mercury Review Assessment Area

The initial assessment area defined for the independent review included the FCAP and all properties within a 1.25 km radius of the site (CDM Smith, 2014). This area was selected to be consistent with that applied in historical public documents. The area investigated by WSP was conservatively increased to a radius of approximately 1.5 km from the FCAP, and also included:

- Sediment sampling locations within Penrhyn Estuary and near the adjacent foreshore area, to assess the extent to which mercury impacts may have migrated to these areas via drains.
- Some public parks located outside the 1.5 km radius. WSP (2015a) indicated that these were targeted to assess potential background levels of mercury. In addition, the Stage 1 report recommended assessment of some public parks to alleviate community concerns that mercury waste may have been deposited in these locations (however it is noted that the Stage 1 investigation did not identify any evidence that unauthorised or illegal dumping had occurred).

For the purposes of this EHRA, the assessment area was generally defined as the area within 1.5 km of the FCAP (see **Figure 1a**). However, locations outside this radius where sampling has been undertaken were also considered in the EHRA.

Relevant site details for the assessment area are summarised within **Table 2** below, with planning maps for the local government authorities provided in **Appendix A**.

Table 2: Assessment Area Details

Item	Detail
Location	11 km south of Sydney.
Area Extent	Approximately 7 km^2
Local Government Authorities	Botany Bay City Council – western and central portion of assessment area Randwick City Council – far eastern portion of assessment area
Suburbs	Suburbs within the assessment area are shown on **Figure 1b** and include: • Banksmeadow • Hillsdale • Matraville • Port Botany • Botany • Eastgardens • Maroubra • Pagewood

Item	Detail
Current Zonings	Mix of zonings and land uses across assessment area, including: General Industrial (IN1), Light Industrial (IN2). Low Density Residential (R2), Medium Density Residential (R3), various mixed use and commercial zonings (B2, B4, B5, B7), Public Recreation (RE1), Primary Production Small Lots (RU4), Environmental Conservation (E2).
Botany Industrial Park	The BIP is present in the central/western portion of the assessment area. The BIP is a 73 hectare complex which houses a number of large industrial facilities, including Qenos, Orica and Huntsman.
SEPP's	Portions of the assessment area are subject to the State Environmental Planning Policy (SEPP) (Three Ports) 2013 and SEPP (Major Development) 2005.
Potentially Sensitive Land Uses	Residential and commercial land uses are present in the eastern part of the area under investigation, with schools and other sensitive land uses also present. A small area of residential houses is also located at the far western edge. Port Botany and Penrhyn Estuary are to the south, with various parks scattered throughout. Eastgardens shopping centre is at the northern boundary of the assessment area.

2.3 FCAP History

The chlor-alkali plant which operated at the Orica site from 1944 to 2002 used mercury cell technology to manufacture chlorine, caustic soda, hydrochloric acid, sodium hypochlorite and ferric chloride from saline water. The mercury cell method was a common chlorine production technology in the 20th century; however, this method is being phased out internationally due to the potential environmental and health effects associated with mercury use (EuroChlor, 2014).

Orica constructed a new chlor-alkali plant at their Botany site in 2002, using a membrane cell process which does not require mercury. Following construction of the new plant, the FCAP was demolished between 2004 and 2007. Environmental investigations were conducted to assess the extent of mercury impacts at the source and surrounds, with remediation of mercury impacts on-site commencing in 2011 (Orica, 2015b).

2.3.1 Mercury Use at the FCAP

An assessment of historical use of mercury at the FCAP was presented in the Stage 1 investigation, incorporating a calculation of known imported volumes of mercury relative to known outputs (CDM Smith, 2014). These mass balance calculations indicated the following:

- Approximately 957 tonnes of mercury were used over 58 years of operation.
- Of the mercury imported to site, approximately 50% was 'lost' and cannot be reliably accounted for. Sources of mercury loss included:
  - Discharge to sewer and stormwater;
  - Fugitive emissions to air during operations;
  - Mercury loss into the products produced;
  - Loss to soil and groundwater over time;
  - Disposal or loss as waste or sludge, ultimately disposed of to Springvale Drain, sewer, or landfill; and

- Mercury accumulation within building materials.

The performance of the Botany FCAP with regards to mercury losses was reportedly consistent with other chlor-alkali plants operating internationally, based on a review of 62 chlor-alkali plants operating in Europe (CDM Smith, 2014). The comparison data reported in Stage 1 indicated that the average percentage of mercury that could be accounted for at each plant was approximately 45%, for the years reviewed (1986, 1987, 1989) (CDM Smith, 2014).

2.4 Mercury in the Environment

Mercury is a heavy metal that is present in trace amounts in all environmental media (ATSDR, 1999). It can be found in a number of different forms which exhibit variable environmental behaviours and toxicity. Detailed reviews of mercury are available from a number of agencies; information summarised below was adapted from sources that include ATSDR (1999), WHO (2003), EA (2009) and NEPC (2013).

Mercury in the environment is most commonly encountered in the following forms:

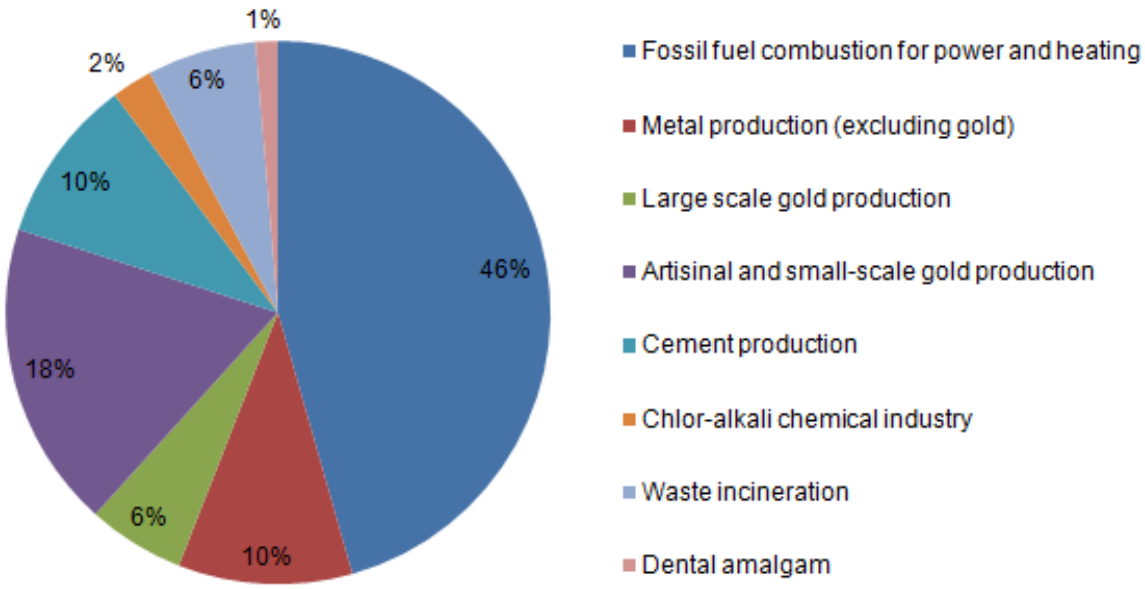
- Elemental or metallic mercury (0 oxidative state) is the most common form, and is a 'pure' form which is unbound to other elements. Elemental mercury is a shiny, silver white metal liquid at room temperature. Elemental mercury will readily evaporate and form mercury vapours which are colourless and odourless.
- Inorganic mercury (+1 mercurous or +2 mercuric state) occurs when mercury combines with other inorganic elements such as chlorine, sulphur or oxygen. These compounds are called mercury salts and are white powders or crystals, except for mercuric sulphide which is red. When mercury bonds with particulate matter and soil in the environment it is largely as inorganic mercury.
- Organic mercury compounds result when mercury combines with carbon, with methylmercury compounds the most common organic mercury form. In most cases the exact identity of the compound is not known. In the past, methylmercury compounds were used for commercial purposes, while in the environment, methylmercury is produced naturally by microbial activity.

2.4.1 Sources

Mercury occurs naturally in the environment within mineral deposits, and becomes distributed through the environment by both natural and anthropogenic processes. The primary natural sources of mercury include degassing of the earth's crust and oceans, and emissions from volcanoes. Anthropogenic sources include mining, fossil fuel combustion, waste incineration, and industrial emissions. Concentrations (above naturally occurring background levels) of heavy metals such as lead and mercury are common in urban soils in inner Sydney and other cities internationally, due to factors such as the historical use of impacted soils as fill material.

Industrial uses of mercury include the chlor-alkali industry, electrical industry (lamp and battery manufacture), the processing of gold ores, and a range of industrial, medical and laboratory instruments. Mercury was also historically used in dental amalgams, paints, pharmaceuticals and as a fungicide or bactericide. These uses have been largely discontinued.

The contribution of these various sources to global mercury levels are indicated in the figure below (from UNEP, 2008).



2.4.2 Environmental Behaviours

Atmospheric mercury exists mainly as elemental mercury (>90%), with other forms such as particle-bound and gaseous divalent mercury comprising less than 5% each. Elemental mercury can remain in the vapour phase for extended periods of time, with large transport distances possible via dispersion in air.

Mercury can be deposited to land and surface water via wet or dry deposition processes. Once bound to particles to form inorganic mercury complexes, mercury will readily be deposited to the Earth's surface. Mercury usually stays on the surface of sediments or soil in strongly bound inorganic forms, and does not move through the soil to groundwater. If mercury enters surface water bodies in any form, it is likely to settle to the bottom sediments where it can remain for a long time.

Elemental mercury will normally transform into inorganic forms in well aerated surface soils, however the elemental form can remain stable in soil under strongly reducing conditions. Elemental mercury has a low water solubility and will easily volatilise from surface soils. This volatilisation is accelerated by soil microbial processes, particularly where soil moisture content is high.

In surface soils, most mercury is likely present as water soluble mercuric (Hg^{2+}) complexes, most of which will bind to soil minerals or other surfaces. The mercuric compounds formed will vary depending on soil conditions such as pH, temperature and organic matter content.

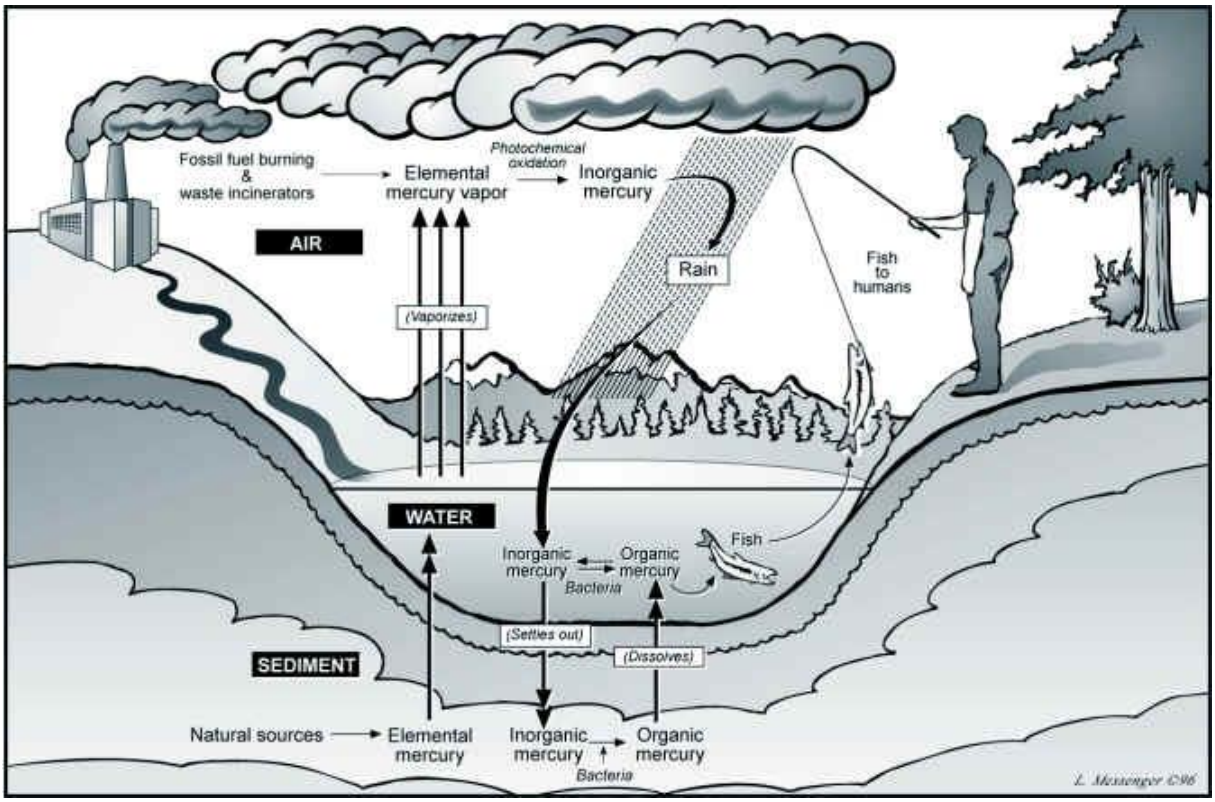
Organic mercury compounds (e.g. methylmercury) are formed in both soils and in aquatic environments due to biological and/or chemical transformation processes. Methylmercury can also be de-methylated back to inorganic or elemental mercury forms.

In surface soils, it has been estimated that approximately 1-3% of the mercury present occurs as methylated mercury, with the majority of the remainder present as inorganic mercury.

Mercury is persistent within the environment and can bioaccumulate in the food chain. Bioaccumulation is the process of an organism absorbing a chemical from its environment, and that chemical then accumulating within the food chain (e.g. fish may absorb mercury from the water column, and predators such as birds or humans who eat these fish over time may accumulate measurable concentrations of mercury within their body).

Based on the potential for long-range transport in air, persistence in water, soil and sediment, bioaccumulation, human toxicity and ecotoxicity, mercury is considered a persistent and problematic pollutant.

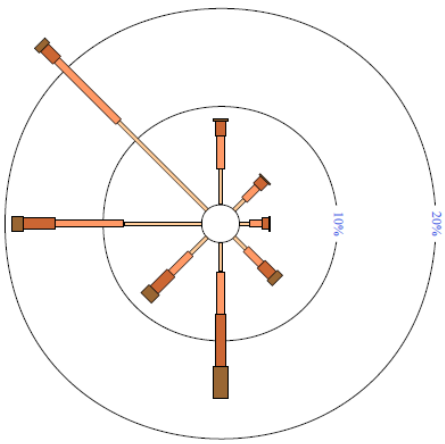
The forms of mercury encountered and their migration within the environment is represented in the figure below (from UWEC, 2003).



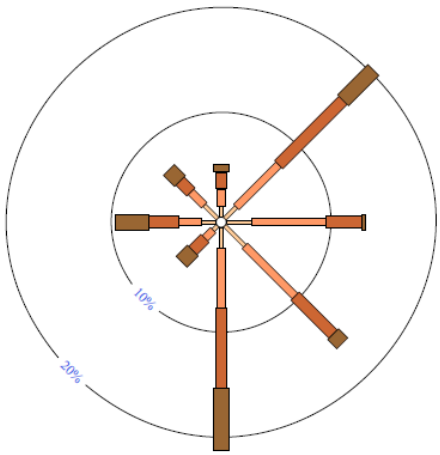
2.5 Site Environmental Factors

2.5.1 Prevailing Wind Direction

Wind roses from the Bureau of Meteorology for Sydney airport, presented below, show that prevailing wind directions are from the northwest, west and south in the morning, and from the northeast, east, southeast and south in the afternoons (BoM, 2015). This indicates there is no dominant prevailing wind direction at the site, and airborne dispersion of impacts from the FCAP may have occurred in any direction.



9 am Annual Average Wind Rose



3 pm Annual Average Wind Rose

2.5.2 Geology

The site is located over the Botany Basin, which covers an area of approximately 80 km^2 to the south of Sydney (Golder, 2011). The Botany Basin is comprised of Quaternary sediments up to 80 m thick overlying Hawkesbury Sandstone bedrock. The shallow sediments in the region generally comprise medium to coarse grained sand interspersed with occasional thin peat and clay bands, with these lower permeability bands becoming more common towards Penrhyn Estuary, within the assessment area.

Previous assessments within the area (Golder, 2011; CDM Smith, 2014) indicate the presence of three main stratigraphic layers:

- Layer 1 – Upper sand zone, generally 0 to 6 m thick – comprised of fill that overlies medium to high density sand, with some peat or clay layers.
- Layer 2 – Middle sand zone, generally 10 to 20 m thick – fine grained, sub-angular to subrounded, poorly sorted sands, with some peat or clay layers.
- Layer 3 – Basal zone, generally 2 to 10 m thick – variable layer of clayey sand and sandy clay, with discontinuous layers of gravel, peat and peaty clay.

For the purposes of the EPA Independent Review, a detailed assessment of regional geology was not undertaken and was not considered necessary for an assessment of potential exposures to the local community. Sampling undertaken by WSP (2015b) investigated soils to a maximum depth of 0.5 m bgl; the Stage 2 works reported that shallow soils encountered were comprised of loose grey brown topsoil with organic matter, leaf litter and grass roots, grading to a loose medium grained light grey or yellow sand.

2.5.3 Hydrogeology

The assessment area overlies the Botany Aquifer, present within the Botany Sands (Golder, 2011). The aquifer has been utilised for potable water historically, and for industrial water more recently, although since 2003 an embargo has been placed on the use of existing bores and on the acceptance of new licence applications to extract groundwater from this aquifer (DPI, 2015). The aquifer is considered vulnerable to contamination due to the current overlying land uses, the permeability of the sands, and the shallow depth to groundwater.

Key hydrogeological information is summarised in **Table 3** below, with this information taken from the Stage 1 report (CDM Smith, 2014) and the 2010 Conceptual Site Model (Golder, 2011).

Table 3: Hydrogeological Information

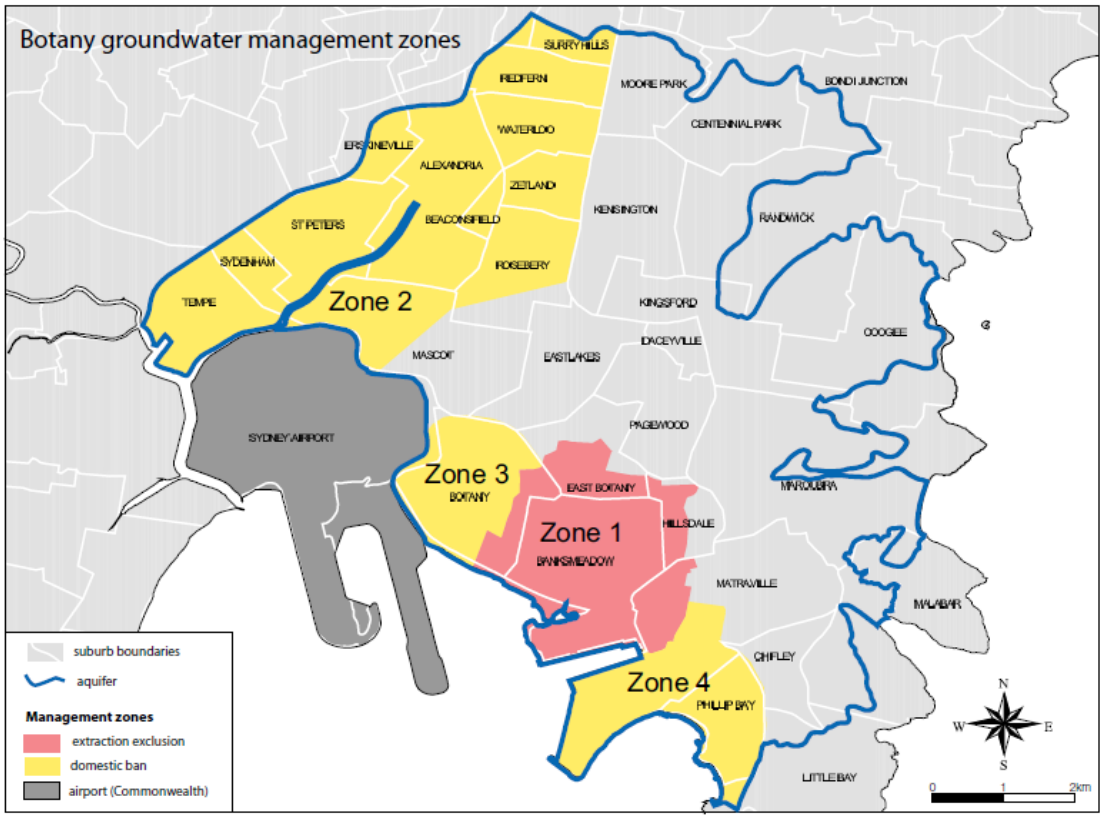
Item	Detail
Depth to groundwater	Northern end of aquifer – approximately 35 m bgl at Centennial Park Southern end of aquifer – 0 m bgl where groundwater discharges to Botany Bay FCAP – approximately 4-7 m bgl.
Flow direction	Predominantly to the south-west
Hydraulic conductivity	Layer 1 – 18 m/day Layer 2 – 23 m/day Layer 3 – 1.2 m/day
Hydraulic gradient	1:120 (~0.008 m/m)

2.5.4 Groundwater Use Restrictions

Due to the presence of groundwater contamination within the Botany Aquifer, groundwater extraction restrictions were introduced in 2003. While only parts of the aquifer are known to be impacted, and significant remedial works have been conducted for a number of sites, a precautionary approach to the use of groundwater has been applied given the history of the area, shallow water table and highly permeable soils (DPI, 2015). The groundwater restrictions in this area are defined by four management zones, as described by DPI:

- Zone 1 – the Orica exclusion area, where all groundwater use is banned.
- Zones 2 to 4 – where domestic groundwater use is banned.

These exclusion zones are shown on the figure below, taken from the Department of Primary Industries (DPI, 2015).



The NSW Public Health Unit has also recommended that bore water in the Botany area not be used for any purpose. This advice was proposed as a precautionary measure due to the identified presence of 1,2-dichloroethane at Botany Golf Course; however, the specific area to which this recommendation applies is not specified (NSW Health, 2013).

2.5.5 Stormwater and Surface Water

Historically, the FCAP was not connected to sewer, and prior to 1958 all effluent and sludges went to the Springvale Drain (CDM Smith, 2014). While an on-site waste water treatment plant was commissioned in 1958 to treat effluent and sludge, the drain was historically an on-going source of mercury contamination until it was remediated in 1999.

Surface water discharge from the site has the potential to travel via stormwater drains into Penrhyn Estuary and Botany Bay. However, the CDM Smith report notes that mercury was not detected in surface water samples collected from Springvale Drain in 1996, suggesting that mercury contamination was not sourced or mobilised via surface water.

The location of the Springvale Drain is shown on **Figure 1**.

2.5.6 Penrhyn Estuary

Penrhyn Estuary has been subject to significant changes and impacts from the surrounding industrial activities, including Sydney Airport, the BIP, and port developments reshaping the shoreline. CDM Smith (2014) concluded that historically, the highest quantities of mercury were discharged to Penrhyn Estuary prior to 1958, at which time sewer was installed so effluent could be directed to the Malabar Treatment Plant. Further reductions in rates of discharge would have occurred following the realignment and remediation of Springvale Drain in 1999. Due to the development of the shore subsequent to 1958, the most contaminated sediments associated with mercury releases from the FCAP were either remediated or contained by the soils above; however, it was not reported whether contaminated materials were removed or capped (CDM Smith, 2014).

Access to Penrhyn Estuary has been restricted over time as the surrounding industrial developments have encroached on the area. Boat ramps previously accessed from Penrhyn Road are no longer accessible to the public, with a reduction in recreational access to this area.

A fishing ban in Penrhyn Estuary and Port Botany was issued by the NSW Department of Primary Industries in September 2004 (DPI, 2004). This included a ban on the collection of shellfish and finfish due to concerns that elevated levels of contaminants in seafood in this area may pose a risk to public health. Signs are posted to inform the public that the area is contaminated and they should not fish or swim in the area, and should avoid wading.

The location of Penrhyn Estuary is shown on **Figure 1**.

3.0 Conceptual Site Model

Based on the site setting information provided above, a conceptual site model (CSM) was developed. As defined within the Assessment of Site Contamination NEPM, a CSM is “a representation of site-related information regarding contamination sources, receptors and exposure pathways between those sources and receptors” (pg. 14, Schedule B2).

A well-developed CSM assists with understanding how the contamination, once released to the environment, may impact on health. The key elements of a CSM include:

- A source or release of contamination.
- Environmental media which may be impacted. These include soil, surface water, vapours, or particles in air, and provide a pathway for migration of impacts through the environment.
- The presence of receptors, such as residents or workers.
- Potentially complete exposure pathways, representing a mechanism by which the receptors are exposed, such as inhalation or ingestion.

This CSM presents an overview of the relevant sources, potential environmental migration pathways, and key receptors in the assessment area. This provides a framework for assessing potential human health risks from mercury.

The CSM discussed below is presented graphically in **Figure 5.**

3.1 Sources

In addition to the range of background sources present within all urban environments (see **Section 2.4**), the primary identified source of mercury in the assessment area was considered to be the historical operations at the FCAP site. The CDM Smith report provides a detailed overview of the site history and potential releases, as summarised in **Section 2.3.1**.

The key primary on-site source of mercury at the FCAP was elemental mercury present within the FCAP during operations and post-closure (prior to remediation).

In addition to primary sources, secondary sources can be a significant ongoing source of releases to the environment. These secondary sources relate to environmental impacts which occurred as a result of the initial, primary release, but may continue to act as an ongoing source. Some of the key secondary sources of mercury impact which are related to FCAP operations are listed below, along with the likely mercury forms present in each media (see **Section 2.4** for discussion on the forms of mercury encountered in the environment):

- Contaminated soil beneath the FCAP. Likely to be comprised of elemental and inorganic mercury forms.
- Contaminated groundwater beneath the FCAP and extending down-gradient to the southwest towards Penrhyn Estuary. Likely to be comprised of inorganic mercury forms.
- Airborne releases during site operations and during remediation of the FCAP (noting the presence of a building over the remediation area to capture these releases). Likely to be a combination of elemental mercury vapours and inorganic mercury bound to particulates.
- Sediment in Springvale Drain, prior to remediation. Likely to be comprised of inorganic mercury forms, with potential for some methylmercury to be present (noting sampling reported methylmercury below limits of reporting in sediment in the estuary).
- Mercury in the sediment and food chain of Penrhyn Estuary. Likely to be comprised of inorganic mercury forms, with potential for methylmercury to be present in fish (noting sampling reported methylmercury below limits of reporting in sediment).

3.2 Pathways

The main media via which the contaminants may migrate (i.e. the 'pathway'), can be summarised as:

- Air – as either vapour/gaseous phase, or as airborne dust/particles.
- Surface water – through stormwater networks, overland flows, and/or surface water bodies.
- Groundwater – migration may occur vertically or horizontally through an aquifer.
- Soil – while migration through soil can be slow, residence time can subsequently be protracted.
- Biota – through accumulation of contaminants in food sources, particularly seafood.

The mechanisms by which these media provide pathways of exposure, for consideration when assessing mercury in proximity to the FCAP, are summarised below:

- Inhalation of vapours or particles. As no dominant prevailing wind direction has been identified (**Section 2.5.1**), this pathway may be expected to have occurred across the whole assessment area.
- Direct contact (dermal contact or incidental ingestion) with surface water within drainage network or at Penrhyn Estuary, in areas to the southwest of the FCAP. This pathway would generally be restricted to maintenance workers operating in below ground pits or drains. Direct contact by the general public would not be significant, and should be incomplete for the majority of receptors given the warning signs in place in Penrhyn Estuary (**Section 2.5.6**).
- Direct contact with groundwater was not considered to be a complete pathway, due to the groundwater extraction ban in place (**Section 2.5.4**).
- Direct contact with soil may occur in any area where mercury deposition has occurred, although accumulation of mercury in soils from deposition was not identified as being significant (**Section 4.1**).
- Ingestion of biota, particularly seafood. This pathway was not considered significant, and should be incomplete for the majority of receptors given the fishing ban in place in Penrhyn Estuary (**Section 2.5.6**).

Based on the review of potential pathways, inhalation and potential direct contact with soils impacted by mercury were the key potentially complete pathways identified in this CSM. Other pathways such as fish consumption have also been considered in the Tier 1 assessment for initial screening purposes.

3.3 Receptors

The assessment area includes a range of land uses, including residential, schools, public open space, commercial, and industrial (**Section 2.2.2**). The characteristics of the population potentially exposed within this area will vary according to the land use, with residents (including adults and children) generally considered the most highly exposed and sensitive receptors. This is due to residential scenarios assuming exposures may occur by children and adults who reside at a property for 365 days a year for up to 35 years (NEPC, 2013). Such exposure assumptions would be more conservative than those associated with other sensitive land uses, including schools, child care centres, aged care facilities, etc.

This Tier 1 EHRA has therefore focused on assessment of residential receptors within the assessment area, as these are the most sensitive receptors located in proximity to the FCAP. It was also assumed that local (or other) residents may regularly consume fish from the Penrhyn Estuary.

4.0 Environmental Data Review

The information discussed below was taken from the Stage 2 works (WSP, 2015b; WSP, 2015c), unless otherwise noted; these reports should be referenced for information on the field works, sampling methods and laboratory analyses. A review of the information relevant to the EHRA, including a discussion on the spatial distribution and relative scale of mercury impacts, is provided below.

The concentrations reported were compared against published screening criteria in the WSP reports, with these screening criteria generally adopted within the EHRA. **Section 5** presents a more detailed overview of the appropriateness of the screening criteria, including an assessment of the level of protection provided by these criteria with consideration of site specific factors.

4.1 Soil

4.1.1 Public Lands Sampling

WSP drilled 148 soil bores across parks, road verges and public lands assessed during February 2015 (WSP, 2015b). Two samples were collected from each borehole; one at the surface (0-0.05 m below ground level (bgl)) and one from 0.4-0.5 m bgl. Where refusal was encountered at depths less than 0.5 m, the deeper sample was collected at the point of refusal (e.g. 0.3-0.4 m bgl, etc). Only one borehole (BH116) could not be drilled to a sufficient depth to enable a second sample to be collected.

Soil samples were analysed for total mercury at all locations (295 samples); no soil samples were analysed for speciated forms of mercury such as inorganic, elemental, or methylmercury. It is likely based on the known behaviours of mercury that it was present in soil as inorganic mercury, however data were compared to both inorganic and methylmercury criteria to provide a conservative assessment of the results.

A subset of locations (17 samples in total) were also analysed for lead, chromium, polychlorinated biphenyls (PCB), and polycyclic aromatic hydrocarbons (PAH).

The maximum concentrations reported in soil, and the calculated 95% upper confidence limit of the mean concentration (95% UCL)[1], are summarised in **Table 4** below.

Table 4: Soil Analytical Data Summary

Chemical	Depth (m bgl)	Maximum concentration (mg/kg)	95% UCL of the Mean Concentration (mg/kg)	Adopted Criteria (mg/kg) HIL-A [a]
Total Mercury	0.0-0.05	4.7	0.35	10 / 40 [b]
	0.4-0.05	2.7	0.23	10 / 40 [b]
Lead	-	209	96	300

[1] The 95% UCL is a statistical measure that represents an estimated average for a dataset with consideration of the measured variability and potential uncertainty in that data set. The 95% UCL is a value which one can be 95% confident will be higher than the true mean (i.e. if this sampling exercise was repeated multiple times, the calculated 95%UCL would equal or exceed the true population mean 95% of the time).

Chemical	Depth (m bgl)	Maximum concentration (mg/kg)	95% UCL of the Mean Concentration (mg/kg)	Adopted Criteria (mg/kg) HIL-A [a]
Chromium	-	12	6.7	100
Naphthalene	-	<0.5	NA	3 [c]
Benzo(a)pyrene TEQ [d]	-	2.6	NA	3
Total PAHs	-	19.9	NA	300
Total PCBs	-	<0.1	NA	1

[a] Health investigation level (HIL) A for residential scenarios with garden / accessible soil (NEPC, 2013) applied in this table, for a conservative first screen. The basis of this number is discussed further in **Section 5**.

[b] HIL-A's are provided for inorganic mercury (40 mg/kg) and methyl mercury (10 mg/kg). Soil data were not speciated, with results presented as total mercury only. Further discussion on this is provided in **Section 5**.

[c] HSL-A for sand soils, 0-<1 m (NEPC, 2013). Conservatively adopted, this is the lowest criteria for naphthalene provided in the NEPM.

[d] Toxic equivalency factor – this is the sum of all carcinogenic PAHs, adjusted for relative toxicity to B(a)P

NA Not applicable. A 95%UCL could not be calculated due to insufficient data points above the limit of reporting

A map showing the soil sampling locations and a summary of the mercury results is presented in **Figure 2a** (surface soils) and **2b** (deeper locations).

The spatial distribution of mercury in soil does not indicate a clear relationship between maximum concentrations in soil and proximity to the FCAP, i.e. the locations of highest mercury concentrations were randomly distributed around the assessment area, rather than concentrated in close proximity to the FCAP (see **Figures 2a** and **2b**).

While **Figures 2a** and **2b** indicate a slight cluster of mercury detects in soil to the east and northeast of the FCAP, the concentrations reported were low (i.e. less than 10% of the residential soil screening criteria), and were consistent with those reported at greater distance from the FCAP. The results were therefore not considered to indicate significant deposition of FCAP derived mercury over time.

Information on background levels of mercury in soil indicate that average concentrations in virgin and cultivated soils in a number of countries ranged from 0.02 to 0.625 mg/kg, with highest concentrations reported in urban areas and surface soils (ATSDR, 1999). Mercury has also been reported at concentrations ranging from 0.01 to 0.55 mg/kg in orchard soils in New York state (ATSDR, 1999). The reported concentrations of mercury in the majority of soil samples analysed were within this background range. The 95% upper confidence limit of the mean mercury concentration reported by WSP (2015b) was also within this range for both surface and sub-surface soils.

4.1.2 Private Lands Sampling

Following the sampling of public lands (WSP, 2015b), further sampling of soils on private properties was undertaken within the assessment area (WSP, 2015c). Only landholders of four properties chose to proceed with this stage of the works. Samples were subsequently taken from each. To maintain privacy of the land owners, these sampling locations have not been shown on the attached figures.

WSP drilled an initial nine soil bores across the four properties assessed during July 2015 (WSP, 2015c). Two samples were collected from each borehole; one at the surface (0-0.05 m bgl) and one from 0.4-0.5 m bgl.

From these first 9 samples, the reported mercury concentration in one location within a small garden bed was elevated (873 mg/kg; BH151 at a depth of 0.4-0.5 m bgl). The reported concentration in the surface soil sample collected from the same borehole (BH151) was 50.2 mg/kg.

The reported concentrations in two samples collected at nearby BH152 were 19.5 mg/kg (surface sample) and 18.2 mg/kg (0.4-0.5 m bgl). Although these results were higher than the maximum reported from the public lands sampling, both results from BH152 were below the adopted residential screening criteria for inorganic mercury.

To further assess the mercury identified at BH151, an additional 21 soil bores were investigated across the area in proximity to BH151, with BH158 and BH159 located approximately 0.5 m to the north and south of BH151, respectively. The additional data indicated that the mercury impact was highly localised, with mercury concentrations in all other samples collected from this property reported at concentrations consistent with the results from the public land sampling (i.e. <0.1 to 6 mg/kg).

Given the depth and the localised nature of the impact in the garden bed, it is likely that the mercury detected was associated with historical activities unrelated to the FCAP, such as burial of domestic waste (e.g. batteries or fungicides) or use of previously contaminated soil (e.g. obtained from an industrial area) to fill the garden bed. Regardless of the source, the NSW EPA has discussed these results with the landowner and the impacted soil will be removed. Concentrations of mercury at the property are expected to be below adopted criteria upon completion of those works.

4.2 Vapour

Mercury vapour concentrations were measured at all soil bore locations and at several drainage line and pit locations (WSP, 2015b). The sampling was undertaken using a Lumex RA-915 portable mercury vapour analyser, which has a manufacturer reported detection limit of 0.002 µg/m^3. The specifications for the portable vapour analyser indicate that the equipment converts mercury from a bound state to the atomic state, thereby reporting total mercury concentrations from all forms.

Vapour concentrations (representative of total mercury) were recorded at up to 176 locations (see **Figures 3a, 3b** and **3c**). No measurements of speciated forms of mercury such as inorganic, elemental, or methylmercury were undertaken. It is likely, based on the known behaviours of mercury, that reported concentrations were a combination of elemental mercury vapours and inorganic mercury particles.

The maximum concentrations reported in vapour, and the calculated 95% upper confidence limit (95%UCL) results (WSP, 2015b), are summarised in **Table 5** below.

Table 5: Mercury Vapour Analyser Results Summary

Chemical	Location	Maximum concentration (µg/m^3)	95% UCL Concentration (µg/m^3)	Adopted Criteria (µg/m^3) WHO [a]
Total Mercury	Inside drains	0.034	0.024	0.2
	Surface level	0.074	0.031	0.2
	1 m above surface	0.076	0.039	0.2

[a] Tolerable concentration in air derived by the World Health Organization (2003). The basis of this number is discussed further in **Section 5**.

The mercury vapour concentrations reported during private lands sampling ranged from <0.002 to 0.047 µg/m^3 (WSP, 2015c).

The spatial distribution of mercury in vapour, as shown on the figures, indicates higher ambient air concentrations of mercury to the east and southeast of the FCAP (noting that limited data was collected to the west across industrial areas) (**Figures 3b** and **3c**). While the figure indicates highest mercury vapour concentrations to the east and southeast of the FCAP on the days of sampling, the concentrations reported were relatively low.

On-site monitoring of mercury in ambient air is conducted by Orica, and is publically reported as a 24 hour rolling average per month. A review of the last years' worth of data (December 2014 to November 2015; Orica, 2015b) indicate on-site vapour concentrations were approximately 0.12 µg/m^3 during February 2015, when the majority of the WSP sampling was completed (WSP, 2015b). The maximum concentration reported from this period was 0.16 µg/m^3 in Mar 2015. These reported on-site concentrations were below adopted ambient air criteria, and higher than those reported off-site during the Stage 2 investigations.

A conservative screening level air dispersion modelling exercise was conducted as part of Stage 1 (Appendix L, CDM Smith, 2014). The model predicted possible worst case ground level concentrations of mercury that could have occurred during operation of the facility. The results indicated that annual average ground level air concentrations of mercury would be below adopted screening criteria within approximately 500 m of the site. Sampling data indicate that the modelling was overly conservative for assessing current exposure scenarios, with concentrations at the site boundary below the adopted criteria.

Information on background levels of mercury in air indicate average concentrations of 0.01 to 0.02 µg/m^3 are typically reported, with higher concentrations (up to approximately 0.05 µg/m^3 reported in urban and industrialised areas (ATSDR, 1999; USEPA, 1980). Much higher concentrations (10-15 µg/m^3) have been reported near point emission sources such as mines, refineries and agricultural fields treated with mercury fungicides. Many of the vapour samples analysed were reported to have mercury within this background range, although the concentrations reported to the east and southeast of the FCAP were slightly higher than this background range (**Figures 3b** and **3c**). However, some mercury vapour concentrations above background were also reported to the north, east and west at distances greater than 1 km from the site, with lower ambient air concentrations reported closer to the site. These concentrations may be indicative of mercury sources other than the FCAP in the region, e.g. high levels of fossil fuel combustion within heavily industrialised areas.

The concentrations of mercury in air detected during Stage 2 works were generally consistent with background urban levels, and were not indicative of a significant secondary source of mercury.

4.3 Sediment

WSP collected 20 sediment samples from Penrhyn Estuary and the area to the west of the estuary (see **Figure 4**) in February 2015 (WSP, 2015b). Samples were all collected from the sediment surface (0-0.05 m), at the sediment/water interface.

Sediment samples were analysed for total mercury at all locations, and the 2 samples with highest reported total mercury concentrations were also analysed for methylmercury. No other speciation of mercury was included in the analytical program by WSP (2015b). Methylmercury was not detected in the 2 samples analysed, suggesting that the mercury present in sediment was an inorganic mercury form.

The maximum concentrations reported in sediment, and the calculated 95% upper confidence limit (95%UCL) results, are summarised in **Table 6** below.

Table 6: Sediment Analytical Data Summary

Chemical	Maximum concentration (mg/kg)	95% UCL Concentration (mg/kg)	Adopted Criteria (mg/kg) HIL-C a
Total Mercury	0.9	0.3	80 b
Methylmercury	<0.1	NA	13

[a] Health investigation level (HIL) C for recreational / public open space scenarios (NEPC, 2013) applied in this table, for a conservative first screen. The basis of this number is discussed further in **Section 5**.
[b] Criteria for inorganic mercury applied.
NA – Not applicable. A 95%UCL could not be calculated due to insufficient data points.

The concentrations reported in sediment were low, with no distinct spatial distribution across the estuary (see **Figure 4**). Limited information is available on background levels of mercury in sediment; however, the concentrations reported were lower than the median concentration of 1.3 mg/kg reported across 175 sites monitored by the National Oceanic and Atmospheric Administration (NOAA) (ATSDR, 1999). Higher concentrations (up to 3.3 mg/kg) were reported by NOAA in urban estuaries and waterways in the United States, including locations in New York, New Jersey and California. The concentrations reported near the site were therefore considered low and not indicative of a significant secondary source of mercury (in addition to typical urban background).

4.4 Biota

4.4.1 Fish

WSP engaged Ecosure to undertake fish sampling within Penrhyn Estuary in February 2015 (Ecosure, 2015; WSP, 2015b). During this exercise 35 fish samples, representative of 6 different fish species, were collected. Samples included adult and juvenile individuals for all sampled species, excluding luderick, for which only an adult specimen was caught, and a single yellow-fin bream, which was below the regulated size limit for bream.

Biota sampling is by its nature opportunistic, and the dataset was therefore considered likely to be representative of species that a recreational angler may catch within the investigated area. Some of the species caught, including whiting, luderick, mullet and bream, are typical of those likely to be kept for eating, and the available data were therefore considered to be representative of potential fish tissue concentrations which may be ingested by anglers in Penrhyn Estuary.

It was not stated if analyses for mercury in fish was speciated, or if the concentrations reported represent total mercury (WSP, 2015b). While it was therefore assumed that the concentrations represent a total mercury number, it is likely that the form present within fish would predominantly be comprised of methylmercury.

The maximum concentrations reported in fish are summarised in **Table 7** below. These have been compared against the lowest of the FSANZ (2015) criteria for mercury in seafood, which is designed for comparison against the mean fish concentration, for lower order fish. Higher criteria can be adopted for assessment of higher order / predatory fish (to allow for bioaccumulation), or for comparison against the maximum concentration in fish. Use of the lower value presented in the table below provides a conservative assessment.

Table 7: Fish Analytical Data Summary

Chemical	Species	Number of samples	Average concentration (mg/kg)	Maximum concentration (mg/kg)	Adopted Criteria (mg/kg) FSANZ (2015)[1]
Total Mercury	Sea mullet	10	0.056	0.068	0.5
	Silver biddy	4	0.060	0.068	0.5
	Luderick	2	0.175	0.180	0.5
	Whiting	8	0.068	0.095	0.5
	Smooth toadfish	10	0.100	0.160	0.5
	Yellow-fin bream	1	-	0.30	0.5

1 FSANZ criteria is intended to be applied as a mean concentration.

While it is noted that only limited sample numbers were available to be analysed for some fish species (e.g. luderick and bream), results of four previous investigations for these (and other) species within Penrhyn Estuary indicated a comparable range of concentrations: <0.1-0.45 mg/kg for luderick and <0.1-0.25 for yellow-fin bream (see Ecosure, 2015). Importantly, neither the current (Ecosure, 2015) or previous (1993-1994, 1996-1998, 2004 and 2015) investigations reported any individual fish mercury concentration greater than 0.45 mg/kg. All concentrations reported historically in the Penrhyn Estuary have therefore been below the mean and maximum levels required for fish as per the Australia and New Zealand Food Standards Code.

An assessment of concentrations of mercury within Australian food supplies was presented in the 23rd Australian Total Diet Study (FSANZ, 2011). The study detected total mercury in the majority of foods sampled, included grains, fruits, vegetables, bread, dairy products and meats. Average background concentrations of mercury in the diet ranged from <0.00050 mg/kg (canola oil and beer) to 0.82 mg/kg (mushrooms). The study assessed methylmercury in selected seafood sources, and reported average methylmercury concentrations in seafood to be 0.014 to 0.12 mg/kg (maximum 0.02 to 0.31 mg/kg). Average total mercury concentrations in these sources ranged from 0.042 to 0.15 mg/kg (maximum 0.067 to 0.39 mg/kg).

4.4.2 Vegetation

Although bioaccumulation within vegetation is not considered a significant pathway of migration for mercury in the environment, WSP collected 8 vegetation samples at Site 4 in the private land assessment (WSP, 2015c). Samples were collected to further assess potential bioaccumulation pathways from the elevated mercury concentration reported at BH151 into vegetation, although the impact at BH151 was not considered to be associated with the FCAP operations. Samples included green leafy samples (weeds, parsley, strawberry leaves) and fruit samples (lemon and loquat, both fruit and leaves).

Samples were analysed for total mercury (WSP, 2015c), with the reported concentrations ranging from <0.01 to 0.03 mg/kg. Mercury concentrations in the edible portion of the fruit analysed were below the limit of reporting. These concentrations were considered consistent with background levels of mercury in food (FSANZ, 2011).

4.5 Data Quality

A data review was undertaken to assess the quality of the WSP data. In line with NSW EPA contaminated land guidance this requires an assessment of the data Precision, Accuracy, Representativeness, Completeness and Comparability (PARCC parameters), whereby:

- Precision is a quantitative measure of the variability (or reproducibility) of the data.
- Accuracy (bias) is a quantitative measure of the closeness of reported data to the true value.
- Representativeness is the confidence that data are representative of each media assessed.
- Completeness is a measure of the amount of useable data from a data collection activity.
- Comparability is the confidence (expressed qualitatively) that data may be considered to be equivalent for each sampling and analytical event.

The evaluation of the QA/QC (quality assurance / quality control) procedures relevant to the sampling program discussed above was conducted with reference to Appendix V of the *Guidelines for the NSW Site Auditor Scheme (2nd edition)*. The data review considered the information presented within the SAQP (WSP, 2015a) and the analytical reports (WSP, 2015b; WSP, 2015c).

A detailed review of the data quality is provided in **Appendix B**.

In general, the QA/QC information presented in the WSP reports was adequate and generally reported in accordance with the requirements of NSW OEH (2011). An independent review of a proportion of the laboratory data indicates that the minor non-conformances identified would not adversely impact on the reliability of the dataset, particularly given the volume and consistency of sampling results.

5.0 Tier 1 Environmental Health Risk Assessment

Through consideration of the relevant background information, the site specific CSM, and the available sampling results, this screening level EHRA was developed.

5.1 Issue Identification

Based on the information presented above, it was identified that mercury was present across the assessment area.

Mercury was detected in vapour, soil, sediment and fish in the Stage 2 sampling works (WSP, 2015b; WSP, 2015c). Concentrations reported were below adopted screening criteria, but in some locations were marginally higher than typical urban background levels reported in the literature. The spatial distribution and relative concentrations reported indicates potential contribution from background sources other than the FCAP (as discussed in **Section 4**). Irrespective of the source of the mercury, assessment of the potential health risks was completed. In addition, given the potential for exposure to mercury from multiple pathways, a more detailed assessment was undertaken to assess potential risks from exposure to multiple environmental media and via all exposure pathways combined.

5.2 Toxicity of Mercury

Any assessment of health impacts associated with exposure to mercury requires consideration of the form of mercury present. A detailed assessment of mercury toxicity is provided in **Appendix C**, with a brief overview provided in **Table 8** below.

Table 8: Mercury Toxicity Overview

Mercury Form	Toxicity Overview
Elemental	Inhalation and absorption via the lungs is the key route of exposure for the general population. The central nervous system is considered to be the most sensitive indicator of effects due to inhalation exposure to elemental mercury. Elemental mercury does not have sufficient data to assess its cancer causing ability, but the effects noted have a threshold in the dose, below which these effects will not occur.
Inorganic	Ingestion is the key pathway for exposure to inorganic mercury, although gastrointestinal absorption rates are low (<20%). Ingestion of high levels of inorganic mercury have been associated with toxicity to the kidney and gastrointestinal tract. Available evidence in animals indicates that the effects of inorganic mercury have a threshold in the dose, below which these effects will not occur.
Methylmercury	Ingestion via the food chain, particularly in seafood, is the key route of exposure for the general population. The brain is the primary toxicity target of ingested methylmercury in humans, with the brain of the developing foetus more sensitive than that of the adult. While there is some evidence of tumour formation in animal studies, the evidence indicates that non-cancer effects would be expected to occur at concentrations lower than those required for tumour formation. Therefore, methylmercury should be assessed based on a dose below its threshold, as for the other two forms of mercury.

5.3 Assessment of Adopted Criteria

A summary of the basis for the derivation of the adopted screening criteria is provided in **Appendix D**. The spreadsheet presents the toxicity values utilised in the criteria derivation, and outlines the associated exposure assumptions. A discussion on their appropriateness is presented below.

5.3.1 Soil

The adopted soil criteria were selected from the NEPM (NEPC, 2013), and are representative of current Australian guidance and practices. The toxicity values and exposure assumptions were considered appropriate and conservative.

The available soil criteria were derived for assessment of either inorganic or methylmercury; no soil criteria for elemental mercury were provided in the NEPM. As speciated soil data were not available, and concentrations were reported as total mercury only, assumptions on the form of mercury present were necessary. An assessment of the likely forms present in soil, and the appropriateness of the available inorganic and methylmercury soil criteria, indicated that:

- *The presence of elemental mercury in off-site areas in shallow soils was considered highly unlikely due to the low concentrations reported, and as elemental mercury will readily sorb to particles and form inorganic mercury.*
- *While the majority of mercury reported in soil was likely to be inorganic, some methylmercury may be present due to microbial processes.*
- *The reported soil concentrations for total mercury were below the criteria for both inorganic and methylmercury in all public lands samples; therefore, even if 100% of the mercury in soil was the more toxic methylmercury form, soil concentrations would not exceed the screening level assessment.*

Further discussion on potential for additivity between pathways is provided in **Section 5.4** below.

5.3.2 Vapour

The adopted ambient air screening criterion was selected from the WHO (2003). The WHO review provides a detailed overview of available mercury toxicity, and although it is now over 10 years old, the information remains current. Additionally, the WHO guidance was recommended for adoption within the recent NEPM review of mercury toxicity (NEPC, 2013). The value is based on continuous exposures (i.e. 24 hours a day, seven days a week, throughout the year). The toxicity value and exposure assumptions were therefore considered appropriate and conservative.

The available criteria were derived based on protection of exposures to elemental mercury vapours, instead of a combination of these vapours with inorganic mercury bound to particulates. As the vapour is considered to be the most toxic form of mercury via the inhalation pathway, the criteria was considered protective of the total mercury concentrations reported by WSP (2015b).

The reported vapour concentrations were below the adopted ambient air screening criteria; therefore, even if 100% of the mercury in vapour was the more toxic elemental mercury form, air concentrations would not exceed the screening level assessment.

Further discussion on potential for additivity between pathways is provided in **Section 5.4** below.

5.3.3 Sediment

The sediment data were compared against the available soil criteria for public open space use of land (HIL-Cs, adopted from the NEPM) in the absence of criteria specific to assessing human health exposures to sediments. However, the sediments sampled were generally inaccessible at both high and low tides.

Furthermore, the exposure assumptions associated with the soil criteria (i.e. potential for daily contact with soils at a park) would be highly conservative for assessing largely inaccessible sediments, particularly when the presence of signs warning against swimming or wading in the estuary are factored in.

The available criteria were derived for assessment of either inorganic or methylmercury; no criteria for elemental mercury were provided in the NEPM. Speciated analyses for methylmercury on a sub-set of sediment samples indicated that methylmercury was not detectable, and the mercury present is therefore considered likely to be inorganic.

As the sediments were below both inorganic and methylmercury criteria, mercury in sediment does not exceed the screening level assessment. Furthermore, direct contact with these sediments is highly unlikely.

5.3.4 Fish Consumption

The fish data were compared against the FSANZ criterion for consumption of mercury in seafood (FSANZ, 2015) which are representative of current Australian guidance and practices. The criterion is protective of potential exposures by women of child bearing age (the most sensitive potential sub-population) and represents a seafood ingestion rate consistent with current Australian assumptions (enHealth, 2012b).

The criterion was derived assuming 100% of the mercury present may be the more toxic methylmercury form.

The toxicity values and exposure assumptions were considered appropriate and conservative.

As the concentrations reported in fish in the estuary were below the adopted criteria, mercury in seafood does not exceed the screening level assessment. Additionally, the concentrations reported were consistent with background levels present in seafood sold within Australia, and represent concentrations which the general population would be regularly exposed to through ingestion of seafood.

5.4 Risk Characterisation

5.4.1 Background

Total potential risks were assessed with consideration of additivity from all potential media and pathways (including those considered unlikely and/or less significant). The calculations associated with this are presented in **Appendix C**.

The approach to assessment of risk comprised comparison of chemical concentrations in environmental media to the relevant Tier 1 screening levels for each medium (described above in **Section 5.3**). The adopted screening criteria were derived on the basis of a threshold approach to assessing toxic effects. A threshold approach is adopted for toxic effects that are either known or presumed on the basis of scientific information to have a dose below which adverse effects will not occur. This threshold dose is identified based on extensive scientific research into the way the chemical causes toxicity, and how the chemical is absorbed, metabolised and excreted by the body. Thresholds are also considered relevant for sensitive sub-populations such as children, pregnant/lactating women and the elderly.

Risks to human health for chemicals assessed on the basis of a threshold approach are estimated by dividing the estimate of the chemical intake by the estimate of a “safe” dose. The safe dose is a concentration below which an adverse effect is not considered likely, with an allowance for appropriate safety factors. These “safe” doses have various names such as a tolerable daily intake (TDI), reference dose (RfD), or acceptable daily intake (ADI) (although it is noted that there are subtle differences in the specific definitions of these terms).

For assessment of inhalation exposure, the 'safe' threshold levels are usually termed a tolerable concentration or reference concentration. The resulting ratio of exposure to tolerable or acceptable daily intake is referred to as the hazard quotient (HQ) and when several hazard quotients are added together, the result is called the hazard index (HI). A potentially unacceptable chemical intake or exposure may be indicated if the hazard quotient or hazard index is greater than a value of 1, but generally a range within several fold on either side may be acceptable due to the imprecision of the underlying data and the conservative assumptions incorporated into the assessment. In other words, interpreting a HI of 1 as representing a different risk profile to a HI of 3 or even 10 suggests a higher level of precision than is warranted in the context of the overall uncertainty, conservatism and safety factors applied in the development of screening levels and/or hazard indices. The following extract from enHealth (2012a) further explains this principal:

> *"The HI approach is essentially quite conservative in providing an estimate of cumulative risk, since safety factors of between 100 and 10,000 are commonly used to adjust the estimated no observed adverse effect level (NOAEL) to derive the ADI or TDI estimates. ...When the overall HI is less than 1, it is generally assumed that cumulative risk is within reasonable bounds and that there is no need to undertake a more refined risk assessment. Even when HI is greater than 1, it does not imply that risks are unacceptable, although there is clearly some erosion of the conservatism built into each of the processes of determining components of the HQ calculation (exposure and TDI). When the HI is greater than 10 there is more reason to undertake further investigation of the risks…"* (enHealth, 2012a)

A similar hazard index / hazard quotient approach can be applied to comparison of chemical concentrations in environmental media to relevant screening levels. Published screening criteria are generally derived so that exposure to the adopted criteria concentration equals a hazard quotient or index of 1, with some allowance for imprecision of the estimate and existing background exposures. The hazard index specifically accounts for potential additivity in toxicity among multiple chemicals or pathways. In addition, the inherent conservatism of an individual chemical criterion is also considered sufficient to address additivity inherent in the hazard index.

The hazard quotients and hazard indices relevant to the mercury exposures assessed in this EHRA are all considered 'chronic' values, i.e. potential exposures are assumed to occur repeatedly and/or continuously over the majority of a receptor's lifetime. This is because the screening levels have been derived based on TDIs or ADIs which assume long-term continuous (chronic) exposure, and assuming continuous exposure over a lifetime. This is a more conservative approach than the evaluation of sub-chronic exposures (typically defined as less than 3 to 6 months; NEPC, 2013), and/or acute exposures (typically less than 14 days).

5.4.2 Site Specific Assessment

For the purposes of this Tier 1 EHRA, a more detailed assessment of additivity of exposures was undertaken, due to potential for exposures to mercury from multiple pathways. Additivity was assessed by:

- Calculation of the ratio of the maximum concentration reported for each form of mercury in each environmental medium to the relevant screening criteria concentration – e.g. chronic Hazard Quotient = 4.7 mg/kg in soil ÷ 40 mg/kg (inorganic mercury HIL-A) = 0.12.
- Adjustment of the ratio calculated to account for background allocations within screening criteria, if any.
- Calculation of total risk (i.e. the hazard index), by adding the hazard quotients associated with exposure.

An addition of hazard quotients among exposure pathways or chemicals is generally only required when the toxic effect associated with the exposures is the same among pathways. If a chemical, or a form of the chemical, affects the kidneys when ingested, but affects the central nervous system if inhaled, these effects can be assessed independently. However, a highly conservative assessment of risk can also be undertaken in the first instance by summing hazard quotients across all individual chemicals or forms of mercury.

Based on the discussion above, an assessment of the potential total risk profile was undertaken for the following scenarios:

1. Assumption of additivity from all media (soil, fish, sediment, air), assuming the most toxic form may be present in all media for all scenarios. This is the most conservative potential scenario, and would overestimate actual risk profiles.
2. Assumption of additivity across exposures for each form of mercury. This approach also adopted reasonable yet conservative assumptions regarding the form of mercury which is likely present in some environmental media. For example:

    - It was assumed that the total mercury concentration reported in soil comprised 90% inorganic mercury and 10% methylmercury. This is consistent with, but slightly more conservative than, expected ratios of inorganic to methylmercury as discussed in **Section 2.4.2**.
    - It was assumed that 100% of mercury in sediment was present as methylmercury. While the available speciated data indicate that this is likely to actually be present as inorganic mercury, due to the higher potential for methylmercury to form in aquatic environments (as compared to well aerated surface soils), a conservative approach was adopted.
    - It was assumed that the total mercury concentration in fish comprised 100% methylmercury. This is consistent with fish survey data (FSANZ, 2011) which indicate the majority of total mercury in fish and seafood is methylmercury (see **Section 4.4.1**).
    - It was assumed that the total mercury concentration in air comprised 100% elemental mercury.

The calculations and key assumptions for the assessment of risk are presented in **Appendix C**, with the results summarised in **Table 9** below.

Table 9: Summary of Estimated Health Risks (Hazard Indices)

Form	Exposure Media	Hazard Quotient – Maximum concentrations	Hazard Quotient – 95%UCL concentrations
Scenario 1 – Additivity from all forms of mercury and environmental media			
Most toxic form of mercury present and full additivity assumed	Air (assumed 100% elemental mercury)	0.4	0.2
	Seafood (assumed 100% methylmercury)	0.6	0.2
	Sediment (assumed 100% methylmercury)	0.06	0.02
	Soil (assumed 100% methylmercury)	0.4	0.03
	Hazard Index	1	0.5
Scenario 2 – Additivity assessed for each form of mercury			
Methyl mercury	Air	NA	NA
	Seafood	0.6	0.2
	Sediment	0.06	0.02
	Soil	0.04	0.003
	Hazard Index	0.7	0.3
Inorganic mercury	Air	NA	NA
	Seafood	NA	NA
	Sediment	NA	NA
	Soil	0.06	0.005
	Hazard Index	0.06	0.005
Elemental mercury	Air	0.4	0.2
	Seafood	NA	NA
	Sediment	NA	NA
	Soil	NA	NA
	Hazard Index	0.4	0.2

NA – not applicable, as form present in the environment does not require inclusion in additivity assessment for given scenario

Hazard Index and Hazard Quotient values were rounded to one significant figure. Total risk estimates may therefore be slightly lower and/or higher than that indicated based on summing of individual pathway risks, due to rounding effects. This is a standard approach in risk assessment, and is applied due to the inherent imprecision and uncertainties/conservatism within the risk assessment process.

The assessment calculated additive risk between pathways for exposure to both maximum and 95% UCL concentrations reported.

The hazard indices for **Scenario 1** were ***0.5*** (assuming continuous exposure to the 95% UCL of the mean concentration in each media) and ***1*** (assuming continuous exposure to the maximum reported concentration in each environmental medium). However; it is also noted that Scenario 1 conservatively assumed that the most toxic form of mercury may be present in all media for all scenarios and is considered to overestimate actual risk.

The hazard indices for **Scenario 2** ranged from ***0.005*** *to* ***0.03*** (based on the 95% UCL media concentrations) or from ***0.06 to 0.7*** (based on the maximum reported media concentrations). The range of hazard indices reflects the hazard indices for each form of mercury, as Scenario 2 accounts for the different toxic effects of each form of mercury, as the different forms may act via a different mechanism on the body; therefore additivity across exposure was not necessarily appropriate.

As discussed above in **Section 5.4.1**, hazard indices equal to or below 1 are considered to provide a high level of confidence that actual exposures do not exceed those which could pose an adverse health risk, since safety factors of between 100 and 10,000 are commonly used to derive the ADI or TDI estimates. In addition, a number of other conservative assumptions were adopted in deriving the hazard indices, particularly for Scenario 1.

As the hazard indices calculated did not exceed 1, even where it was conservatively assumed that the most toxic form of mercury was present in all media and individuals were continuously exposed for their lifetime to the maximum reported mercury concentrations in each environmental medium, risks associated with exposure to mercury within the assessment area were considered to be low and acceptable.

6.0 Conclusions

6.1 Overall Conclusions

This Tier 1 EHRA was completed to address community concerns regarding potential environmental and health impacts due to historic mercury emissions from the Orica FCAP located at the Botany Industrial Park. The EHRA represents Stage 3 of an independent review of the environmental health impacts from historical mercury emissions, and builds upon information collected during Stages 1 and 2 of the review. The primary aim of the independent review was to assess the potential for mercury emissions from the FCAP to have resulted in health risks to the adjacent community.

With consideration to the community concerns which prompted the independent review, the overall conclusions of the Tier 1 EHRA were the following:

- The quantity and quality of data collected during Stages 1 and 2 of the independent review were considered adequate to undertake an environmental health risk assessment, i.e. were adequate to characterise levels of mercury in the environment to which the community may be exposed.
- Health risks to the community due to identified levels of mercury in the environment are classified as acceptable in accordance with Australian and international regulatory guidance, and are not discernibly higher than that expected for the general public in urban areas of NSW.

A more detailed summary of specific findings of the Tier 1 EHRA is provided in **Section 6.2** below.

6.2 Summary of Findings

A summary of the investigation program from Stage 2 of the Orica Botany independent review into mercury can be summarised as follows:

- The assessment of soil shows mercury present above laboratory detection limits (limits of reporting) on residential and public lands across the area investigated. These mercury levels are likely attributable to a combination of historical operations at the FCAP site and background urban sources. However, the concentrations were below adopted screening criteria, demonstrating no expected impact to human health.
- The assessment of ambient air shows mercury above laboratory limits of reporting in the majority of locations sampled. As with soil, these concentrations are likely attributable to a combination of fugitive emissions from the FCAP site and background urban sources. As for soil, the concentrations were below adopted screening criteria, demonstrating no expected impact to human health.
- The assessment of sediment and fish in Penrhyn Estuary and surrounds shows mercury above laboratory limits of reporting in the majority of samples collected. As with soil and air, these concentrations are likely attributable to a combination of fugitive emissions from the FCAP site and background urban/industrial sources. The concentrations were below adopted screening criteria, demonstrating no expected impact to human health.

A review of data quality indicated one modest data gap, and several minor ones. The modest data gap was the lack of information on the proportion of different mercury forms in the analyses. This gap was addressed by the use of two conservative assumptions. The first was that the behaviour of different mercury forms in the environment were assumed to reflect the behaviour of the mercury form with the greatest distribution and movement. The second was that all forms of mercury detected were assumed to be as toxic as methylmercury, the most toxic form. Despite these conservative assumptions, the reported concentrations remain below adopted screening criteria. Minor data gaps associated with QA/QC procedures were noted, but these did not contribute materially to the analysis.

On the basis of the available data and the assumptions presented in this report, the following conclusions are provided:

- The data were considered to have reasonably characterised the area for mercury contamination and were of acceptable quality to use in the decision making process.
- One residence was found to have anomalously high mercury contamination within a narrow plant bed in a back garden area, at a depth of 0.4 meters. It was considered that this was most likely associated with residential waste or uncontrolled importation of fill/soil, rather than from emissions associated with the FCAP. It is understood that the contaminated soil will be managed by the EPA.
- This environmental health risk assessment was based on a conservative screening level assessment, whereby screening criteria published by Australian and international regulators were compared against the upper limits of reported concentrations. All sampling locations (excluding the anomalously high mercury levels reported in one garden bed) were found to have mercury and other contaminant concentrations less than the relevant screening criteria and concentrations were consistent with those reported elsewhere in urban areas.
- Concentrations of other potential contaminants (lead, chromium, polychlorinated biphenyls and polycyclic aromatic hydrocarbons), which were included in the soil sampling program in selected locations, were also reported to be less than relevant health-based screening criteria.

On the basis of these findings, public health risks to the community due to mercury contamination from the FCAP and/or from other background sources of mercury are classified as acceptable in accordance with Australian and international regulatory guidance, and are not discernibly higher than that expected for the general public in urban areas of NSW.

7.0 Principles and Limitations of Investigation

7.1 Inherent Uncertainties and Limitations

The following principles are an integral part of site contamination assessment practices and are intended to be referred to in resolving any ambiguity or exercising such discretion as is accorded the user or site assessor.

Area	Field Observations and Analytical Results
Elimination of Uncertainty	Some uncertainty is inherent in all site investigations and associated data, including that collected by WSP and relied upon in the preparation of this report. Furthermore, any sample, either surface or subsurface, taken for chemical testing may or may not be representative of a larger population or area. Professional judgment and interpretation are inherent in the process, and even when exercised in accordance with objective scientific principles, uncertainty is inevitable. Additional assessment beyond that which was undertaken may reduce the uncertainty.
Failure to Detect	Even when site investigation work is executed competently and in accordance with the appropriate Australian guidance, such as the National Environmental Protection (Assessment of Site Contamination) Amendment Measure ('the NEPM'), it must be recognised that certain conditions present especially difficult target analyte detection problems. Such conditions may include, but are not limited to, complex geological settings, unusual or generally poorly understood behaviour and fate characteristics of certain substances, complex, discontinuous, random, or heterogeneous distributions of target analytes, physical impediments to investigation imposed by the location of services, structures and other man-made objects, and the inherent limitations of assessment technologies.
Limitations of Information	The effectiveness of any site investigation may be compromised by limitations or defects in the information used to define the objectives and scope of the investigation, including inability to obtain information concerning historic site uses or prior site assessment activities despite the efforts of the user and assessor to obtain such information.
Chemical Analysis Error	Chemical testing methods have inherent uncertainties and limitations. Senversa has provided a third party review of the data collected by WSP and relied upon in this report, in accordance with the requirements of NSW EPA contaminated land guidance. Minor data quality issues were identified and are discussed within the relevant section of the report.
Level of Assessment	The investigation herein should not be considered to be an exhaustive assessment of environmental conditions within the assessment area. There is a point at which the effort of information obtained and the time required to obtain it outweigh the benefit of the information gained and, in the context of private transactions and contractual responsibilities, may become a material detriment to the orderly conduct of business. If the presence of target analytes is confirmed on a property, the extent of further assessment is a function of the degree of confidence required and the degree of uncertainty acceptable in relation to the objectives of the assessment.
Comparison with Subsequent Inquiry	The results of the risk assessment presented herein were determined in accordance with generally accepted protocols and with consideration of available site conditions. The justification and adequacy of the investigation findings in a subsequent inquiry should be evaluated based on the reasonableness of judgments made at the time and under the circumstances in which they were made.

Area	Field Observations and Analytical Results
Data Useability	Investigation data generally only represent the site conditions at the time the data were generated. Therefore, the data collected (by others) and relied upon in this report has a finite lifetime depending on the application and use being made of the data. In all respects, a future reader of this report should evaluate whether previously generated data are appropriate for any subsequent use beyond the original purpose for which they were collected, or are otherwise subject to lifetime limits imposed by other laws, regulations or regulatory policies.
Nature of Advice	The works discussed herein are intended to develop and present sound, scientifically valid data concerning actual site conditions. Senversa does not seek or purport to provide legal or business advice.

7.2 Project Specific Uncertainties

Specific uncertainties and limitations noted for this investigation are as follows:

- The assessment was undertaken using data collected and reported by another consultant, WSP Environmental Pty Ltd. Review of the data quality has been undertaken, with data gaps and data quality issues identified and discussed within the report. Main potential gaps or uncertainties include:
  - Lack of speciated mercury analyses, to assess the relative contribution of elemental, inorganic, or methylmercury forms to the total mercury concentrations.
  - Minor non-conformances with quality assurance / quality control sample frequency during the sampling program.

  The above and other inherent uncertainties were addressed through the adoption of conservative assumptions, as described in this report.
- Quantitative and qualitative human health and environmental risk assessments involve a number of uncertainties and limitations. As a consequence, conservative assumptions are generally made to deliberately overestimate risks and provide an additional margin of safety. Thus, the results presented herein are likely to be overly protective, although, to a limited extent they may not provide complete protection of all receptors in all circumstances.
- The services performed in the preparation of this report were conducted in a manner consistent with the level of skill and care ordinarily exercised by professional engineers and scientists practising under similar conditions.

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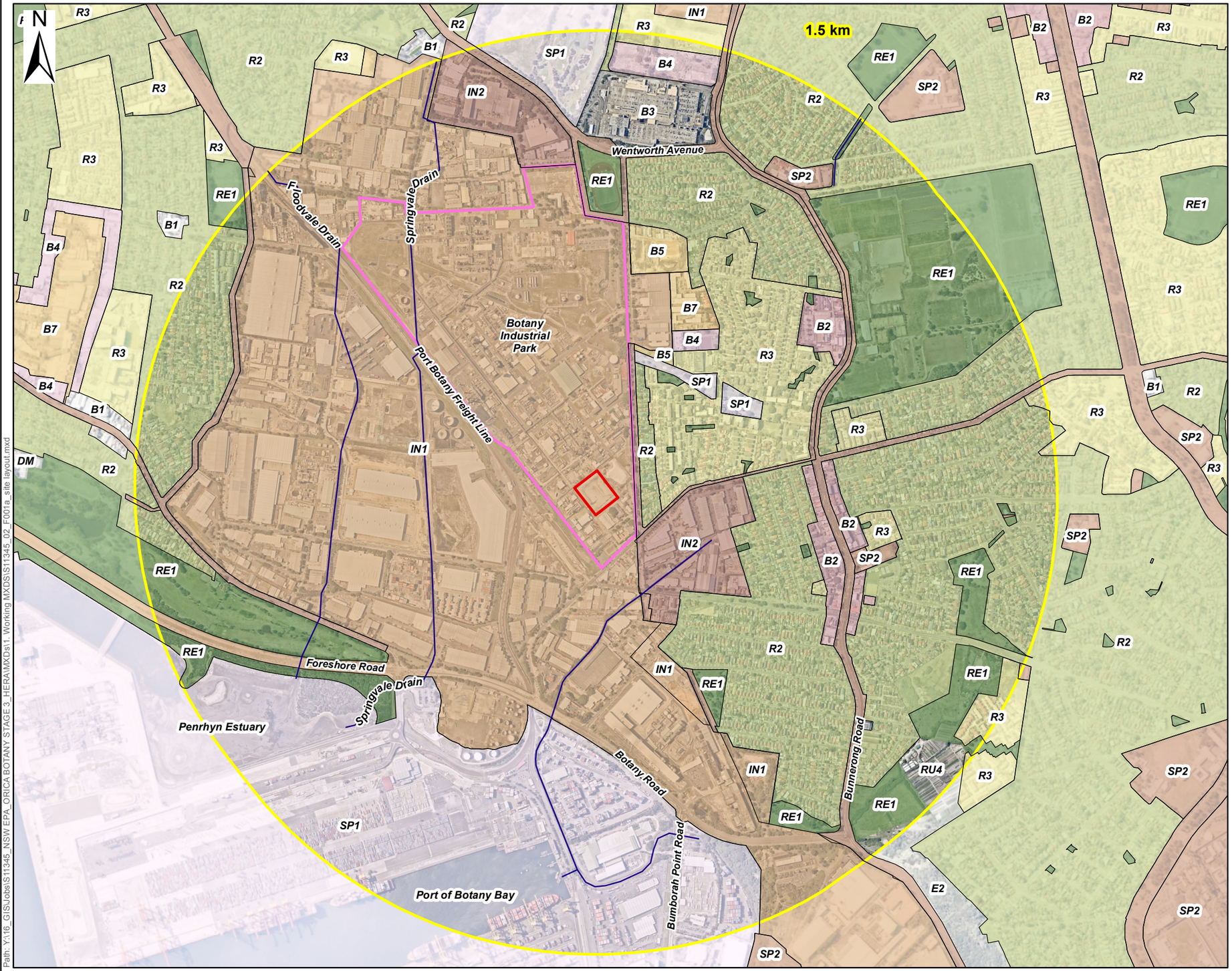
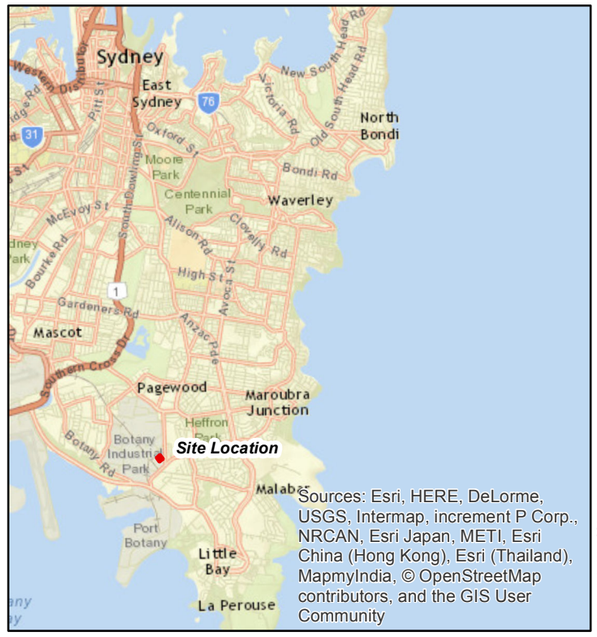
Figures





Planning

- Public Recreation, RE1
- Private Recreation, RE2
- Low Density Residential, R2
- Medium Density Residential, R3
- National Parks and Nature Reserves, E1
- Business Development, B5
- Business Park, B7
- General Industrial, IN1
- Infrastructure, SP2
- Light Industrial, IN2
- Local Centre, B2
- Mixed Use, B4
- Special Activities, SP1
- Water Areas

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Fax: (03) 9606 0074
Website: www.senversa.com.au

Legend

- Drains Approximate
- FCAP Site Boundary
- Botany Industrial Park
- Assessment Area within 1.5 km of FCAP

Designed:	V. Lazenby	Date:	18/01/2016
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0 125 250 500 750 1,000 Metres

Datum GDA 1994, Projection MGA Zone 56

Figure No: 1a

Title: FCAP and Assessment Area Location

Project: Tier 1 Environmental Health Risk Assessment

Location: Orica Botany

Client: NSW Environment Protection Authority

Path: Y:\16_GIS\Jobs\S11345_NSW EPA_ORICA BOTANY STAGE 3_HERA\MXDs\1. Working MXDs\S11345_02_F001b_Suburbs in Assessment Area.mxd

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Website: www.senversa.com.au

Legend

- FCAP Site Boundary
- Assessment Area within 1.5 km of FCAP
- Suburb Boundary

Designed:	V. Lazenby	Date:	18/01/2016
Drawn:	M. Byrne	Revision:	0
Checked:	K. Hanson	Scale:	1:14,000(A3)
File:	S11345_02_F001b_Suburbs in Assessment Area		

0 140 280 560 840 1,120 Metres

Datum GDA 1994, Projection MGA Zone 56

Figure No: 1b

Title: Suburbs within Assessment Area and Surrounds

Project: Tier 1 Environmental Health Risk Assessment

Location: Orica Botany

Client: NSW Environmental Protection Authority

Path: Y:\16_GIS\Jobs\S11345_NSW EPA_ORICA BOTANY STAGE 3_HERA\MXDs\1. Working MXDS\S11345_02_F002a_soil mercury results surface.mxd

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Fax: (03) 9606 0074
Website: www.senversa.com.au

Legend

Soil Mercury Results at surface (mg/kg)
- <LOR
- 0.1 - 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0

- Botany Industrial Park
- 1.5 km Buffer from FCAP
- Drains Approximate
- FCAP Site Boundary

Designed:	V. Lazenby	Date:	7/12/2015
Drawn:	S. Koroblitsas	Revision:	0
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File:	S11345_02_F002a_soil mercury results surface		

0 125 250 500 750 1,000 Metres

Datum GDA 1994, Projection MGA Zone 56

Figure No: 2a

Title: Mercury Soil Results – Surface Soils (0-0.05 m)

Project: Tier 1 Environmental Health Risk Assessment

Location: Orica Botany

Client: NSW Environment Protection Authority

Path: Y:\16_GIS\Jobs\S11345_NSW EPA_ORICA BOTANY STAGE 3_HERAIM\MXDs\1. Working MXDS\S11345_02_F002b_soil mercury results depth.mxd

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Fax: (03) 9606 0074
Website: www.senversa.com.au

Legend

Soil Mercury Results at depth (mg/kg)
- <LOR
- 0.1 - 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0

- Drains Approximate
- FCAP Site Boundary
- Botany Industrial Park
- 1.5 km Buffer from FCAP

Designed:	V. Lazenby	Date:	7/12/2015
Drawn:	S. Koroblitsas	Revision:	0
Checked:	K. Hanson	Scale:	1:14,000(A3)
File:	S11345_02_F002b_soil mercury results depth		

0 125 250 500 750 1,000 Metres

Datum GDA 1994, Projection MGA Zone 56

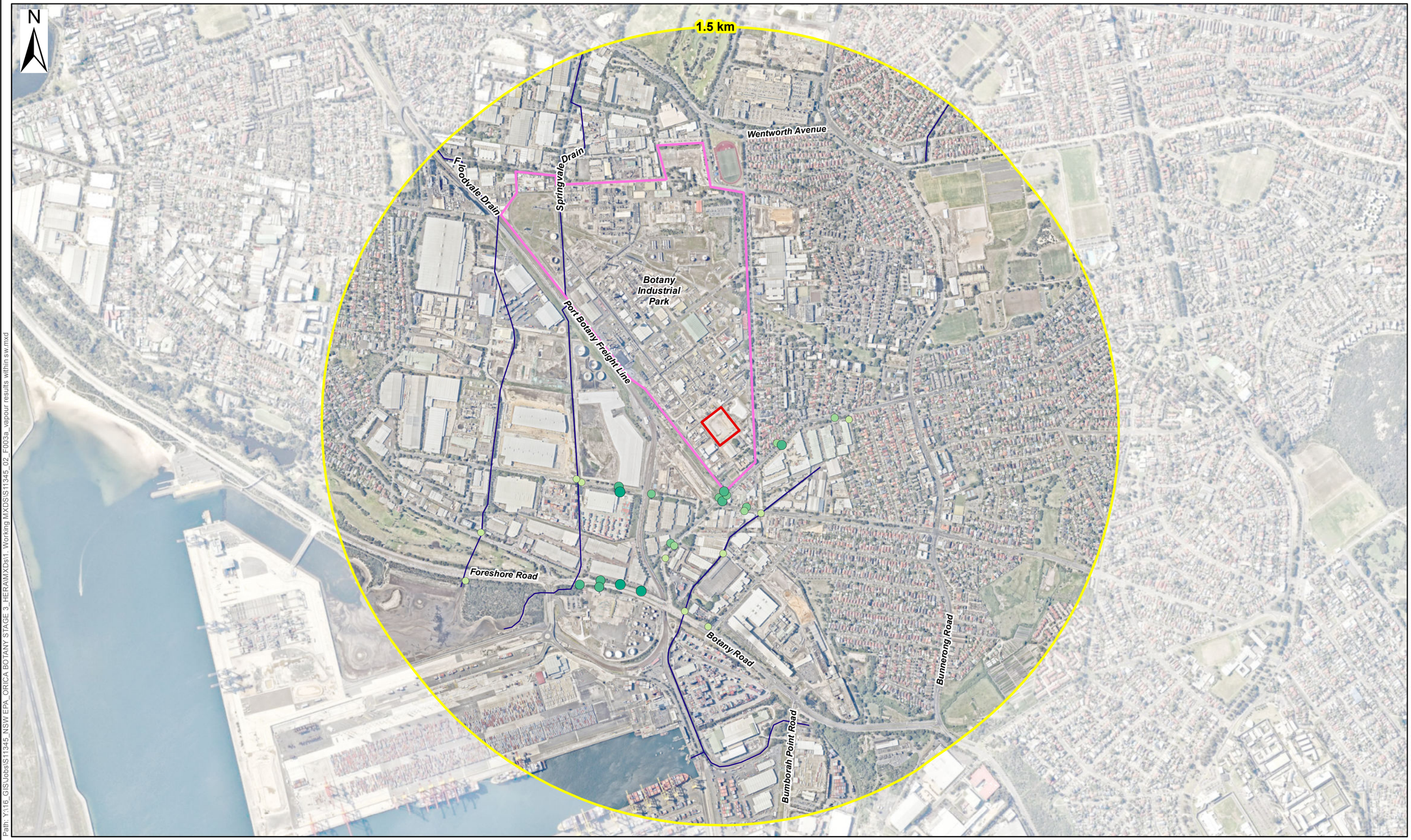
Figure No: 2b

Title: Mercury Soil Results – Deeper Soils (0.4-0.5 m)

Project: Tier 1 Environmental Health Risk Assessment

Location: Orica Botany

Client: NSW Environment Protection Authority



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Fax: (03) 9606 0074
Website: www.senversa.com.au

Legend

Stormwater Vapour Conc Inside (ng/m3)

- <LOR
- <LOR - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80

FCAP Site Boundary
Botany Industrial Park
1.5 km Buffer from FCAP
Drains Approximate

Designed:	V. Lazenby	Date:	7/12/2015
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File:	S11345_02_F003a_vapour results within sw		

0 125 250 500 750 1,000 Metres

Datum GDA 1994, Projection MGA Zone 56

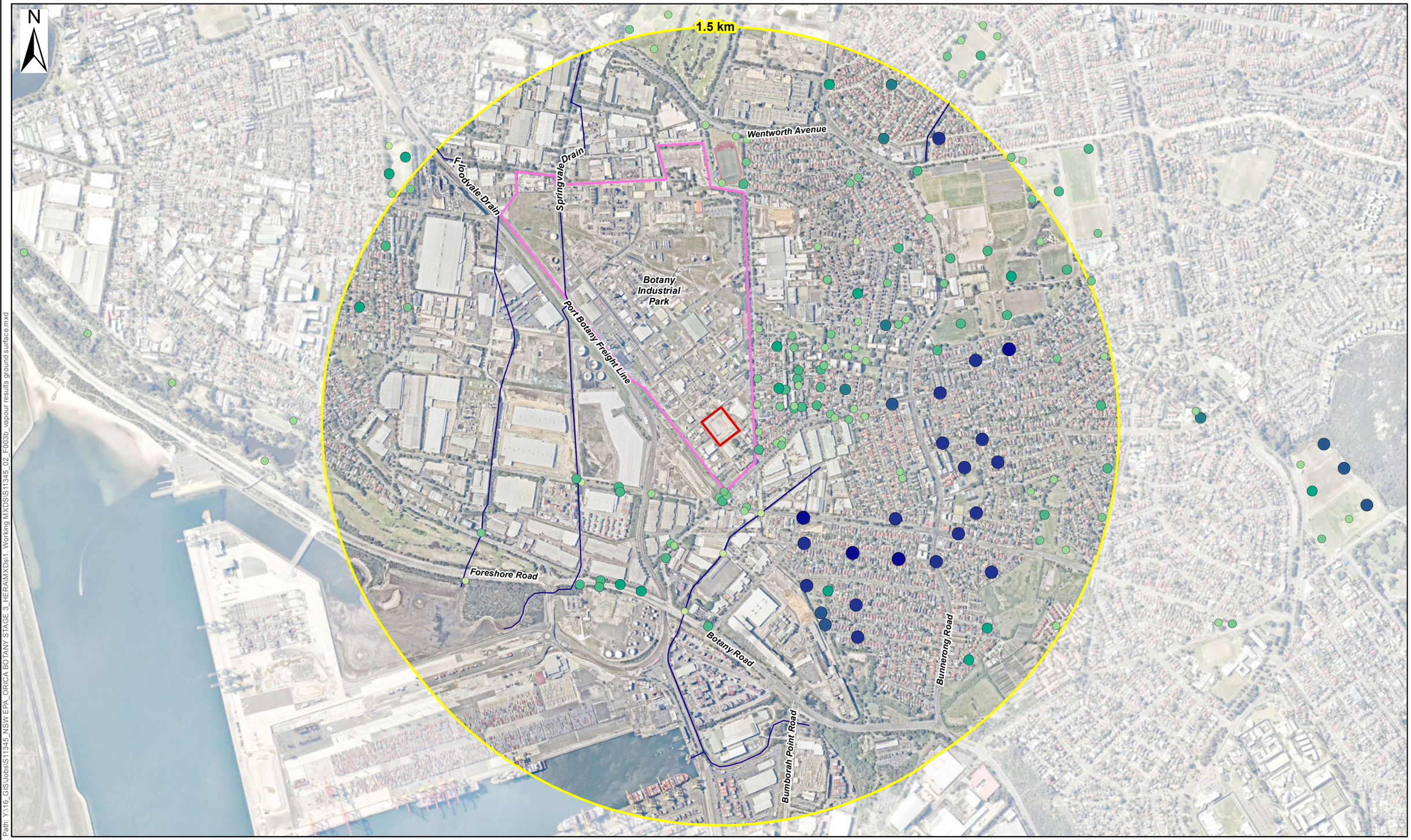
Figure No: 3a

Title: Mercury Vapour Results – Within Stormwater Drains

Project: Tier 1 Environmental Health Risk Assessment

Location: Orica Botany

Client: NSW Environment Protection Authority



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senversa
Address: Level 14, 309 Kent Street, Sydney NSW 2000
Phone: (02) 9994 8016
Fax: (03) 9606 0074
Website: www.senversa.com.au

Legend

Vapour Concentrations Surface (ng/m3)

- <LOR
- <LOR - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- Drains Approximate
- FCAP Site Boundary
- 1.5 km Buffer from FCAP
- Botany Industrial Park

Designed:	V. Lazenby	Date:	7/12/2015
Drawn:	S. Koroblitsas	Revision:	0
Checked:	K. Hanson	Scale:	1:14,000(A3)
File:	S11345_02_F003b_vapour results ground surface		

0 125 250 500 750 1,000 Metres

Datum GDA 1994, Projection MGA Zone 56

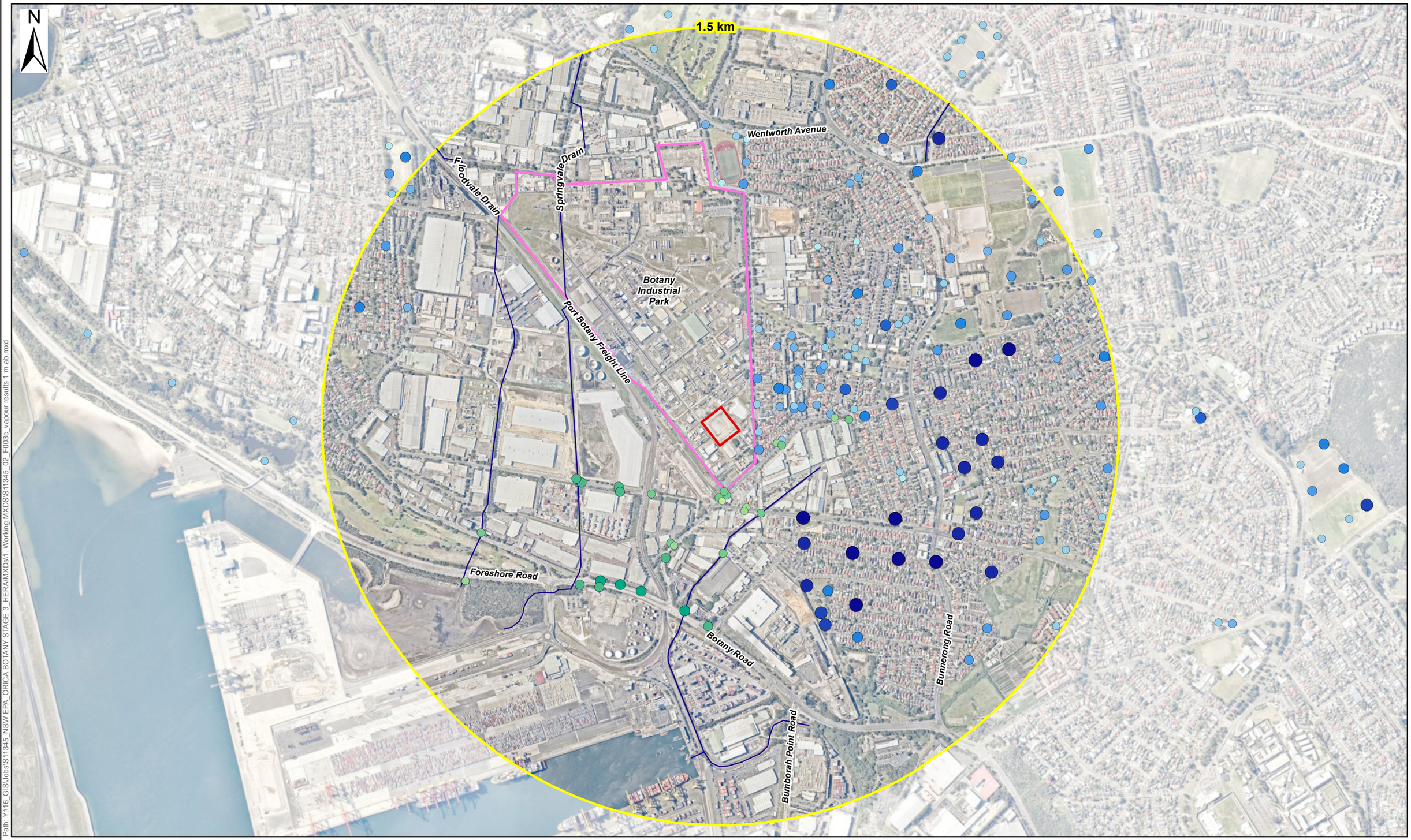
Figure No: 3b

Title: Mercury Vapour Results – At Ground Surface

Project: Tier 1 Environmental Health Risk Assessment

Location: Orica Botany

Client: NSW Environment Protection Authority



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senversa
Address: Level 14, 309 Kent Street, Sydney NSW 2000
Phone: (02) 9994 8016
Fax: (03) 9606 0074
Website: www.senversa.com.au

Legend

Vapour Concentrations at 1 m ABG (ng/m3)

- <LOR
- <LOR - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- Drains Approximate
- FCAP Site Boundary
- Botany Industrial Park
- 1.5 km Buffer from FCAP

Designed:	V. Lazenby	Date:	7/12/2015
Drawn:	S. Koroblitsas	Revision:	0
Checked:	K. Hanson	Scale:	1:14,000(A3)
File:	S11345_02_F003c_vapour results 1 m ab		

0 125 250 500 750 1,000 Metres

Datum GDA 1994, Projection MGA Zone 56

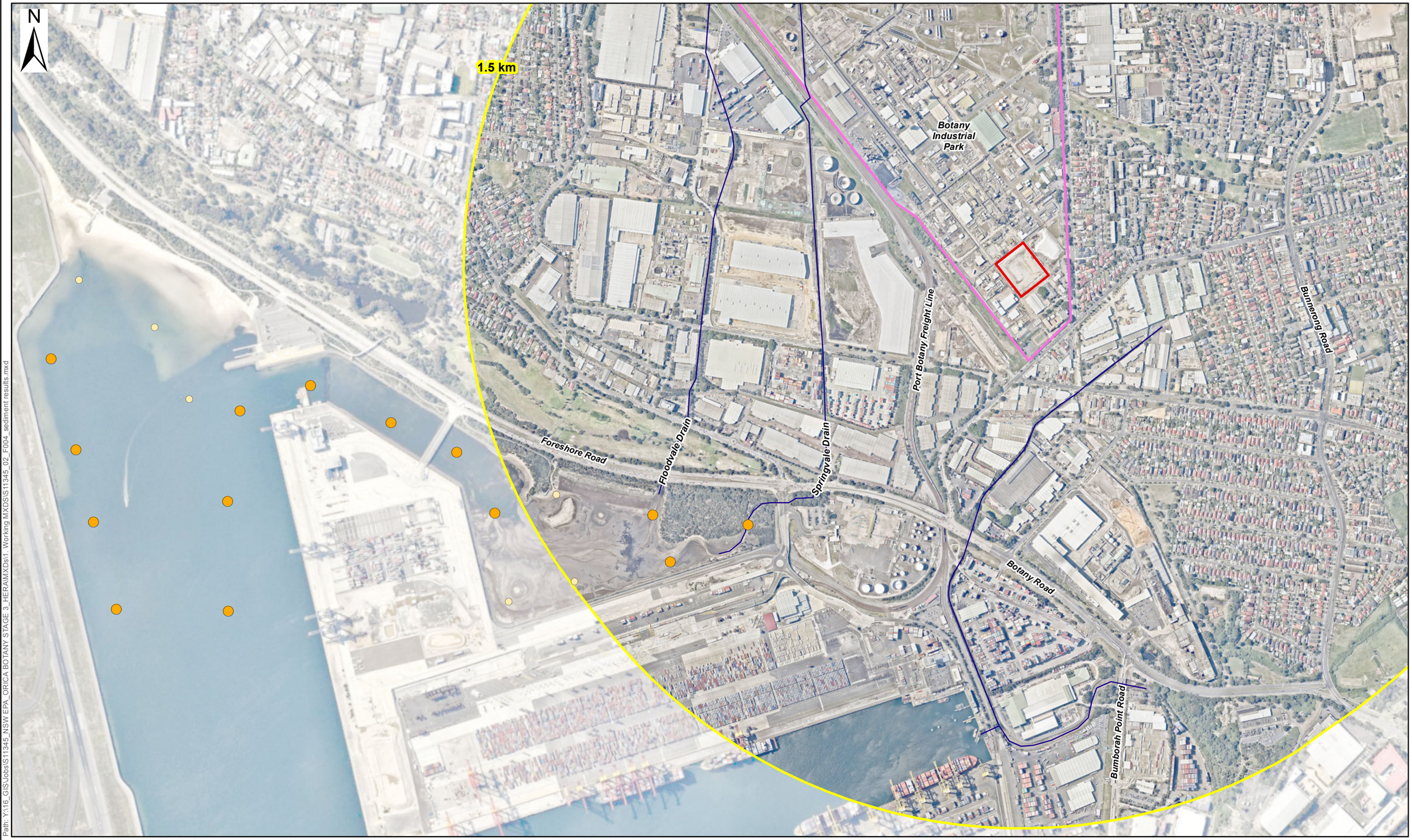
Figure No: 3c

Title: Mercury Vapour Results – 1 Metre Above Ground Surface

Project: Tier 1 Environmental Health Risk Assessment

Location: Orica Botany

Client: NSW Environment Protection Authority



senversa
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Phone: (02) 9994 8016
Fax: (03) 9606 0074
Website: www.senversa.com.au

Legend

Sediment Samples

- <LOR
- >LOR - 1.0 mg/kg
- Drains Approximate
- FCAP Site Boundary
- Botany Industrial Park
- 1.5 km Buffer from FCAP

Designed:	V. Lazenby	Date:	7/12/2015
Drawn:	S. Koroblitsas	Revision:	0
Checked:	K. Hanson	Scale:	1:10,000(A3)
File:	S11345_02_F004_sediment results		

0 62.5 125 250 375 500 Metres

Datum GDA 1994, Projection MGA Zone 56

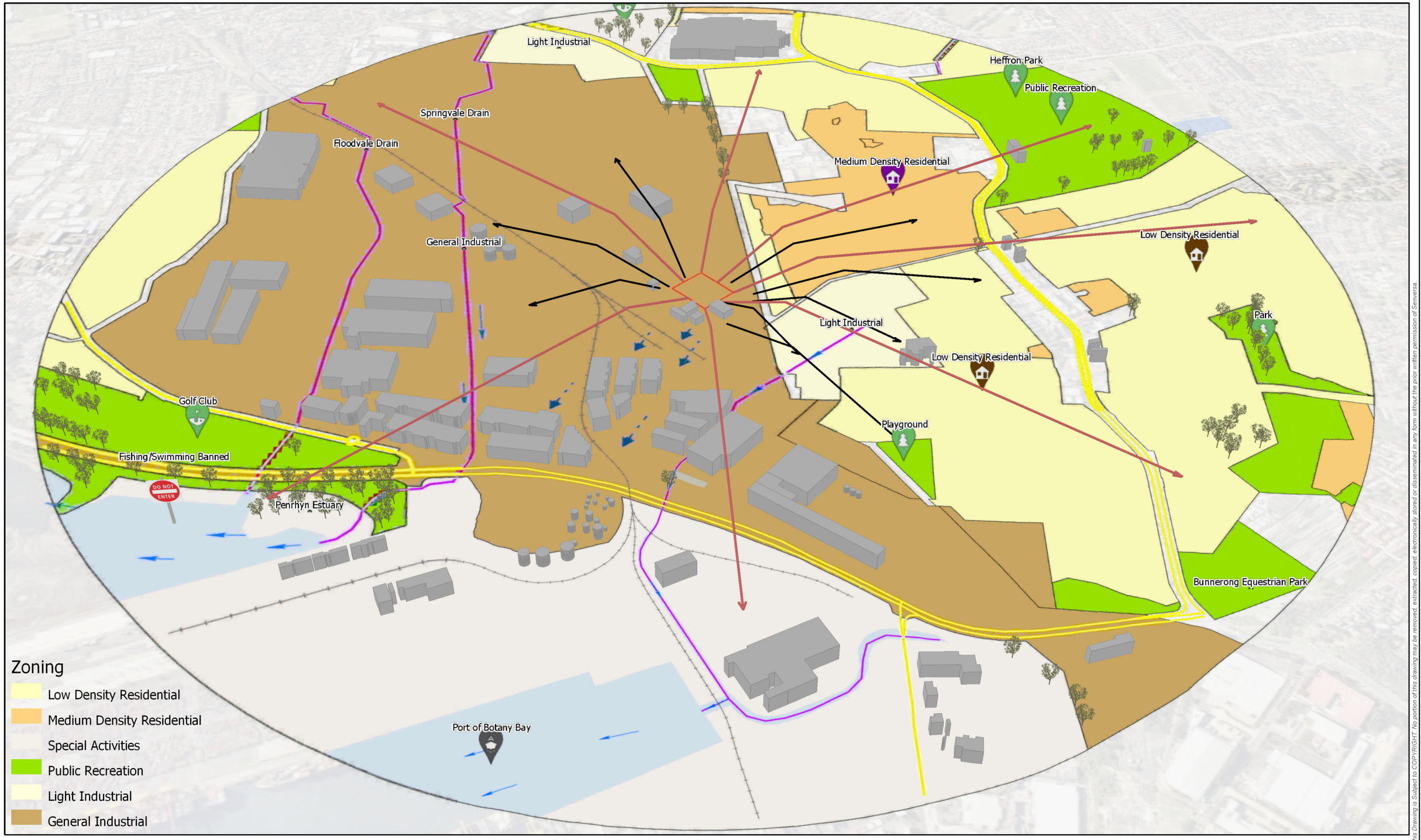
Figure No: 4

Title: Sediment Sample Results

Project: Tier 1 Environmental Health Risk Assessment

Location: Orica Botany

Client: NSW Environment Protection Authority



Path: C:\Users\stefanos.koroblitsas\Documents\ArcGIS\Projects\MyProject8\MyProject8.aprx

senversa
Address: Ground Floor, 51 Clarke Street, Southbank VIC 3006
Phone: (03) 9606 0070
Fax: (03) 9606 0074
Website: www.senversa.com.au

- 1.5 Km from FCAP
- Mercury Migration in Groundwater
- Mercury Migration in Surface Water
- Estimated Mercury Migration in Particles
- Estimated Mercury Migration as Vapour
- Drains approximate
- FCAP Site Boundary

Designed:	V. Lazenby	Date:	7/12/2015
Drawn:	S. Koroblitsas	Revision:	0
Checked:	K. Hanson	Scale:	(A3)
File:	MyProject8		

0 25 50 100 150 200 Meters
Datum GDA 1994, Projection MGA Zone 56

Figure No: 5

Title: Conceptual Site Model

Project: Tier 1 Environmental Health Risk Assessment

Location: Orica Botany

Client: NSW Environment Protection Authority

Appendix A: Local Government Planning and Land Use Maps

Botany Bay Local Environmental Plan 2013

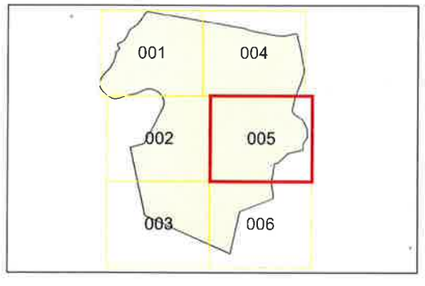
Land Zoning Map - Sheet LZN_005

Zone

- B1 Neighbourhood Centre
- B2 Local Centre
- B3 Commercial Core
- B4 Mixed Use
- B5 Business Development
- B7 Business Park
- IN1 General Industrial
- IN2 Light Industrial
- R2 Low Density Residential
- R3 Medium Density Residential
- R4 High Density Residential
- RE1 Public Recreation
- RE2 Private Recreation
- SP1 Special Activities
- SP2 Infrastructure
- W3 Working Waterways
- MD SEPP (Major Development) 2005
- DM Deferred Matter

Cadastre

Base data 5/11/2012 © Land and Property Information (LPI)



N

0 200 400 m

Scale 1:10,000 @ A3

Projection GDA 1994 Zone 56

Map identification number:
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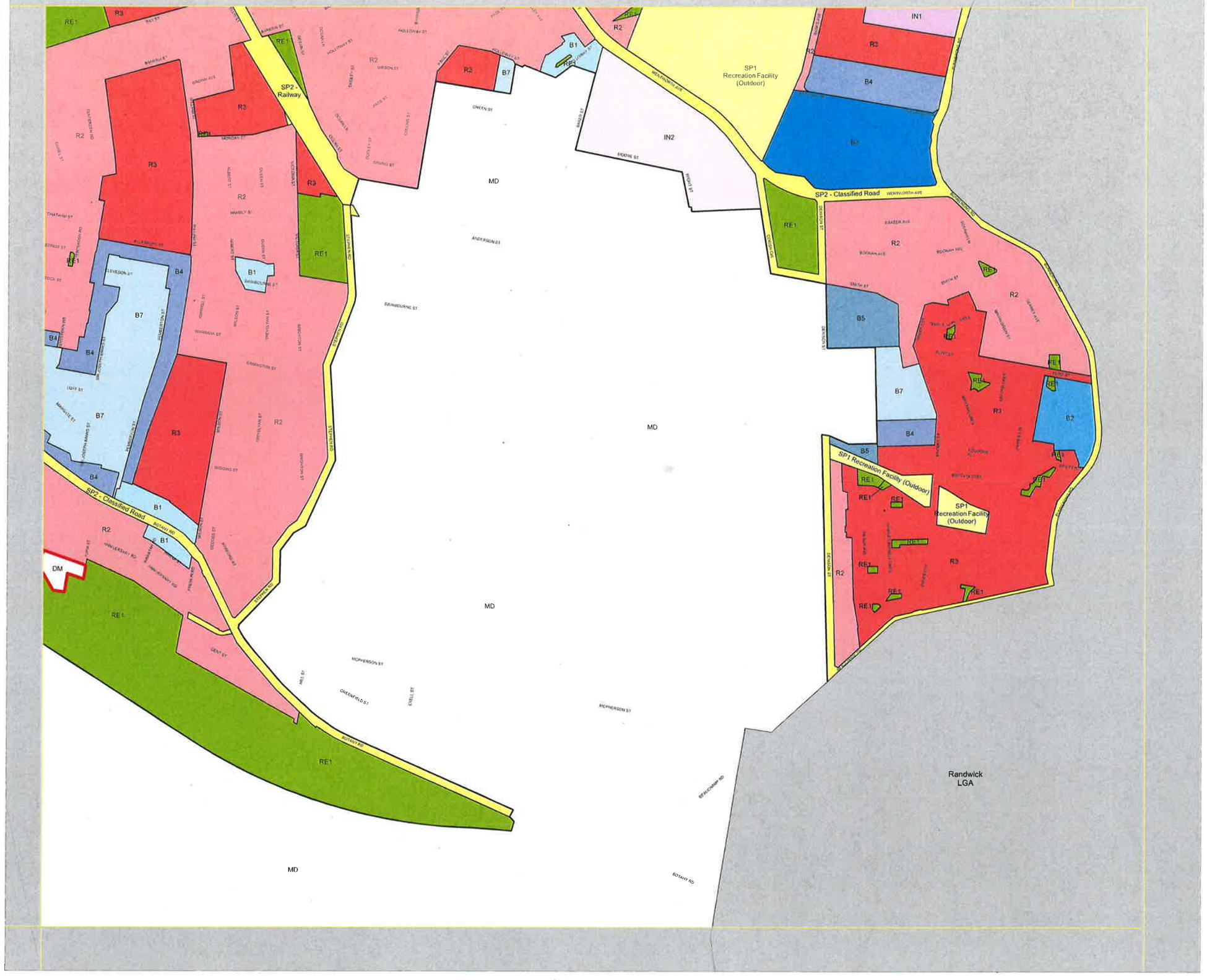


NSW GOVERNMENT Planning & Infrastructure

State Environmental Planning Policy (Three Ports) 2013 Land Zoning Map

Sheet LZN_001
Port Botany

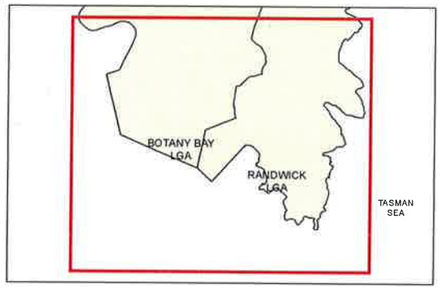
- Subject Land

Zone

- IN1 General Industrial
- IN3 Heavy Industrial
- RE1 Public Recreation
- SP1 Special Activities
- DM Deferred Matter
- UL Unzoned Land
- Container Depots Prohibition Area

Cadastre

Cadastre 18/2/2014 © Land and Property Information (LPI)



Projection: MGA Zone 56
Datum: GDA94

0 250 500 750 1,000 m

Scale: 1:30,000 @ A3

Map Identification Number
SEPP_TPT_LZN_001_030_20140218

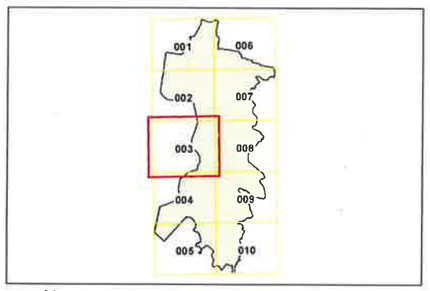
Randwick Local Environmental Plan 2012

Land Zoning Map - Sheet LZN_003

Zone

- B1 Neighbourhood Centre
- B2 Local Centre
- E1 National Parks and Nature Reserves
- E2 Environmental Conservation
- IN2 Light Industrial
- R1 General Residential
- R2 Low Density Residential
- R3 Medium Density Residential
- RE1 Public Recreation
- RE2 Private Recreation
- RU4 Primary Production Small Lots
- SP1 Special Activities
- SP2 Infrastructure
- MD SEPP (Major Development) 2005

Cadastre



N

0 200 Metres

Projection: GDA 1994 MGA Zone 56

Scale: 1:10,000 @ A3

Map identification number: 6550_COM_LZN_003_010_20120615

BOTANY BAY LGA

MAROUBRA

MATRAVILLE

SP2 CLASSIFIED ROAD

SP2 EDUCATIONAL ESTABLISHMENT

SP2 PLACE OF PUBLIC WORSHIP

SP2 ELECTRICITY GENERATING WORKS

SP2 CLASSIFIED ROAD BEAUCHAMP ROAD

BUNNERONG ROAD

ANZAC PARADE

Randwick City Council
a sense of community

Randwick Local Environmental Plan 2012

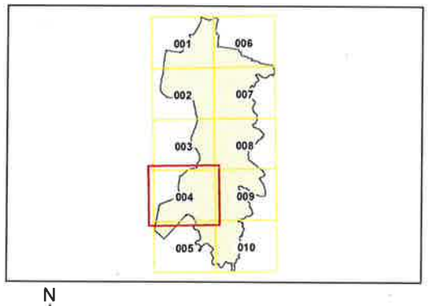
Land Zoning Map - Sheet LZN_004

Zone

- B1 Neighbourhood Centre
- B2 Local Centre
- E1 National Parks and Nature Reserves
- E2 Environmental Conservation
- IN2 Light Industrial
- R1 General Residential
- R2 Low Density Residential
- R3 Medium Density Residential
- RE1 Public Recreation
- RE2 Private Recreation
- RU4 Primary Production Small Lots
- SP1 Special Activities
- SP2 Infrastructure
- MD SEPP (Major Development) 2005

Cadastre

Base data 01/01/2008 © Land and Property Information (LPI) Addendum data 12/11/2012
© Randwick City Council



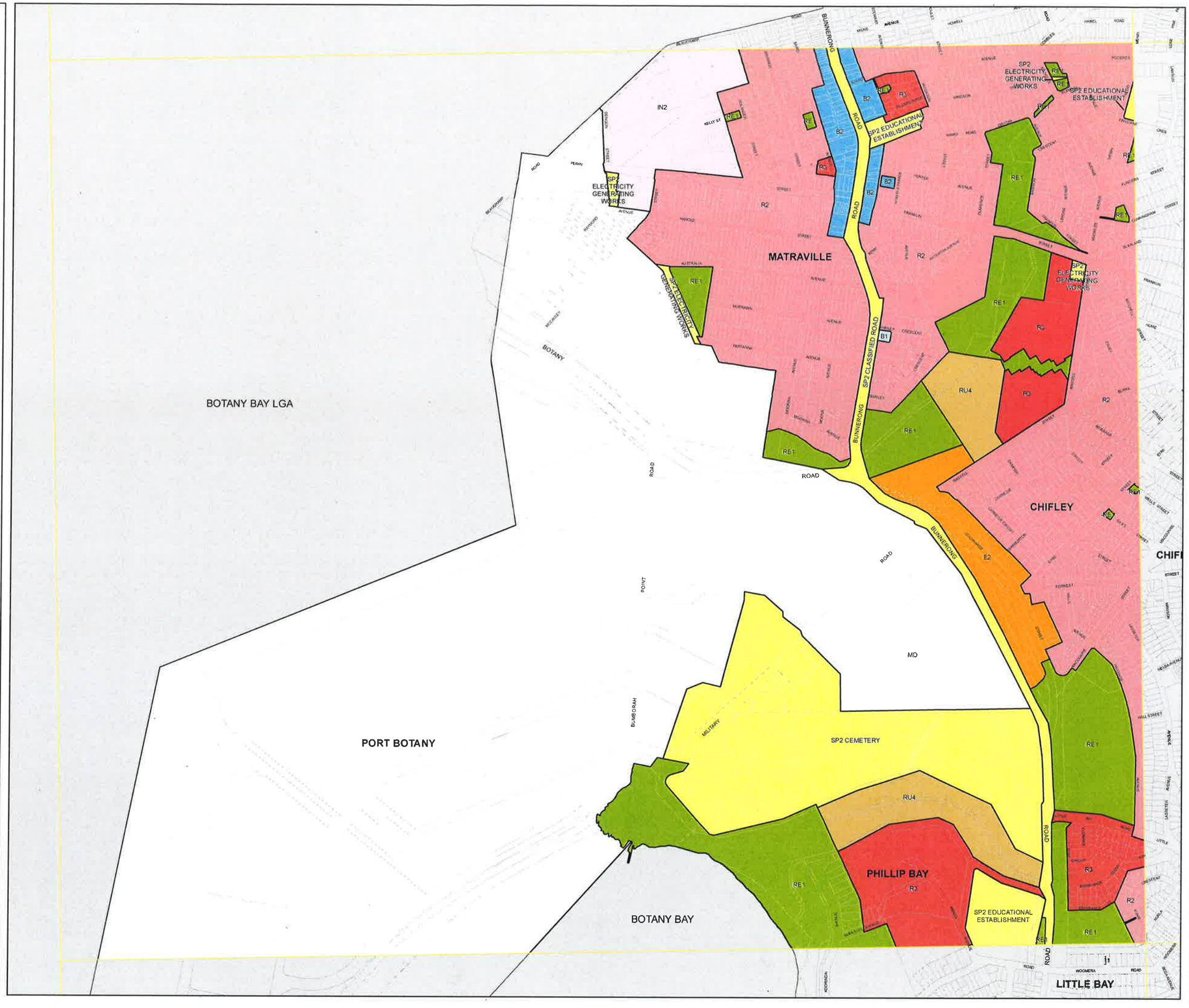
N

0 200 400 Metres

Projection: GDA 1994 MGA Zone 56

Scale: 1:10,000 @ A3

Map identification number: 6550_COM_LZN_004_010_20121113



Appendix B: Data Quality Review

Table B-1 Evaluation of Field QA/QC

	Objective/ Guidance Document	Summary of Methodology	Comments
Data Quality Objectives (DQOs) articulated.	AS 4482.1 – 2005.	The scope of works was devised in general accordance with the seven step data quality process as defined in Australian Standard AS 4482.1 Guide to the investigation and sampling of sites with potentially contaminated soil Part 1: Non-volatile and semi-volatile compounds.	The DQO process was outlined in the SAQP. It is considered that the DQOs were articulated in general accordance with AS 4482.1.
QA/QC program includes field replicate samples.	Analysis of 5% field duplicate samples RPD +/- 30% for inorganic analyses RPD +/- 50% for organic analyses AS4482.1, NEPC (2013).	Soil investigation included field replicate sampling at a rate of approximately one replicate sample for every twenty-two original samples for intra-laboratory and inter-laboratory analysis. The replicate sample ratio was slightly lower than the minimum recommended in the investigation and validation works. RPDs were within the acceptable ranges.	While the duplicate sample frequency was slightly lower than that recommended in relevant guidance documents, this is not considered a significant issue due to the relatively large dataset and the availability of 15 duplicate sets (public lands sampling). The RPDs were within the acceptable range.
QA/QC program includes field blanks, trip blanks and equipment blanks.	NEPC (2013) One trip spike sample analysed for each form of media. One trip blank sample analysed for each form of media. At least one rinsate sample (collected from non-disposable equipment) analysed each day of fieldwork.	Field QC procedures were generally undertaken in accordance with SAQP. Field QC sampling including trip spikes, trip blanks and rinsate samples were undertaken.	A low frequency of rinsates, trip spikes and trip blanks was adopted within the SAQP. However, the low frequency of these QC samples were not considered a significant issue due to the decontamination procedures utilised during sampling procedures, which are unlikely to result in cross-contamination. Although dedicated sample gloves were used, sampling tools such as a hand auger were used between locations. Further, if cross-contamination did occur, it would be likely to result in reporting of elevated concentrations where they were not present, rather than result in under-estimation of concentrations. The low rate of rinsate, spike and blank samples is therefore considered unlikely to significantly impact on assessment findings.
All relevant media assessed.	NEPC (2013).	As part of the seven step DQO process, the need to assess soils, air, sediment, and fish were identified. Characterisation of the site addressed these media.	All relevant media for this investigation of the assessment area were assessed.
Sample collection, handling, preservation, containers and transportation procedures.	Sampling undertaken in accordance with standard procedures; chain of custody documentation completed; appropriate sample containers and transportation used NEPC (2013).	Sample collection was undertaken in accordance with procedures outlined in the SAQP. All sampling data were recorded on chain of custody sheets. Samples transferred into laboratory prepared glass jars and capped immediately labelled with individual and unique identification. Sample jars placed in cooled, insulated and sealed container for transport to the laboratory.	The sampling and handling procedures undertaken in the site investigations were presented in the WSP reports. Overall the reported sampling and handling procedures are considered appropriate with consideration to relevant guidance.

	Objective/ Guidance Document	Summary of Methodology	Comments
Sample rationale.	NEPC (2013).	The rationale for the selection of the type and number of samples collected for the site investigation and validation works were outlined in the SAQP.	The sampling program rationale was developed in accordance with NEPM (2013) guidance and was sufficient to address characterisation of the assessment area.
Sampling is representative of site conditions.	NEPC (2013)	The type, number and locations of samples collected during the site investigations were outlined in the SAQP.	Overall the sampling program was acceptable for assessing impacts across the assessment area.
Logs provided and appropriate.	Documentation of field activities in field notes and borelogs. NSW OEH (2011).	Provided as an appendix in WSP reports. Individual samples were recorded on the bore logs along with the sample identity, location, depth, initials of sampler, duplicate locations, duplicate type, and site observations.	Generally field notes were not provided in the reports, however borelogs were provided for soil sampling locations and biota sampling records were provided in the Ecosure appendix (WSP, 2015b). Overall, documentation of field activities was adequate to enable interpretation of the results.
Field screening.	NEPC (2013).	Vapour sampling was conducted using a portable field meter.	Field screening of soil samples was generally adequate and the equipment calibration documentation was provided.
Sampling devices/ techniques.	AS 4482.1, AS4482.2, NEPC (2013).	Sampling devices and techniques were generally described in the SAQP. These methods included: Soil – hand auger and disposal nitrile gloves Air – portable field analyser Sediments – not specified Fish – netting technique, undertaken by sub-contractor (Ecosure)	The procedures are consistent with those recommended in relevant guidance documents.

Table B-2 Evaluation of Laboratory QA/QC

	Objective/ Guidance Document	Summary of Methodology	Comments
Appropriate methodologies used for sample analyses.	Laboratories performing analyses accredited by the National Association of Testing Authorities (NATA) for the methods used. NEPC (2013)	The primary laboratory used was ALS Environmental – NATA Accreditation No. 825 The secondary laboratory used was Envirolab Services Pty Ltd – NATA Accreditation No. 2901	The primary and secondary laboratories used are all NATA accredited for the methods used. The laboratory reports were NATA stamped and signed by a NATA signatory.
Appropriate practical quantitation limits (PQLs).	Less than validation criteria – NEPC (2013)	The PQLs for all analytical data were below the site criteria.	PQLs were below site validation criteria.
Laboratory QA/QC plan.	Holding times met Laboratory QC samples including surrogate spikes, laboratory control samples, laboratory duplicate samples, laboratory blank samples, matrix spike samples meet acceptance standards NEPC (2013)	Holding times were generally met and the majority of laboratory QC exceedances were documented in the laboratory reports.	While laboratory QC exceedances were generally minor and do not affect the outcome of the assessment, some minor QC exceedances were not identified or discussed by WSP (e.g. holding time exceedance SED13, ES1505565). These exceedances were not considered significant or likely to impact on data evaluation, as they did not relate to key chemicals of interest (i.e. mercury) in the investigation. .

Table B-3 Overall Sampling and Analysis Methodology Assessment

Data Quality Indicator	Considerations	Requirements	Comments
Precision	Field	SOPs appropriate and complied with.	The WSP internal SOP documents were not presented in the reports. The reports however outlined the field methodologies for sampling. Field precision was adequately evaluated through the collection of replicate samples.
	Laboratory	Analysis of: • laboratory and inter-laboratory duplicates; • field duplicates; and • laboratory prepared volatile trip spikes.	Analysis was undertaken of laboratory duplicates, inter-laboratory duplicates, and field duplicates. It was considered that the data set generated were of acceptable precision.
Accuracy	Field	SOPs appropriate and complied with.	The WSP internal SOP documents were not presented in the reports. The reports however outlined the field methodologies for sampling conducted, and the field records indicate that these were followed. Field accuracy was evaluated (in part) through the collection of trip blanks, rinsate blanks, and use of laboratory prepared spikes, although the frequency of these samples was low. Notwithstanding this low frequency, it is considered that cross-contamination and/or analyte loss during sampling and transport activities is low, and samples collected are therefore considered to accurately reflect conditions in the sampled locations at the time of sampling.
	Laboratory	Analysis of: • trip blanks; • rinsate blanks; • reagent blanks; • method blanks; • matrix spikes; • matrix spike duplicates; • surrogate spikes; • reference materials; • laboratory control samples; • laboratory prepared spikes.	Very few QC non-conformances or discrepancies were documented in the laboratory reports and assessed in the QA/QC sections of the reports. The number and nature of QC exceedances was minor compared to the overall number of QC results, and an acceptable level of laboratory accuracy was demonstrated.
Representativeness	Field	Appropriate media sampled. All media identified sampled.	Sampling was conducted in accordance with NEPC (2013) and the sampling program was adjusted according to site observations. Results were considered representative of the overall material investigated, and representative of the range of conditions across the assessment area.
	Laboratory	All samples analysed according to NEPC (2013).	Analysis of samples was undertaken in accordance with NEPC (2013) using laboratories which were NATA accredited for the methods used. Analytical suites for collected samples were identified prior to commencement of the sampling program.

Comparability	Field	Experienced samplers and all team members instructed by Project Manager on sampling protocols. Samples collected using same methods.	Reporting on measures taken by WSP to ensure an experienced and consistent sampling team, adherence to internal SOPs and minimisation of climatic impacts were not provided. Given the high degree of scrutiny of these works by regulators and the Steering panel, it is expected that these were sufficient to provide an appropriate dataset for characterisation and validation of the site.
	Laboratory	Same analytical methods used. Same primary laboratory used to analyse samples. Acceptable RPD between primary and field replicate samples. Adequate laboratory internal quality control and quality assurance results.	Primary and secondary laboratories utilised the same analytical methods when analysing replicate samples, and acceptable RPDs were reported between primary and field replicate samples. Internal laboratory QA/QC results were predominantly within adopted acceptance criteria. Some slight non-conformances were noted, however are not considered to impact on the suitability of the dataset for characterisation of the site.
Completeness	Field	All critical locations sampled. All samples collected (from grid and at depth). SOPs appropriate and complied with. Experienced samplers. Documentation correct.	Sampling locations nominated and sampled were considered suitable for the purpose of characterising the range of concentrations across the assessment area. The collection of samples was generally as discussed in the SAQP using experienced personnel and the chain of custody documentation provided was generally complete. Although reporting on the results by WSP was basic and factual only, the reports indicated that the dataset was complete and had been collected in a suitable manner from the locations nominated in the SAQP.
	Laboratory	All critical samples analysed. All analytes analysed. Appropriate methods and PQLs. Sample documentation complete. Sample holding times complied with.	Samples were analysed for key contaminants (total mercury at a minimum) within holding times, excluding one exceedance for soil moisture, and utilising appropriate methods to achieve PQLs below relevant screening criteria. Chain of custody documentation was generally in good order.

Appendix C: Mercury Toxicity Profile

1.0 Toxicological Profile for Mercury

1.1 General

Many reviews of mercury behaviour and toxicity have been prepared by both Australian and international agencies (ATSDR, 1999; DEFRA&EA, 2002; EA, 2009; NEPC, 2013; IPCS, 2003; WHO, 1989, 1990, 1991, 2000, 2003, 2004, 2006, 2011). The information below has been extracted and summarised from these sources, however the reader is referred to the above documents for further detailed information.

Mercury is a heavy metal that exists in several forms: metallic or elemental mercury (0 oxidation state); inorganic mercury (+1 mercurous or +2 mercuric state); and organic mercury (covalently bound to organic compounds):

- Metallic mercury (also referred to as elemental mercury) is a shiny, silver white metal liquid at room temperature and is recognisable as the silver liquid in older metal thermometers. At room temperature, metallic mercury will evaporate and form elemental mercury vapours that are colourless and odourless.
- Inorganic mercury occurs when mercury combines with other inorganic elements such as chlorine, sulphur or oxygen. These compounds are called mercury salts and are white powders or crystals, except for mercuric sulphide which is red. Some inorganic mercury compounds are used as fungicides, skin lightening creams, antiseptic and disinfecting agents, tattoo dyes and colour paints.
- Organic mercury compounds result when mercury combines with carbon to form methylmercury compounds. The methylmercury cation is present in these compounds, associated with a simple or complex anion such as chloride or a protein, however in most cases the exact identity of the compound is not known. In the past, methylmercury compounds have been used for commercial purposes. In the environment, methylmercury is produced primarily by microorganisms rather than by human activity.

Mercury occurs naturally in the environment within mineral deposits, and becomes distributed through the environment by both natural and anthropogenic processes. The primary natural sources of mercury include degassing of the earth's crust and oceans, and emissions from volcanoes. Anthropogenic sources include mining, fossil fuel combustion, waste incineration, and industrial emissions.

Industrial uses of mercury include the chlor-alkali industry (use as cathodes in the electrolysis of sodium chloride to produce caustic soda and chloride), electrical industry (lamp and battery manufacture), the processing of gold ores, and a range of industrial, medical and laboratory instruments. Mercury was also historically used in dental amalgams, paints, pharmaceuticals, in the treatment of fur for producing felt hats, and as a fungicide or bactericide, however these uses have been largely discontinued over the past few decades.

Mercury emissions from anthropogenic sources can occur in all three forms, however atmospheric mercury exists mainly as elemental mercury (>90%), with other forms such as particle-bound and gaseous divalent mercury comprising less than 5% each. Once released, mercury can be deposited to land and surface water, where it may then sorb to soil and sediment particles. Mercury usually stays on the surface of sediments or soil and does not move through the soil to groundwater. If mercury enters the water in any form, it is likely to settle to bottom sediments where it can remain for a long time.

In well aerated surface soils, elemental mercury will normally transform into inorganic salts, however it can remain stable in soil under strongly reducing conditions. Elemental mercury has a low water

solubility and will easily volatilise from surface soils, and release to air is probably a significant component in the geochemical cycling of mercury. This volatilisation is accelerated by soil microbial processes, particularly where soil moisture content is high.

In surface soils, most mercury is likely present as water soluble mercuric (Hg^{2+}) complexes, most of which will bind to soil minerals or other surfaces. The mercuric compounds may also form a range of different inorganic and organic compounds depending on soil conditions such as pH, temperature and organic matter content.

Organic mercury compounds (e.g. methylmercury) is formed in both soils and in aquatic environments due to biological and/or chemical transformation processes. Methylmercury can also be de-methylated back to inorganic or elemental mercury forms.

In surface soils, it has been estimated that approximately 1-3% of the mercury present occurs as methylated mercury, with the majority of the remainder present as inorganic mercury. The amount of methylated mercury depends in part on the organic composition of the soil, with higher amounts of the methylated form expected in soils that have more organic content.

Mercury is persistent in the environment and will bioaccumulate through the food web, particularly in aquatic environments.

Based on the potential for long-range transport, persistence in water, soil and sediment, bioaccumulation, human toxicity and ecotoxicity, mercury is considered persistent and problematic.

1.2 Pharmacokinetics

1.2.1 Elemental Mercury

The majority (approximately 80%) of inhaled elemental mercury is absorbed through the lungs, however very little is absorbed through the gastrointestinal tract following ingestion (0.01%). Some dermal absorption of mercury vapour from air may occur, however this is estimated to be a small proportion of that absorbed through inhalation.

Once absorbed, elemental mercury is lipophilic and will rapidly distribute to all tissues. It can also cross the blood-brain and foetal barriers. Highest mercury levels, approximately 50-90% of total mercury within the body, are found in the kidney.

Elemental mercury absorbed into the bloodstream will be oxidised within red blood cells to the divalent form, which is predominantly non-diffusible and will bind to proteins within the blood (albumin and globulins). This transformation may also occur in other tissues, although to a lesser extent. In the brain and foetus, mercury which has oxidised to the divalent form will be trapped and not excreted, as it will not readily cross the blood-brain barrier or the placenta.

A small amount of methylation may occur, however studies of this are currently considered inconclusive.

Elemental mercury is excreted from the body primarily by urine and faeces, with a half-life in the order of 1 to 2 months. Excretion can also occur by breast milk.

1.2.2 Inorganic Mercury

Estimates of absorption following inhalation exposure to inorganic mercuric compounds are not available, however have been described by IPCS (2003) to be ‘low’. This is most likely because inorganic mercury will be inhaled as aerosol or dust particles, the majority of which will be deposited in the upper respiratory system and cleared from the lungs via mucociliary activity. Gastrointestinal absorption from food is estimated to be low (5-10%), however absorption may be greater for children. In studies with rats, gastrointestinal absorption has been estimated at 20-25%. Dermal absorption of both mercuric and mercurous salts has been demonstrated to occur in laboratory animals, but the extent of absorption has not been quantified. In humans, reports of mercury toxicity from use of dermal

ointments containing mercury salts provides evidence that dermal absorption occurs, however the extent/rate of absorption is not known.

Once absorbed, inorganic mercury compounds are distributed to all tissues, with the majority deposited in the kidney and liver. Inorganic mercury compounds have relatively poor lipid solubility, thus the fraction which crosses the blood-brain barrier or placenta is much lower than for elemental mercury.

As with elemental mercury, the majority of inorganic mercury is excreted in urine and faeces with a half-life of approximately 1 to 2 months.

1.2.3 Methylmercury

Methylmercury is readily absorbed through the lungs following inhalation exposure, and after ingestion (95% gastrointestinal absorption recorded in multiple studies). Dermal absorption of methylmercury is also expected, however this has not been quantified.

Once absorbed, methylmercury is distributed to all tissues, and reaches the brain and foetus. The majority is deposited in the kidney, however there is a lower degree of kidney deposition than other mercury compounds.

Methylmercury is metabolised to inorganic (mercuric) mercury, however to a lesser extent than elemental mercury. Excretion occurs following transfer into bile, demethylation to inorganic form by gut flora, followed by elimination in faeces, with an estimated half-life of approximately 70 days for adults. The half-life is decreased in lactating women (approximately 45 days) due to excretion in breast milk.

1.3 Health Effects

1.3.1 Non-Cancer Health Effects

Elemental Mercury:

The central nervous system is considered to be the most sensitive indicator of effects due to inhalation exposure to elemental mercury, however acute inhalation exposure has also been associated with effects to the respiratory tract and kidney. Effects on the lung also observed from high exposure levels (1-40 mg/m^3). At lower concentrations during occupation exposure (20-30 µg/m^3), mild central nervous system toxicity has been reported. Kidney and thyroid effects are also possible at these exposure levels. Inhalation of elemental mercury has not been associated with reproductive or developmental effects.

Inorganic Mercury:

Based on human studies and/or case reports, single or repeated ingestion of high levels of inorganic mercury have been associated with toxicity to the kidney and gastrointestinal tract. Kidney effects have also been reported in rats and mice following repeated oral exposure. Embryotoxicity was also reported in laboratory animal studies, however only at doses that were toxic to the mother.

Methylmercury:

The brain is the primary toxicity target of ingested methylmercury in humans, with the brain of the developing foetus more sensitive than that of the adult.

1.3.2 Genotoxicity and Mutagenicity

Limited data are available regarding the genotoxicity of elemental mercury, however information available from studies of worker exposure do not indicate mutagenic potential.

Inorganic mercury forms (mercuric chloride) has been shown to bind to DNA and cause clastogenicity (chromosome damage) in mammalian cells in culture, however both positive and negative results have been reported *in vivo* with the reason for discrepancy not understood. Inorganic mercury salts have not been shown to cause point mutations.

Dietary methylmercury ingestion has been reported to cause chromosomal aberrations and sister chromatid exchanges in humans, however these studies are associated with a range of uncertainties and/or confounding factors. Methylmercury does, however, appear to cause genotoxic effects in some experimental systems, including DNA damage in human nerve and lung cells and bacteria, and chromosome aberrations in human lymphocytes. ATSDR (1999) has concluded that methylmercury has some genotoxic potential.

1.3.3 Carcinogenicity

The International Agency for Research on Cancer (IARC) and the United States Environmental Protection Agency (USEPA) did not consider it possible to classify elemental mercury as to its carcinogenicity.

Mercuric chloride is designated by the USEPA as a "possible human carcinogen" based on long term oral studies in mice and rats which administered mercuric chloride by stomach tube. However, tumours in mice (kidney) were only seen at doses that were nephrotoxic, and as such not associated with a genotoxic cause. Tumours in rats were not necessarily treatment related (thyroid) or considered likely to have resulted from direct irritation of tissue such that they are not relevant to lower concentrations to which humans would typically be exposed. Overall, while some tumours have been reported following exposure of laboratory animals to inorganic mercury, it is likely that the underlying mechanisms have a threshold.

IARC and USEPA have classified methylmercury as a possible human carcinogen based on long-term studies with laboratory animals. Relevant investigations include a number of mice studies, in which kidney tumours were reported at high doses that also caused kidney toxicity, however studies with rats have not indicated carcinogenic effects. The tumours observed in mice are considered by the USEPA to have resulted from a non-genotoxic mechanism, i.e. attempts by the kidney to repair mercury induced toxicity. The tumours are therefore not expected to occur at the lower doses to which humans are likely exposed as a result of environmental contamination, and non-cancer effects would be expected at exposure levels lower than those required for tumour formation.

1.4 Published Toxicity Reference Values

A number of agencies, primarily international, have derived health criteria values or toxicity reference values (TRVs) for the various forms of mercury. These have been reviewed and are summarised in the tables below.

Table 1: Published TRVs for Elemental Mercury or Mercury Vapour

Exposure Route	Value	Source	Notes
Inhalation	0.2 µg/m^3	IPCS (2003)	"Tolerable concentration", based on occupational studies which indicated 20 µg/m^3 resulted in "slight, but not clinically observable" central nervous system effects. Value was extrapolated to continuous exposure (4.8 µg/m^3), then divided by uncertainty factors of 10 for sensitivity variation within the human population and 3 for use of a LOAEL for mild subclinical effects rather than a NOAEL.
Inhalation	1 µg/m^3	WHO (2000)	Based on studies of occupational exposure to mercury vapour which demonstrated a low frequency of objective tremor, biochemical signs of kidney effects, and 'non-specific' symptoms in workers exposed to 10-30 µg/m^3 (based on static samplers), however true exposure concentrations based on personal samplers were estimated to be three times higher (30-90 µg/m^3). These concentrations were divided by 3 to convert from workplace to

Exposure Route	Value	Source	Notes
			continuous exposure, and an uncertainty factor of 20 applied (10 to account for more sensitive subgroups within the population and 2 to convert the LOAELs to NOAELs. Value was derived for mercury vapour, but WHO indicated it would also be applicable to inorganic mercury.
Inhalation	0.05 µg/m^3	EC (2001)	Based on studies of occupationally exposed humans which suggested slight central nervous system effects at 25-30 µg/m^3, but also considering studies which suggested that the limit for adverse effects may be lower than this. An uncertainty factor of 500 was therefore applied to account for the use of a LOAEL (5), conversion of occupational exposure during working life to continuous exposure over a lifetime (10) and individual susceptibility variation (10).
Inhalation	0.3 µg/m^3	IRIS	Reference concentrations (RfC), based on LOAEL for nervous system effects in workers exposed to mercury vapour of 25 µg/m^3, converted to continuous exposure concentration of 9 µg/m^3, and with uncertainty factor of 30 applied (10 for protection of sensitive human sub-populations and 3 for deficiencies in the database). RfC was assigned a medium confidence rating, due to uncertainties in the true exposure levels in the studied workers, and the lack of reproductive and developmental studies. Value was last revised in 1995, however a screening level review by an EPA contractor in 2002 did not identify any critical new studies relevant to the RfC.
Inhalation	0.2 µg/m^3	ATSDR (1999)	Based on epidemiological study which identified central nervous system effects in men occupationally exposed over an average period of 15 years to average vapour concentration of 26 µg/m^3. This was converted to a continuous exposure concentration of 6.2 µg/m^3, and modified by an uncertainty factor of 30 (10 for sensitivity within the human population and 3 for use of a LOAEL).
Inhalation	0.2 µg/m^3	RIVM (2001)	Tolerable Concentration in Air (TCA) derived from same study and using same assumptions as ATSDR (1999) above.

Table 2: Published TRVs for Inorganic Mercury

Exposure Route	Value	Source	Notes
Oral	0.002 mg/kg/day	IPCS (2003)	Tolerable Daily Intake (TDI), based on kidney lesions induced by mercuric chloride in 26-week oral study in rats. Study NOAEL of 0.23 mg/kg/day was adjusted from 5 days per week experimental regimen to daily equivalent (0.16 mg/kg/day), then divided by uncertainty factor of 100 (10 each for interspecies and interindividual variability). Value is similar to that which would be derived from a 2-year rat study in which deaths occurred at doses of 1.9 mg/kg/day (LOAEL), with application of uncertainty factor of 1,000 (100 for interspecies and interindividual variability, and 10 to convert a serious LOAEL to a NOAEL. This TDI has been used as the basis for the WHO (2011) drinking water guideline.
Oral	0.004 mg/kg/week (0.0006 mg/kg/day)	JECFA (WHO, 2011)	Based on relative kidney weight increase in male rats. Point of departure was $BMDL_{10}$ of 0.06 mg/kg/day (lower 95% confidence limit of dose associated with 10% response). A 10% change was considered appropriate because the kidney weight data were modelled from mean values, and animals in the lowest dose group (0.325 mg/kg/day) already exhibited a 10% increase, and severity of nephropathy was significantly increased only at much higher doses (1.25 mg/kg/day). A 100 fold uncertainty factor was then applied, however JECFA did not report the basis of this value.
Oral	0.0003 mg/kg/day	IRIS	Reference dose (RfD) derived in 1995. Based on autoimmune response observed in rats exposed to mercuric chloride in three subchronic feeding and subcutaneous exposure studies. LOAEL of 0.3 mg/kg/day was approximated from all three studies. Total uncertainty factor of 1000 applied (10 for use of LOAEL, 10 for use of subchronic studies, 10 for inter- and intra-species variability).
Oral	0.002 mg/kg/day	RIVM (2001)	Oral TDI derived based on kidney effects observed in rats after chronic oral exposure. Value is the study NOAEL (0.23 mg/kg/day) with an uncertainty factor of 100 (for inter- and intra-species differences) applied.
Oral	--	ATSDR (1999)	No chronic duration minimal risk level (MRL) was derived. A sub-chronic value of 0.002 mg/kg/day was derived.
Oral	0.002 mg/kg/day	EA (2009)	Adopted / referenced from WHO (IPCS, 2003), as utilised in the WHO (2011) drinking water guidelines.
Inhalation	1 µg/m^3	WHO (2000)	Based on derivation for elemental mercury (see Table 1 above), but considered by WHO to also be applicable for inorganic mercury.
Inhalation	0.2 µg/m^3	EA (2009)	Value is for elemental mercury vapour as derived by IPCS (2003), and was assumed by EA (2009) to be also relevant to inorganic mercury in air.

Table 3: Published TRVs for Methylmercury

Exposure Route	Value	Source	Notes
Oral	0.003 mg/kg/week (0.0004 mg/kg/day)	FSANZ (2003)	Value referenced from JECFA (1989), based on methylmercury. Note that JECFA has since revised this number (WHO, 2003; 2006), as it is not considered to be protective of women of child-bearing age to protect the developing foetus (see below).
Oral	0.0016 mg/kg/week (0.00023 mg/kg/day)	JECFA (WHO, 2004) (Value reconfirmed at 2006 meeting; WHO, 2006)	Provisional Tolerable Weekly Intake (PTWI), based on epidemiological studies of populations of Seychelles and Faroe Islands, utilising mercury hair concentration as a biomarker of long-term methylmercury intake. A maternal hair concentration of 14 µg/g was identified as a NOAEL for neurobehavioural effects in children based on examinations of 5.5 year old Seychellois children, utilising a benchmark dose analysis (lower 95% confidence limit on benchmark dose associated with 5% change in response). Hair concentrations were converted to an equivalent blood mercury concentration of 56 µg/L based on a number of studies of individuals exposed to methylmercury (however none in Seychelles or Faroe Islands). The blood concentration was then converted to an average daily intake of 1.5 µg/kg/day using a one compartment pharmacokinetic model, incorporating blood volume and body weight for women in pregnancy state. An uncertainty factor of 2 was applied to account for interindividual differences (this value reflected the variability of hair to blood concentrations observed across individuals), and a factor $10^{0.5}$ (3.2) for inter-individual variation in pharmacokinetics, which had not been incorporated in the pharmacokinetic modelling. In 2006 (WHO, 2006) JECFA confirmed that an earlier PTWI of 3.3 µg/kg/week would not pose a risk of neurotoxicity in adults, but that the current value is relevant to women of child-bearing age to protect the embryo and foetus.
Oral	0.0001 mg/kg/day	IRIS	Last updated 2001. RfD based on studies of three populations of children (Faroe Islands, Seychelles, and New Zealand) exposed to mercury in utero due to maternal methylmercury intake. Utilised benchmark dose modelling conducted by the National Research Council (NRC, 2000) to estimate lower 95% confidence limit of cord blood mercury concentration associated with 5% change in neurological response (46-79 µg/L). A one compartment pharmacokinetic model was used to estimate the daily intake that would produce the blood Hg concentration (0.86-1.5 µg/kg/day). A composite uncertainty factor of 10 was then applied to account for pharmacokinetic and pharmacodynamics variability, and uncertainty in the estimation of ingested dose from a blood lead concentration. The RfD was assigned a high confidence rating, as values derived from all three epidemiological studies converged on the same value.
Oral	0.0001 mg/kg/day	EC (2001)	Based on review of USEPA RfD (see above), which was considered “appropriate for Europe”

Exposure Route	Value	Source	Notes
Oral	0.0003 mg/kg/day	ATSDR (1999)	Based on study of Seychelles infants exposed to methylmercury in the womb due to high fish consumption of mothers. They concluded there was no clear evidence of any effect and the mercury level in hair of the highest exposed subgroup was considered to be a NOAEL (15.3 µg/g). Pharmacokinetic modelling was applied to convert the hair concentration to a mean daily intake of 1.3 µg/kg/day (for a 60 kg adult). An uncertainty factor of 3 was applied to account for possible inter-individual variability, and an additional factor of 1.5 to account for uncertainty regarding the power of the neurological examinations of the exposed children.
Oral	0.0001 mg/kg/day	RIVM (2001)	Based on NOAEL of 1.3 µg/kg/day for developmental effects in humans (adopted from ATSDR, 1999), with uncertainty factor of 10 applied to account for inter-individual susceptibility variation.

1.5 Discussion and Recommended Toxicity Reference Values

1.5.1 Elemental Mercury / Mercury Vapour

Oral and Dermal Exposure:

Toxicity data and/or TRVs relevant to oral or dermal exposure to elemental mercury are not available, however it is considered that exposure to elemental mercury through these pathways are likely to be negligible compared to other forms of mercury (inorganic and methylmercury), which likely constitute the majority of total mercury present in food, soil, or water to which humans are exposed.

On this basis, no oral or dermal TRVs for elemental mercury have been adopted.

Inhalation Exposure:

The tolerable concentration of 0.2 µg/m^3 derived by IPCS (2003) is based on the most recent review of available studies in relation to inhalation exposure to mercury vapour, and is considered the most appropriate TRV for assessment of inhalation exposure to this form of mercury. This value has also been proposed by several other expert groups (ATSDR, RIVM), and is similar to that derived by USEPA (IRIS).

A lower value (0.05 µg/m^3) has been proposed by EC (2001), based on the same studies as those considered by other agencies, but with application of additional and/or higher uncertainty factors. Because the judgment of different “safe” concentrations reflects the differing experiences and expertise of these expert bodies, such concentrations should not be expected to be the same, nor is this necessarily desired. However, despite this expectation, or perhaps desire, the EC (2001) “safe” concentration is unusually lower than all other values, which necessitates some explication. This is especially true here, since the main reason for the lower value of EC (2001) is the use of a larger composite uncertainty factor, which has not been used by any other expert group. Until resolution of this difference occurs, our recommendation is to use the value of the IPCS, both because it is more current, and because it matches the expert judgments of other groups. The higher value of the WHO is likewise not recommended, and for somewhat similar reasons.

1.5.2 Inorganic Mercury

Oral Exposure:

The PTWI derived by JECFA (WHO, 2011) is based on the most recent review of available studies in relation to inorganic mercury exposure, and is considered the most appropriate TRV for assessment of oral exposure to inorganic forms of mercury. This value (0.0006 mg/kg/day) was also adopted by the NEPC (2013) in derivation of soil Health Investigation Levels (HILs) within the National Environment Protection (Assessment of Site Contamination) Measure 1999 (as amended 2013). This value (0.0006 mg/kg/day) is considered to represent the most appropriate oral TRV for assessment of oral exposure to inorganic forms of mercury.

Inhalation Exposure:

While the inhalation TRVs adopted by some agencies (WHO, 2003 and EA, 2009) for inorganic mercury do not specifically relate to inhalation of inorganic mercury compounds, Senversa recommends adoption of the lower guideline value derived by IPCS (2003) for screening purposes, where inorganic mercury may be present in air (e.g. bound to airborne particulate).

Dermal Exposure:

No toxicity data or TRVs specific to dermal exposure are available, and the oral TRV is therefore recommended for assessment of dermal exposure to inorganic mercury. As gastrointestinal absorption of inorganic mercury is low (see **Section 1.2.3**), the oral TRV has been adjusted to convert from an administered to absorbed dose using a gastrointestinal absorption factor of 0.07, as recommended by USEPA (2004).

1.5.3 Methylmercury

Oral Exposure:

The PTWI derived by JECFA (WHO, 2004) and reconfirmed in 2006 (WHO, 2006) is based on the most recent review of available studies in relation to methylmercury exposure, and is considered the most appropriate TRV for assessment of oral exposure to methylmercury. The value (0.00023 mg/kg/day) is also similar to those estimated by USEPA (IRIS) at 0.0001 mg/kg-day and ATSDR at 0.0003 mg/kg/day.

Inhalation Exposure:

No inhalation TRVs for methylmercury have been derived. The oral PTWI has therefore been considered to also apply to this exposure pathway. Assuming a daily inhalation rate of 20 m^3/day and average adult body weight of 70 kg, the PTWI equates to a tolerable concentration in air of 0.07 $\mu g/m^3$, which is lower than most inhalation TRVs derived and/or adopted for elemental and inorganic forms of mercury.

Dermal Exposure:

No toxicity data or TRVs specific to dermal exposure are available, and the oral TRV is therefore recommended for assessment of dermal exposure to methylmercury. As gastrointestinal absorption of methylmercury is high (>95%; see **Section 1.2.3**), no adjustment of the oral TRV to convert from administered to absorbed dose is considered to be required).

1.6 Background Intakes

1.6.1 Food, Water and Diet

According to NHMRC (2011), food is the main route of exposure to both inorganic and organic mercury, and fish are often the primary source within this category. The proportion of inorganic to organic mercury within fish depends on the type of seafood. Fish in a higher trophic level, that is to say, higher in the food web such as shark, have a higher percentage of organic mercury, such as methyl mercury. Shrimp that are lower in the food chain have mercury that is mostly

inorganic. Furthermore, bigger fish of same species are also more highly methylated than smaller fish. Finally there can be a lot of variability in the mercury content of fish from different water bodies. The average Australian adult dietary intake has been estimated to be approximately 0.004 mg/day (0.06 μg/kg/day for a 70 kg adult). Dietary intake of mercury for toddlers was reported to range from 0.01 to 0.2 μg/kg/day (FSANZ, 2002).

Typical concentrations in Australian reticulated water supplies are usually less than 0.0001 mg/L (NHMRC, 2011), which would correspond to intakes of 0.008 and 0.002 μg/kg/day for a child and adult, respectively (assuming child weighs 13 kg and ingests 1 L of water per day, and adult weighs 70 kg and ingests 2 L of water per day.

Average elemental mercury intakes in people with dental amalgam fillings have been estimated by NHMRC (1999) to be on the order of 0.3 μg per day for children, and 3.5 μg per day for adults (0.02 μg/kg/day and 0.05 μg/kg/day for a 13 kg child and 70 kg adult, respectively. It is noted that the estimated intakes are likely to decrease, as alternatives to mercury dental amalgams are now in use.

Based on the above, the background intake of mercury due to diet, water and dental amalgam fillings is estimated to be 0.23 μg/kg/day for a young child, and 0.11 μg/kg/day for an adult.

1.6.2 Inhalation

Data on mercury concentrations in air within Australia are not available, but the average atmospheric concentration worldwide has been reported by Queensland Health (2002) to be about 20 ng/m^3 (present as mercury vapour), and ATSDR (1999) report that ambient air concentrations average approximately 10 to 20 ng/m^3, with higher levels (10-15 ug/m^3) detected near point emission sources such as mercury mines refineries and agricultural fields treated with mercury fungicides. These data are relevant to mercury vapour, with limited information relating to particulate mercury in air. However one study cited by ATSDR (1999) (Lindberg et al. 1994) indicated that particulate mercury concentrations were approximately 100 to 1000 times lower than vapour concentrations at the same site.

1.7 Summary of Recommended TRVs and Risk Assessment Assumptions for Mercury

Table 4: Summary of Recommendations

Parameter	Elemental Mercury	Inorganic Mercury	Methyl Mercury	Notes
Oral TRV (mg/kg/day)	NA	0.0006	0.0002	
Dermal TRV (mg/kg/day)	NA	0.0004	0.0002	
Inhalation TRV (μg/m^3)	0.2	0.2	0.7	
Dermal Absorption Factor (for soil)	0.001	0.001	0.001	USEPA (1995); default for inorganics in absence of other information.
Dermal Permeability Constant (k_p) (for water exposure) (cm/hr)	0.001	0.001	0.001	USEPA (2004)

1.8 References

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Appendix D: Risk Assessment Spreadsheets

Media	Hg Form Assumed	Criteria	Source	Value	Units	Toxicity value applied			Basis of derivation	Notes
Soil	Methyl Hg	HIL-A (Residential)	NEPM	10	mg/kg	0.00023	mg/kg/day	WHO 2004 and EA 2009	DAF = 0.001, Background = 20%	NEPM derivation current and well accepted within Aus. Uses current exposure data (enHealth 2012), and exposure calculations are provided in Schedule B7 (Vol 19)
		HIL-C (Public open space)	NEPM	13	mg/kg					
	Inorganic Hg	HIL-A	NEPM	80	mg/kg	0.0006	mg/kg/day	WHO 2011	GAF = 0.07, DAF = 0.001, Background = 40%	
		HIL-C	NEPM	13	mg/kg					
Vapour	Vapour	Elemental	WHO (2000)	1	ug/m3	1	ug/m3		Adjusted ambient air LOAEL approx = 20 ug/m3, UF = 20	Based on elemental Hg occupational exposure studies
		Elemental	WHO (2003)	0.2	ug/m3	0.2	ug/m3		LOAEL = 20 ug/m3, adjusted (5/7 * 8/24), UF = 30	Based on elemental Hg occupational exposure studies
Sediment	Methyl Hg	HIL-C	NEPM	80	mg/kg	0.0006	mg/kg/day	WHO 2011	As per notes for HIL-C above	Conservative to apply to submerged sediments
	Inorganic	HIL-C	NEPM	13	mg/kg	0.00023	mg/kg/day	WHO 2004 and EA 200	As per notes for HIL-C above	Conservative to apply to submerged sediments
Fish/Biota	Methyl Hg	Fish / Predatory Fish	FSANZ (2015	0.5 / 1.0	mg/kg	1.6	ug/kg bw per week	PTWI - WHO, 2000	Ingestion of Methyl Hg	Assumes female of child bearing age = 66kg, eats 1 serve (=150g) fish a week Assumes background dietary intake of 0.94 ug/week

HIL = Health investigation level
Vapour criteria refered to in WSP as: Elemental criteria was labelled 'Annual average', inorganic criteria labelled ' Long term'
PTWI Provisional tolerable weekly intake

Scenario 1: Most toxic form of mercury assumed and full additivity assumed

Medium	Hg Form Assumed in Medium	Criteria	Source	Value	Units	Proportion of HQ from FCAP (= 1 minus background)	Max conc. (Total Hg) mg/kg	Hazard Quotient based on maximum concentration (corrected for BG)	95%UCL conc * (Total conc.) mg/kg	Hazard Quotient based on 95%UCL	Notes
Soil	Methyl	HIL-A (Residential)	NEPM	10	mg/kg	0.8	4.7	0.4	0.35	0.03	Assumes all mercury reported in soil is present as methylmercury (more toxic form)
Vapour	Elemental	Long term	WHO (2003)	0.2	ug/m3	1	0.076	0.4	0.039	0.2	Assumes all mercury present in air is present as elemental mercury (more toxic than inorganic which could also contribute to measurements)
Sediment	Methyl	HIL-C	NEPM	13	mg/kg	0.8	0.90	0.06	0.30	0.02	Applied to methylmercury risk profile (grey shaded total below)
Fish/Biota	Methyl	Fish	FSANZ (2011)	0.5	mg/kg	1	0.30	0.6	0.12	0.2	Total concentration assumed to be either 100% methyl or 100% inorganic mercury
							Total HI =	**1**	**Total HI =**	**0.5**	Assumes 100% of Hg in soil and sediment is methyl mercury (i.e. most toxic)

Scenario 2: Reaonable Assumptions Applied Regarding Form of Mercury and Additivity Only Across Individual Mercury Forms

Medium	Hg Form Assumed in Medium	Criteria	Source	Value	Units	Proportion of HQ from FCAP (= 1 minus background)	Max conc. (Total Hg) mg/kg	Hazard Quotient based on maximum concentration (corrected for BG)	95%UCL conc * (Total conc.) mg/kg	Hazard Quotient based on 95%UCL	Notes
Soil	Methyl	HIL-A (Residential)	NEPM	10	mg/kg	0.8	0.47	0.04	0.04	0.003	Assumes 10% of mercury in soil present as methylmercury, remainder as inorganic Hg.
	Inorganic	HIL-A (Residential)	NEPM	40	mg/kg	0.6	4.23	0.06	0.32	0.005	
Vapour	Elemental	Long term	WHO (2003)	0.2	ug/m3	1	0.076	0.4	0.039	0.2	Assumes all mercury present in air is present as elemental mercury (more toxic than inorganic which could also contribute to measurements)
Sediment	Methyl	HIL-C	NEPM	13	mg/kg	0.8	0.90	0.06	0.30	0.02	100% of mercury in sediment assumed as methylmercury
Fish/Biota	Methyl	Fish	FSANZ (2011)	0.5	mg/kg	1	0.30	0.6	0.12	0.2	Total concentration assumed to be 100% methylmercury
						Methyl Mercury	**Total HI =**	**0.7**	**Total HI =**	**0.3**	
						Inorganic Mercury	**Total HI =**	**0.06**	**Total HI =**	**0.005**	
						Elemental Mercury	**Total HI =**	**0.4**	**Total HI =**	**0.2**	

* 95%UCL concentrations directly from WSP reports, with 95%UCL calculated using raw data from Attachment F from public lands report (WSP, 2015b)

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