REPORT NO. 210074

SITE CAPPING INVESTIGATION AT FORMER SOUTH MELBOURNE GASWORKS.

ENVIRONMENTAL EARTH SCIENCES VIC
PORT PHILLIP CITY COUNCIL
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EXECUTIVE SUMMARY

Objective

The objectives of this investigation were to characterise the site cap and extent of contamination in soil and to assess the potential risks posed to beneficial users of the site.

Scope of Work

Environmental Earth Sciences undertook the systematic grid based soil sampling between 18 and 21 January 2011. A total of 41 locations were completed across the site at an approximate density of 12.6 points/ha.

Findings

Site Capping Characterisation

Based on previous reports and visual observation during the field program, the thin layer of brown loam and the yellow-orange sandy clays, where they occur, constitute the capping layer placed over the site as part of the redevelopment (Section 4.3). The capping layer was observed to be at least 0.5m thick where the sandy clays occur (approximately half the site, refer to Figure 7), but thins out to the brown loam layer across the outer edges of the site. The remainder of the site consists of the thin sandy gravel layer of the pathways, lain directly on top of impacted material, or is sealed beneath site buildings. However, the physical assessment of the capping layer has indicated that discrete exposed soil areas of the site (specifically about boreholes BH4 and BH8, and test-pit TP7) contain less than the required 0.5m of capping.

In general, the capping layer was found to be irregular (less than 0.5m deep) and contaminated with gasworks waste including polycyclic aromatic hydrocarbons and therefore the existing site capping can be considered in-adequate.

Contaminant Characterisation

Comparison of results to Tier 1 published criteria and modified site specific trigger levels (SSTL) {including statistical analysis of identified soil populations based on elevated chemicals of concern and depth of impact below the ground surface} indicates that the PAHs including BaP and Naphthalene, TRH (C_{16}-C_{34}), TRH (C_{34}-C_{40}) exceeded the criteria.

In addition, the distribution of contamination (including gasworks waste) was observed to be widespread and thus visually identifying and delineating the areas of contamination can be considered difficult.

Recommendations

Given the distribution of contamination is widespread and thus visually identifying and delineating the areas of contamination can be considered difficult and several soil samples were observed above the Tier 1 published criteria and modified SSTL, it is recommended that the implementation of the isolation and capping remediation option (refer to Environmental Earth Sciences RAP, 2014_v4), taking into account City of Port Phillip (CoPP) future landscaping plans, be implemented.

It is also recommended that the two Interim Contamination Management Plans (ICMPs) for the site be updated to provide the current site status and framework for addressing the required management for the residual soil contamination within the site.

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1 INTRODUCTION

The site was formerly the manufacturing area of the South Melbourne Gasworks (SMG), and operated from 1871 to 1965, with some aspects remaining functional until 1971. The site was redeveloped and has been used as a park since the 1980's by the City of Port Phillip (CoPP).

The site is currently managed in accordance with two Interim Contamination Management Plans (ICMPs); one applicable to the Southport Community Nursing Home and the other to the Gasworks Arts Park. The ICMPs are subject to changes and amendments pending remediation and/or management.

The site is currently undergoing a two stage 53V audit commissioned by CoPP to assess risks of harm posed by the site. The first stage of the 53V audit was undertaken by Dr. Peter Nadebaum of GHD in December 2008 and involved undertaking a '*preliminary assessment of available information regarding risks associated with groundwater and soil contamination to determine what further investigation and remediation works would be required to complete the audit'*.

The findings of the first stage were documented in a report entitled "*Section 53V Environmental Audit – Interim Report*" (December, 2008). As detailed in the audit report, further environmental investigation and monitoring works are required to address the higher risk issues identified at the site, determine requirements for remediation and the sites suitability for future land uses. One of the issues identified by the Auditor as requiring further assessment was the extent of contamination in soil and shallow fill, and the performance requirements for capping and control of future activities.

Environmental Earth Sciences VIC prepared a scope and methodology for environmental investigational works at the former South Melbourne Gasworks in accordance with information provided within the tender document Sections 3.1 to 3.4 (*Specification*), and in reference to the Auditor's comments detailed in the Interim Audit Report (December 2008).

This scope and methodology was refined once a detailed review of existing site environmental reports was undertaken. The development of a Sampling and Analysis Plan (SAP) was finalised following comments received within GHD 31/26548/189319 Letter entitled '*Gasworks Site Environmental Audit Sampling and Analysis Plan*' and SAP discussion between Environmental Earth Sciences VIC, CoPP and GHD on 2 December 2010 and on 12 January 2011.

Professional judgement was used to extrapolate between inspected areas, however, even under ideal circumstances actual conditions may vary from those inferred to exist. The actual interface between materials and variation in groundwater quality may be more abrupt or gradual than the report indicates.

The work reported upon in this document has been undertaken in accordance with discussion between Environmental Earth Sciences VIC, the Auditor and City of Port Philip.

2 OBJECTIVE

The objectives of this investigation were to characterise the site cap and extent of contamination in soil and to assess the potential risks posed to beneficial users of the site.

3 SITE IDENTIFICATION

3.1 Site location

The site is currently owned by CoPP in conjunction with the State of Victoria. CoPP currently operate as the 'Committee of Management' for the site. The site is situated in Albert Park and is bounded by Graham Street to the south, Pickles Street to the west, Richardson Street to the north and Foote Street/Bridport Street to the east (refer to Figure 1 and Figure 2).

3.2 Current site uses and condition

The site covers an area of 3.21 hectares (ha) and includes 'Gasworks Arts Park' and 'Southport Community Nursing Home'. Gasworks Arts Park incorporates 2.67 ha of the site, consisting of grassed and landscaped areas, playground, BBQ and rotunda facilities, small wetlands all linked by gravel access tracks. A number of community based events are held within the grounds of Gasworks Arts Park including monthly farmer's market, dog training, school holiday programs activities, and private and public functions.

Eleven buildings exist within the Gasworks Arts Park incorporating historic gasworks buildings retained as part of the site redevelopment and a few buildings, including administration buildings have been constructed since the redevelopment. Current buildings within Gasworks Arts Park are detailed below and locations are provided in Figure 2:

- Gasworks Arts Park Building 1 – *Sculpture Studio;*
- Gasworks Arts Park Building 2 – *Arts and Craft Studio;*
- Gasworks Arts Park Building 3 – *Ceramics Studio;*
- Gasworks Arts Park Building 4 – *Visual Arts Studio 1, 2 and 2;*
- Gasworks Arts Park Building 5 – *Gatehouse Building – Bookshop;*
- Gasworks Arts Park Building 6 – *Café and Angela Robarts-Bird Gallery;*
- Gasworks Arts Park Building 7 – *Main Theatre, Foyer and Dressing Room;*
- Gasworks Arts Park Building 8 – *Electricity Sub-station;*
- Gasworks Arts Park Building 9 – *Gasworks Admin Offices;*
- Gasworks Arts Park Building 10 – *Darkroom;* and
- Gasworks Arts Park Building 11 – *Studio Theatre – Workshop.*

The Southport site covers an area of 0.54 ha and is situated in the northeast corner of the SMG site (refer to Figure 2). The Southport Community Nursing Home occupies the majority of the Southport Site (fronting Richardson Street) and incorporates a brick building (i.e. nursing home), and open grass, paving and landscaped gardens.

The South Melbourne Gas Regulator Site (i.e. Alinta Site) is situated on the corner Pickles and Richardson Streets and is not included within the investigational area. This area is covered by bitumen hard stand, and is occupied by a brick building in the northern portion of the site, which was a historical part of the original SMG infrastructure. The building housed the regulator station, which controlled pressure in the gas distribution pipes. It should be noted that the Alinta site is not included within the investigation area.

3.3 Proposed future land use

The CoPP has advised that the future land use of Gasworks Park is likely to remain '*Open Space Parkland*', and the Southport site to remain a nursing home, which may be developed into another community use sometime in the future.

4 SITE HISTORY

4.1 Summary of site history

In 1871 the South Melbourne Gas Company was established and leased 2.43 ha of land on Pickles Street on the boundary of what are now the suburbs of Albert Park and Port Melbourne. The construction of the Port Melbourne gas manufacturing plant was completed in 1873. Following completion, the South Melbourne Gas Company merged with Melbourne and Collingwood Gas Companies, forming the Metropolitan Gas Company.

A crown grant for the leased site was issued to the Metropolitan Gas Company in 1878, with an additional 1ha of land being purchased in the northern section (East of Pickles Street). The main manufacturing plant for Gasworks was developed in this area. The operation was expanded over the following years with establishment of the meter shop site (1885), No. 1 Holder site (1888) and laboratory and oil store (1913). Following a short period of closure during the depression, some sections of the plant never reopened. Gas manufacture, however continued up until 1971 with the Gas and Fuel Corporation of Victoria becoming the registered proprietor of all properties onsite in 1955.

The City of South Melbourne and Government of Victoria acquired the manufacturing plant in 1979, redeveloping it into Gasworks Park. Gas and Fuel Corporation of Victoria still operate a small depot in the northern corner of the former gasworks site (i.e. Alinta site), however this is not part of the area under investigation. Southport Community Nursing Home was constructed on city owned land to the north-east of the site in 1981.

Investigations into the contamination status of the site commenced around 1985 with EPA Victoria issuing a Clean Up notice to Gas and Fuel Corporation of Victoria in 1988. The Gas and Fuel Corporation commenced assessment and remediation across the site as required under the Clean up Notice, resulting in EPA Victoria declaring the site suitable for park use in 1992. A historic site review prepared in 2004 by Golder Associates, however recommends that CoPP conduct further assessment and management of the site due to potential risks associated with soil and groundwater contamination.

For further detail regarding site history please refer to Environmental Earth Sciences VIC (2010).

4.2 Historic gasworks site layout, operations and process

Gas manufacturing processes that are believed to have been undertaken on-site include;

- Coal carbonisation plant (CCP);
- Complete gasification plant (CWGP); and
- Oil Gas Plant (OGP).

Coal Carbonisation was noted (Golder Associates, 2004a) to have been undertaken in the west and central portions of the site in areas of the coke plant, retort houses and the coal store. Further purification of coal gas involved removal of sulfide, cyanide and ammonia.

The complete gasification plant was located in the south-western corner of the site and combined the vertical retorts process with that of water gas plants to maximise gas yield. Complete gasification generated a number of waste products including tar, oil and water emulsion and sulfate.

The oil gas plant was located in the north-western portion of the site. The OGP process was similar to that of the CWGP and produced similar wastes, however instead of coal tar, lampblack was produced.

Condensers within the eastern portion of the site were used to remove tars and water from coal gas. The tar was likely stored in adjacent tar tanks, or pumped to storage tanks located in the northern portion of the site. Note that it is likely or at least possible that tar and ammoniacal liquor was disposed to tar wells or off-site to nearby waterways.

Washers within the eastern portion of the site were used in removing naphthalene and ammonia from gas, and phenol and tar acid from ammonia waste. This process may have involved the use of water, oils, benzene, sulfuric acid and sodium hydroxide.

Purifiers were located in the north-eastern (above-ground) and south-eastern (below-ground) portions of the site. Gas purifiers were used for removal of sulfur and cyanide from the gas. Purifier wastes are expected to have concentrated levels of complexed cyanides, sulfur or sulfates, volatile PAHs and TPHs.

Historic infrastructure known to exist on site is presented in Figure 9 which also includes the following in addition to the process infrastructure previously mentioned:

- boiler room;
- meter room;
- electrical sub-station;
- workshop and amenities (i.e. toilets, mess room and office);
- ferro-cyanide plant;
- sulfate store;
- liquor wells;
- tar tanks; and
- laboratory.

4.3 Previous investigations

4.3.1 Golder Associates

A total of eleven documents, detailing environmental works undertaken by Golder Associates at the site between 2004 and 2007, were provided for review as part of this soil capping investigation. The reports detail the site history, site conceptual model, soil and groundwater investigations undertaken and recommendations for further investigation and remediation.

From these works Golder Associates concluded the site history indicated significant potential for contamination of soil and groundwater to have occurred from historical on-site gasworks processes and/or the storage/management of on-site waste. As little remediation of on-site soil was conducted, the potential for the soil to still be contaminated was high. Remediation was limited to excavation of 0.5 m of contaminated fill material and replacement with “clean soil” in the south-eastern corner of the site. Other remedial works have been limited to landscaping and the placing of topsoil and clay over the site.

The general stratigraphy within Gasworks Park was observed to comprise a layer of fill material overlying natural sands, clayey sands and sandy clays. Fill material varied between 0.5 m and 3.2 m in thickness and surface fill material generally comprised black sands with fragments of coke, bricks and glass.

Soil impacts included:

- heavy metals (As, Cu, Hg, Ni and Pb), total petroleum hydrocarbons (TPH) (C_{10}-C_{36}), benzene, total cyanide, monocyclic aromatic hydrocarbons (MAHs), total polycyclic aromatic hydrocarbons (PAH) and benzo(a)pyrene (BaP) concentrations above applicable NEPM HIL guidelines;
- visual signs of contamination at the surface including, the presence of coke and spent oxide pieces in some garden beds and the playground;
- odorous and visually contaminated ash; and
- acidic soil with pH values ranging from 2.7-8.5.

Concentrations of BaP and total PAH were reported at up to 970 mg/kg and 37,000 mg/kg, respectively. TPH (C_{10}-C_{36}) concentrations were reported at up to 116,000 mg/kg. Elevated contaminant concentrations were generally confined to fill material. Elevated concentrations of BaP and total PAH were reported in natural soil at depths up to 8.2 m BGL (south of the grassed area).

The highest contaminant concentrations were identified in boreholes drilled in the area of the former tar tank and purifiers in the south western portion of the Southport site, and the former boilers and underground purifiers, in the southern portion of the Gasworks Park. No elevated chemical concentrations were reported in the south western portion of the park.

A qualitative assessment of health risks posed by consumption of edible vegetables from the site concluded this risk to be negligible to very low. Golder Associates did not consider the soil profile across the site suitable for redevelopment to high to medium density residential use or recreational/open space or aged care use unless remediated and/or managed. Some of the beneficial uses of land were considered to be precluded, including maintenance of ecosystem (plant growth) and aesthetics.

For more detail of previous environmental investigations undertaken at the site please refer to Environmental Earth Sciences VIC (2010a).

4.3.2 GHD

GHD undertook a preliminary assessment of the risks associated with groundwater and soil contamination at SMG as part of the 53V audit currently being undertaken by Dr. Peter Nadebaum. The objective and method of the '*screening risk assessment*' was to formulate the auditor's opinion on the risk posed to the relevant beneficial uses. This report also documents what further investigation and remediation work may be required to complete the audit.

In each case, a particular scenario and level of effect was considered, and the likelihood of this scenario occurring was then determined based on the information obtained from the preliminary review of information pertaining to SMG and in consultation with stakeholders.

Findings of the screening risk assessment process, taking into account the relevant control measures, identified the following:

- 50 medium risk scenarios;
- 99 low risk scenarios; and
- 115 negligible risk scenarios.

The auditor identified that the soil required further assessment to resolve the extent of contamination in soil and shallow fill, and the performance requirements for capping and control of future activities.

4.4 Previous remediation

It is understood that little remediation of on-site soil has been conducted, aside from excavation of 0.5 m of contaminated fill material and replacement with "clean soil" in the south-eastern corner of the site. Other remedial works have been limited to landscaping and the placement of topsoil and clay (capping layer) over the site (of unknown depth). No record has been made available documenting these works, and the origin of the imported soil is not known.

4.5 Identified chemicals of potential concern

Contaminants of potential concern (CoPC) are associated the numerous gas manufacturing processes performed during the site historical use as a gas manufacturing plant. These include:

- PAHs from tar, coke, ash and oil wastes;
- TPH from tar, oil wastes as well as oil storages;
- heavy metals such as arsenic (As) from concentration of coal minerals;
- ammonia, cyanide, sulfates and sulfides from gas purification and waste water treatment;
- phenols from tar wastes; and
- monocyclic aromatic hydrocarbons (MAHs) including but not limited to benzene, toluene, ethylbenzene and xylenes (BTEX) for oil wastes.

5 REGIONAL SETTING

5.1 Surrounding area features

South Melbourne Gasworks is surrounded by low density residential houses to the north and west across Richardson Street and Bridport Street. High density residential units are present across Pickles Street to the east, and to the south are high density resident units currently under construction.

The nearest surface water body to the site is Port Phillip Bay approximately 350 m south of the site (Figure 1).

5.2 Topography and drainage

Surface topography at the site is relatively flat, sloping slightly from east to west. Regionally, land slopes towards Port Phillip Bay. Recorded site surface elevations range from 2.105 to 2.670 metres Australian Height Datum (mAHD). Site surface topography is defined by fill material and does not represent natural conditions.

5.3 Geology

According to the Geological Survey of Victoria (GSV 1974) *Melbourne 1:63,360 map sheet*, outcropping geology beneath the site is the Recent Holocene aged (0-10,000 year old [yo]) Port Melbourne Sand (PMS), consisting of raised beach ridges of well sorted sand, shelly sand, minor silty or clayey sand. Figure 1 shows the surface geology of the regional area, based on Victorian Department of Primary Industries (DPI) information.

Regionally, the PMS is sequentially underlain by the following formations:

- Pliocene age (late Tertiary era – 5.3 to 1.8 Myo) Brighton Group sediments, consisting of red-brown, yellow and white cross-bedded sands and silty sands (with clay);
- Late Lower Tertiary Eocene aged (36-53 Myo), olivine and titanaugite dense blue-black Older Volcanics basalt (OVB);
- Eocene age (early Tertiary era – 54.8 to 33.7 Myo) sand and silty-sands with clay, with pyritic and lignitic sands, of the Werribee Formation; and
- Late Upper Silurian aged (400 Myo) Dargile Formation sandstone and siltstone.

The OVB outcrops to the north on the northern side of the Yarra River approximately 2.1km from the site, while the Dargile Formation outcrops 1.4km north-east of the site.

The geological units encountered during previous site investigation works included:

- PMS – the upper geological formation at the site, which discontinuously underlies the fill material, and has been identified in lenses up to 2.6 m thick in the southern portion of Gasworks Park;
- Brighton Group – encountered underlying fill material and, where present, the PMS. Brighton Group sediments have been identified extending to a maximum depth of 22 mBGL; and
- OVB – identified underlying Brighton Group sediments at approximately 18 m BGL in the north-eastern portion of the site.

5.4 Soil

The soils of the local area are described in van de Graaff (1996) as comprising dark loams, clays and local sands. These features are consistent with the local geology as described above, being PMS sands and silty/clayey sands. Previous site investigations have confirmed the natural soils onsite to consist of sands, clayey sands and sandy clays.

5.4.1 Potential for acid sulfate soil occurrence

In accordance with *Victorian Best Practice Management Guidelines for Assessing and Managing CASS* (DSE, 2010) a preliminary assessment of coastal acid sulfate soils (CASS) at the site has been undertaken with the following outcomes:

- the site is indicated as having a potential for CASS on DPI CASS Risk Maps (http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_acid_sulfate_soils);
- the site is indicated as having a high probability for CASS in the Atlas of Australian Acid Sulfate Soils (Fitzpatrick *et al*. 2006) risk maps on the Australian Soil Resource Information System (ASRIS) website (http://www.asris.csiro.au/index_ie.html);
- the site is located on Quaternary Holocene (Recent) or Pleistocene (Glacial) geology, with the Port Melbourne Sands likely to contain elevated levels of mineral sulfides;
- the soil landscape mapping indicates soil with a marine origin and potential to contain soil sulfur in an anoxic condition (i.e. high water-tables, swamp or estuarine environments) (http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil-home);
- the site is positioned at less than 5 mAHD, however there are no excavations or groundwater abstraction/ dewatering operations planned at the site that may lower the water table; and
- due to the drawdown of the surrounding sewers which act as groundwater sinks, the water-table has likely been reduced from its natural level, potentially exposing sulfidic sediments.

The conclusion of this preliminary assessment is that there is the potential for CASS to occur on-site, and that this potential should be investigated further.

5.5 Hydrogeology

According to DNRE (1995b) the uppermost aquifer in the region is associated with PMS. The unit has an expected salinity range of 501-1,000 mg/L total dissolved salts (TDS), classing the aquifer in this area as Segment A2 of the State Environment Protection Policy (SEPP) *Groundwaters of Victoria* (GoV). Beneficial uses requiring protection under this segment include: maintenance of ecosystems; acceptable potable supply; agriculture, parks and gardens; stock watering; industrial use; primary contact recreation; and buildings and structures.

Interpretation of the previous groundwater investigations and monitoring events identified several potential aquifer units onsite (Environmental Earth Sciences, 2011b; Golder Associates 2004a-e; 2007). Groundwater flow systems are likely to be present in the following geological units:

- PMS; however, although the PMS may be a water bearing zone, it is not considered to constitute an aquifer beneath the site due to its limited capacity to store and transmit water caused by its shallow intermittent distribution;

- Brighton Group sediments, considered to contain the watertable aquifer beneath the site; and
- Dargile Formation, which forms the basement aquifer/ aquitard beneath most of Melbourne.

Environmental Earth Sciences has completed a groundwater investigation in 2011 (refer to Environmental Earth Sciences VIC, 2011b version 3). In addition, further groundwater sampling on selected monitoring wells was undertaken in June 2013, where the results will be reported as supplementary groundwater investigation report.

The OVB is considered to be acting as an aquiclude between the deeper Dargile Formation and the overlying Quaternary/ late Tertiary aged sediments of PMS and Brighton Group. It is understood that no registered groundwater wells exist within the OVB or Dargile Formation onsite or within a 3 km radius (limits of SKM groundwater well database search) of the site. Therefore it is the utilisation of the watertable aquifer in Brighton Group Sediments which is of interest for this site.

5.5.1 Groundwater flow

Regional groundwater flow in the Dargile Formation is south to south-west towards Port Phillip Bay. Previous groundwater assessments at the site (Golder Associates, 2006a; 2006b; and 2006c) indicate that local groundwater flow in the Brighton Group sediments is influenced by the surrounding sewer system(s).

Groundwater within the Brighton Group sediments beneath Gasworks Park generally flows from the north towards the groundwater depressions to the south and south-west, which is associated with groundwater discharge (i.e. leakage) into the South Yarra main sewer and Hobsons Bay main sewer.

Additionally, groundwater levels along the western boundary of Gasworks Park indicate a minor component of westerly groundwater flow may be influenced by the Pickles Street sewer. The Richardson Street main drain running along the north side of the site may also be influencing local groundwater flow direction in its immediate vicinity.

5.6 Regionally sensitive receptors

On-site contamination and migration off-site of contamination has the potential to impact upon a variety of sensitive receptors. The two main receptor groups relating to the site are the environment (ecological) and human (health), while artificial receptors such as buildings and structures must also be considered.

5.6.1 Ecological

Ecological receptors include any living organisms other than humans, the habitat which supports such organisms, or natural resources, which could be adversely affected by contamination released at or migrated from a site.

Given the site location, local setting and land uses, ecological receptors include (but are not necessarily limited to):

- vegetation growing on-site (native and introduced) – influenced directly by up-take of chemicals within soil;

- fauna (including native and introduced, and local and transitory) – influenced directly by soil contact and potentially influenced through consumption of the vegetation described above; and
- the Port Philip Bay water and sediments – potentially influenced by discharging impacted groundwater.

Based on the Federal Department of the Environment, Water, Heritage and the Arts' databases (formerly the Department of the Environment and Water Resources), no protected ecological sites, reserves or communities exist within 2 km of the site.

5.6.2 Human health

Based on all possible exposure scenarios for the site, sensitive human receptors include young children (for example two years old) who are users of the site and aging residents at the adjacent aged care facility. Given the site location and setting, along with the current and proposed future use, other sensitive human receptors to chemicals within soil, groundwater and vapour include (but are not necessarily limited to):

- park users (adults and children) – potentially influenced by direct contact with soil, ingestion of on-site vegetation and soil, and inhalation of vapour;
- workers (surface and sub-surface workers) – influenced by direct contact with soil and potential inhalation of vapour;
- residents (i.e. Southport aged-care residents and off-site residents) – potentially influenced by direct contact with soil, inhalation of vapour, contact with extracted groundwater and ingestion of vegetation exposed to groundwater; and
- beach users – influenced by groundwater potentially discharging from the site into Port Philip Bay.

5.6.3 Buildings and structures

Buildings and structures at and around the site (which also represent sensitive receptors) include eleven commercial buildings on-site (i.e. bookshop, theatre and ceramics workshop), the Southport Community Nursing Home and residential, commercial and light industrial properties adjacent to the site.

These buildings are considered receptors as sub-surface components (i.e. footings and foundations) will be in contact with soil and potentially groundwater, depending on the depth. Soil which is acidic or corrosive may degrade concrete structures leading to collapse. The conditions of groundwater which may influence structures include pH, conductivity and ionic properties.

Additionally, on-site buildings may be susceptible to vapour intrusion which reduces indoor air quality and has the potential to impact human health. It should be noted that the HSLs adopted are based on direct contact exposure for Gasworks Park and a combination of direct contact and vapour pathway exposures for South Port Nursing Home (discussed further in Section 6). A separate ambient indoor vapour sampling investigation has been undertaken to address this issue.

6 APPLICATION OF RELEVANT GUIDELINES AND ADOPTED CRITERIA

6.1 SEPP (Prevention and Management of Contamination of Land)

The SEPP (2002) *Prevention and Management of Contamination of Land* provides the framework for the protection of land and associated beneficial uses throughout Victoria. The policy allows for a consistent approach to the prevention of contamination of land and clean-up of polluted land in Victoria, and sets environmental quality indicators and objectives for each beneficial use. The SEPP defines certain land use categories and associated beneficial uses of land to be protected.

The beneficial uses of land to be protected are dependent on the proposed land use and are shown in Table 1, with relevant guidelines associated with each beneficial use detailed in Table 2. The investigation process requires that site contamination to be assessed in the context of beneficial uses of soil that need to be protected.

Based on our discussions with City of Port Phillip (CoPP), we understand that the future land-use of both Gasworks Park is likely to remain '*Recreation / Open Space'*, and the Southport site to remain a nursing home, classified as '*Sensitive Use – Other*' under the SEPP (2002). Therefore, the relevant beneficial uses to be protected include:

- modified and highly modified ecosystems;
- human health;
- buildings and structures;
- aesthetics; and
- production of food, flora and fibre.

A protected beneficial use may not apply at a site where background concentrations of a substance are greater than the relevant guideline. Therefore, it is important to determine the concentrations of substances which occur naturally in the region of the site.

6.2 Tier 1 criteria

For the initial environmental assessment of sites, published criteria from reputable sources are utilised to determine if a protected beneficial use is potentially precluded due to contamination at the site. In instances where the level of contamination is less than these criteria then there is no need to assess the risk further or develop site specific criteria. These published established criteria are referred to as Tier 1 criteria.

The Tier 1 criteria adopted were selected as being conservatively protective of the protected beneficial uses listed in Section 6.1, as recommended in the National Environment Protection (Assessment of Site Contamination) Measure (NEPM). The NEPM indicates the use of Health Based Investigation Levels (HIL) and Ecological Investigation Levels (EIL) to screen analytical data to identify conditions that may warrant further investigation and assessment as to whether remediation may be required. The NEPM recommends that site specific risk assessments be used to develop response levels for the CoPC should Tier 1 criteria be exceeded.

6.2.1 NEPM ecological investigation levels (EILs)

As identified in Table 2 the relevant guidelines associated with protection of ecosystems are ecological-based investigation levels (EILs) for soil set out in Schedule B(1) of the National Environment Protection (*Assessment of Site Contamination)* Measure (NEPM 1999). An investigation level is defined as "*the concentration of a contaminant above which further appropriate investigation and evaluation will be required*" (ANZECC 1992). EILs for urban settings have been set on the basis of phytotoxicity or soil survey data. The NEPM defers to ANZECC (1992) for all other contaminants.

In general, the NEPM EILs are considered to protect most sensitive receptors and are known to be very conservative without any or very little scientific support. Where the levels of chemicals in soils are below the NEPM EILs, the condition of the land is considered to satisfy the requirements for protection of all beneficial uses, including production of food, flora and fibre (excepting groundwater quality). These guidelines provide the basis for further investigation of contamination for a range of chemicals and where exceeded, a risk based review of the potential impact from environmental exposure for the proposed residential land use is considered appropriate.

6.2.2 NEPM health investigation levels (HILs)

A review of health-based soil investigation or guidance levels has been undertaken by Langley *et al*. (1995), as part of the "*Third National Workshop on the Health Risk Assessment and Management of Contaminated Sites*". This provided a range of health-based soil investigation levels considered to be safe for a range of generic land-uses for Australia, including sensitive uses. Exceeding these guidelines does not mean the land is not safe, it simply means further investigation or explanation is required.

These guidelines have been published as Health Based Soil Investigation Levels (*National Environmental Health Forum Monographs Soil Series No. 1, 1996*). HILs which have been derived from the National Environmental Health Forum (1996) guidelines are included in Schedule B (1) of the NEPM.

The HIL guidance should only be applied statistically and therefore where adequate characterisation of soil contamination has been completed. This requires that firstly, the data quality is acceptable and secondly, that representative sample data is provided. The data should also be interpreted in terms of background and natural variances in assumptions in the standard scenarios. The NEPM guidance requires the mean concentration of a contaminant be used as a basis for assessment.

The review by Langley *et al* (1995) indicated that the level of any chemical at a discrete location should not exceed the guidance value by more than 250%, and that the standard deviation of any chemical across the site should be less than 50% of the guidance value. These statistical requirements for reviewing data against the guidelines have been adopted in the NEPM Schedule B (7a) *Guideline on health based investigation levels*.

The HIL adopted for Gasworks Park based on its current and proposed continued use is HIL E "Parks, recreational open spaces and playing fields", which is more conservative than HIL F "Commercial/Industrial" that also applies to portions of the site. The HIL adopted for South Port Nursing Home based on its current and proposed continued use is HIL A "Standard residential with garden/accessible soils". As NEPM guidelines do not include HIL criteria for some monocyclic aromatic hydrocarbons (MAHs) and total recovered hydrocarbons (TRH), a combination of CRC Care HSLs and modified site specific trigger levels (SSTL) have been used to assess the following scenario (refer to Section 6.2.3 for further discussion):

- HSL-C "Recreational/Open space" for Gasworks Park (equivalent to HIL E); and

- HSL-A "Residential (low density)" for South Port Nursing Home (equivalent to HIL A).

6.2.3 CRC CARE health screening levels (HSLs)

It is noted that HSLs cannot be applied to non-petroleum sources such as pure solvents or gasworks wastes. This is because the solubility limits are based on petroleum mixtures, and so are the TPH fractions carbon weights and therefore the values cited in this report (Tables 4 and 5) have been altered slightly (modified SSTL) from those published in Tables 3 and 4 of Friebel and Nadebaum (2011), to account for site specific factors using the CRC Care Risk Health Based Criteria Model for direct contact and soil vapour pathway (refer to Appendix G). These include TPH being present 100% in the aromatic fraction, and the presence of an average 0.2m cap over an average 1m thickness of gasworks waste beneath the residential portion of the site (South Port nursing home).

HSL-C has been adopted for Gasworks Park even though it does not account for vapour intrusion into the buildings onsite (Recreational/open space land use assumes no buildings exist). This is because only the open space portion of the parkland section of the site has been considered in this report (no sampling of soil beneath enclosed spaces was undertaken on either the parkland, or nursing home portions of the site). In addition, an indoor vapour assessment has been undertaken, which addresses the indoor vapour intrusion exposure pathway separately. Therefore, we are of the opinion that HSL-C was the appropriate criteria to adopt rather than HSL-D (industrial land-use which is more conservative as it accounts for vapour intrusion into buildings).

6.2.4 Buildings and structures

The SEPP (2002) states that contamination must not cause the land to be corrosive, or to adversely affect the integrity of structures or building materials. The indicators for this are usually pH and sulfate. For pH the Australia Standard AS3600-2009 *Concrete Structures* is referred to with a threshold of pH 4 and for sulfate a value of 2,000 mg/kg is used.

6.2.5 Aesthetics

There are no specific criteria for the protection of aesthetics, however the SEPP states '*that contamination must not cause the land to be offensive to the senses of human beings*'. Therefore aesthetics factors considered in this investigation include odours, domestic and construction waste and visible staining.

6.2.6 Production of food, flora and fibre

The SEPP (2002) states that "*contamination of land must not adversely affect produce quality or yield*". Specific criteria for the protection of food, flora and fibre, are not provided. However, the NEPM EILs are based on phytotoxicity and are therefore used.

7 QUALITY ASSURANCE AND CONTROL

The aim of quality assurance and quality control (QA/QC) is to deliver data that is:

- representative of what is sampled;
- precise;
- accurate; and
- reproducible.

7.1 Data quality objectives

Development of data quality objectives (DQOs) for each project is a requirement of the *National environment protection (assessment of site contamination) measure* (NEPC 1999). This is based on a DQO process formulated by the USEPA for contaminated land assessment and remediation. This has not been formally adopted by EPA Victoria or the contaminated land industry, however it provides sound guidance for a consistent approach in understanding site assessment and remediation. Many environmental practitioners are now following this process. The DQOs are defined in a series of seven steps as outlined in Appendix C.

7.2 Sampling and analysis plan

All sampling locations, methods and laboratory analysis were approved by the Environmental Auditor, Peter Nadebaum (GHD Pty Ltd), prior to the commencement of field works through the following documents:

- Environmental Earth Sciences VIC, 2010. Report number 210074 - *'Sampling and analysis plan for the former South Melbourne Gasworks, Albert Park, Victoria'*;
- GHD 31/26548/189319Letter '*Gasworks Site Environmental Audit Sampling and Analysis Plan*', dated 10 November 2010;
- SAP discussion between Environmental Earth Sciences VIC, City of Port Phillip (CoPP) and GHD on 2 December 2010
- Environmental Earth Sciences VIC, Letter 210074L1 - '*Revised site capping and NAPL investigation sampling and analysis plan for the South Melbourne Gasworks, Albert Park, Victoria*' dated 8 December 2010; and
- correspondence (*via-email*) with the auditor on 13 December 2010 and 20 December 2010.

It must be noted the auditor initially expressed uncertainty into the appropriateness of the investigation. In discussions with CoPP on 15 December 2010 and correspondence with GHD on 13 December 2010 and 20 December 2010, however, it was considered the proposed approach was appropriate as an initial screening tool to identify if a cap is present or not and it's thickness (where applicable).

The rationale behind the selection of sampling locations is provided in Table 3 and described in Sections 7.2.1 to 7.2.2 below.

7.2.1 Soil sampling

Due to the size of Gasworks Park and South Port Community nursing home (approximately 3.21 hectares) a specialised sampling strategy was proposed as an initial screening tool to assess the integrity of the capping across the site. It involved systematic sampling (i.e. random sampling within a grid) of 41 locations across the site at a density of 13.1 points/ha. It should be noted that some of the sampling points can also be considered targeted as they were installed near or within the vicinity of the historical potential source of contamination such as tanks and separation. This strategy resulted in a diameter of 'hot-spot' detection (with a 95% level of confidence) of 33 metres and was considered sufficient to provide a reliable map of the current capping layer and concentrations of contaminates in surface and shallow soils. The 'grid based systematic sampling locations are presented in Figure 3. Where sample locations fell within on-site building footprints, they were relocated based on access constraints.

Most investigation works were undertaken via test pits to give a greater visual interpretation of the capping layer and shallow and underlying soils. In areas where test pits were impractical (i.e. access restricted, areas of hardstand), soil sampling was undertaken from boreholes drilled by Geo-probe drill rig or hydraulic push tube drill rig.

Test pit depths were to the maximum reach of the backhoe/ excavator at approximately 3 metres below ground level (mBGL), while boreholes were to continue until refusal, half a metre into natural material and/or to a maximum depth of 6 mBGL. Soil samples were collected from each change in lithology and/or at the surface, at half a metre depth and 1 m intervals thereafter. Additional soil samples were also collected based on field observations of contamination, photo-ionisation detector (PID) readings or where heterogeneous fill material was encountered.

7.2.2 Laboratory analysis

The analytes selected are based on previously identified CoPC for the target area, and their potential derivatives. Selected soil samples were analysed from each borehole for key CoPC associated with NAPL and gasworks waste including;

- heavy metals (As, Cd Cr, Cu, Pb, Ni, Hg and Zn);
- polycyclic aromatic hydrocarbons (PAHs);
- total petroleum hydrocarbons (TPH)/total recoverable hydrocarbons (TRH);
- cyanide;
- phenols;
- sulfates and sulfides; and
- benzene, toluene, ethyl benzene and xylene (BTEX).

Additional analysis was undertaken based on field observations of soil heterogeneity, odour, PID readings and visual contamination. Furthermore, Australian Standard Leaching Procedure (ASLP) – via class 3b leaching fluids (i.e. acetate and tetraborate) was undertaken on selected samples to assess the leaching potential of chemicals of concern.

The analytical methods selected are based on those recommended by the laboratories and publications such as *Standard methods for the examination of water and waste-water* (APHA 2005), *Soil Chemical methods –Australasia* (Rayment & Lyons 2010) and *Sampling and analysis of waters, waste-waters, soils and wastes* (EPA Victoria Publication IWRG 701, 2009).

7.3 QA/QC Outcomes

Details of the quality assurance and quality control (QA/QC) undertaken for this project is presented in Appendix C. In summary, assurance of quality data from soil sampling has been based on development of an approved sampling and analysis plan and site management plan, appropriate field methodology, careful selection of laboratories and assessment of data against the Measurement Data Quality Indicators (MDQI's).

The QA/QC data reported by ALS and SGS for the documented soil samples were determined to be of sufficient quality to be considered acceptable to comply with the Environmental Earth Sciences quality protocols for the project. This report has therefore concluded that the QA/QC data set and field duplicate results are free of systematic, method biases and field sampling errors, and the data is representative of the site conditions. It can be confidently stated that the MDQI's for this project have been met and the data set is considered to be reliable.

8 FIELD INVESTIGATION

8.1 Site inspection

Environmental Earth Sciences VIC personnel undertook an initial site inspection on 10 September 2010, with a subsequent site inspection and service clearance of proposed sampling locations on 11 January 2011. The site inspection was undertaken to inspect the existing surface material across the Gasworks Park and Southport site, to visually assess potential impacts to beneficial uses of the site (i.e. aesthetic).

8.1.1 Gasworks Park

At the time of the inspection the Gasworks Park consisted of a grassed area in the centre and southern corner of the site, surrounded by landscaped areas. In addition there was a playground in the eastern part of the central grassed area with BBQ and rotunda facilities to the north. The landscaped areas consisted of garden beds with native trees (predominantly *Eucalyptus spp*.) and small wetlands all linked by gravel access tracks.

Areas of patchy grass cover were noted in parts of the grassed centre of the site, however grass coverage was at least 70% in these areas. There was no visible staining or discolouration noted at the surface of the site and no visible gasworks waste or asbestos containing material (ACM) was observed. There was a hydrocarbon odour noted at various times during the inspection, however a specific location could not be identified.

There were eleven buildings noted within the Gasworks Arts Park, including historic gasworks buildings and a few buildings, mostly administration buildings and theatre, which have been constructed since the redevelopment. At the time of the site inspection and fieldworks, the bookshop building was vacant. Current buildings within Gasworks Arts Park are detailed in Section 3.2 and locations are provided in Figure 2.

8.1.2 SouthPort Nursing home

The Southport site is situated in the northeast corner of Gasworks Park (refer to Figure 2). The Southport Community Nursing Home occupies the majority of the Southport Site (fronting Richardson Street) and incorporates a v-shaped brick building (i.e. nursing home), and open grass, paving and landscaped gardens to the west of the building. It is separated from Gasworks Park by a wire fence and raised garden bed with native tree species on the Park side of the fence.

There was no visible staining, discoloration, patchy vegetation cover, gasworks waste, asbestos or asbestos containing material observed at the surface of the site. Nor were any odours noted at the site.

8.2 Site capping investigation

A preliminary systematic grid based soil sampling was undertaken in 26 locations across the site between 18 and 21 January 2011. In addition, 15 soil sampling boreholes were sampled between 27 and 28 January 2011, giving a total sampling density of 12.6 points/ha All sampling was undertaken in accordance with:

- National Environment Protection Council, 1999, *National Environment Protection (Assessment of Site Contamination) Measure*;
- Australian and New Zealand Environment and Conservation Council, 1992, *Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites*;
- State Environment Protection Policy (SEPP), 2002, *Prevention and Management of Contamination of Land*;
- Standards Australia AS 4482.1, 2005, *Guide to the investigation and sampling of sites with potentially contaminated soil. Part 1: Non-volatile and semi-volatile compounds*); and
- Environmental Earth Sciences, 2011, *Soil, gas and groundwater sampling manual*.

In addition, quality control and assurance procedures were followed throughout the site capping investigation. For full details refer to Appendix C.

8.2.1 Test pitting

Test pitting was undertaken via a three tonne excavator to the maximum reach of the excavator which was approximately 3.0 mBGL. The SAP had originally identified 4.0 mBGL as the target depth, however due to refusal at a number of locations and the aim of the investigation was to investigate shallower soils (rather than soils >3.0 mBGL), sampling was generally ceased at 3.0 mBGL. A total of 96 discrete soil samples were collected from 26 test pits (TP1 to TP26) which were positioned across Gasworks Park, including six intra-laboratory and six inter-laboratory quality control (QC) samples. Test pit locations are presented in Figure 3. Samples were generally collected from the surface and 0.5 m intervals, or at distinct changes in lithology or where potential contamination was noted.

Soil samples were collected using a clean stainless steel spatula from the wall of the test pit or from the excavator bucket at depths greater that 1.5 mBGL. The samples collected from the walls of the test pits were scraped clean to avoid cross contamination. The soil sampled was then placed into laboratory prepared glass jars and labelled with a sampling location number, depth of sample collection, site reference and date before being placed into a chilled Esky.

During the collection of samples from test pits, a description of soil texture, colour, pH, odour and photo-ionisation detector (PID) readings were recorded for each stratigraphic unit encountered at each test pit location. Test pit logs are presented in Appendix A.

8.2.2 Borehole sampling

Borehole sampling was undertaken via a hydraulic push tube drill-rig to a maximum depth of 3.0 mBGL. A total of 48 discrete soil samples were collected from 15 boreholes (BH1 to BH11 and BH13 to BH16) were positioned across the Gasworks Park and Southport site, including one intra-laboratory and one inter-laboratory quality control (QC) samples. Borehole locations are presented in Figure 3. Samples were generally collected from the surface and 0.5 m intervals, or at distinct changes in lithology or where potential contamination was noted.

It is noted that the proposed location of BH12 was not undertaken during this investigation, however the combination of 15 boreholes and 26 test pits can be considered sufficient as an initial screening tool to characterise the site cap. Additionally, test pit location TP11 is considered to be in close vicinity of the proposed location of BH12.

Samples were collected from the push tube sleeve (i.e. dedicated clear disposable sleeve) and placed into laboratory prepared glass jars. The jars were labelled with a sampling location number, depth sampled, date and site reference before being stored in a chilled cooler.

During the collection of samples from test pits, a description of soil texture, colour, pH, odour and PID readings were recorded for each stratigraphic unit encountered at each borehole location. Bore logs are presented in Appendix A.

8.2.3 Land topographical survey

A land topographic survey was undertaken by qualified surveyors Heading and Associates on 24 February 2011. The complete survey is present in Appendix E with a simplified version presented in Figure 6. From this survey the location and extent of landscaping and buildings can be determined and it will be essential when calculating soil volumes for remediation (if any).

8.3 Stratigraphy

Field observations such as soil colour, texture, pH and odour were used to identify changes in lithology. The surface fill layer consisted of either a thin layer of brown loam (0.05-0.4 m thick) which covers most of the open areas of the site, or sandy gravel/crushed rock (0.1-0.15 m thick) which constitute the pathway/driveways across the site. The remainder of the site is sealed beneath buildings, which were not investigated in these works.

Both the sandy gravels of the pathways and the brown loam layer were laid directly over various mixed layers of reworked BGS and PMS including sands, gravels, silts and clays heavily impacted with gasworks waste (free layers noted) including ash, coke, clinker, solid and viscous tar and spent oxides, except for:

- the central/northern portion of the site where the brown loam is separated from gasworks waste by a layer of yellow orange sandy clays of reworked natural Brighton Group sediments (Figure 7), likely to have been sourced locally (potentially from site);
- brown silty clay with brick and minor coke and slag inclusions in a band beneath TP10-TP13; and
- firm brown clay with varying amounts of coke, ash and brick inclusions encountered in the south-eastern corner (TP17, TP18, TP19) and a small area on the north-east boundary (TP20, and TP21).

Boreholes BH9, BH11 and BH15 had a thin layer of loam overlying the sandy gravels of a pathway, which is believed to have spilled over from the adjacent landscaped area, hence included with pathway locations. Lastly, test-pit TP8 consisted of a thin layer of brown loam over natural material.

It is likely that the thin layer of brown loam and the yellow orange sandy clays, where they occur, constitute the capping layer, generally >0.5m thick, placed over the site as part of the redevelopment. There was visible contamination of this capping layer, with gasworks waste in most sampling locations, which is attributed to cross contamination through mixing with the existing underlying impacted fill material, rather than importation to site. Based on field observations, it is considered unlikely the brown silty clay beneath test-pits TP10-TP13 forms part of this capping layer.

The firm brown clay on the south-eastern corner of the site is thought to be a result of the excavation of 0.5 m of contaminated fill material and replacement with 0.3m of “clean soil” rather than part of the capping layer. It should be noted that this does not match the historical records of 0.5m of clean backfill.

The depth to natural varies across the site from 0.3 m BGL in the south-west corner to at least 3.0 m BGL at test-pit TP7. Natural material was not reached in 12 locations due to refusal on subsurface infrastructure or services, and not reached in two locations due to depth of fill material (test-pits TP23 and TP7, perched water was also encountered in the latter). Consistent refusal on the foundations/footings of the SouthPort Nursing Home buildings was encountered in boreholes BH3-BH5, therefore some uncertainty as to what lies beneath foundations exists in this area.

By correlating the depth to natural material (Figure 8) with the topographic map (Figure 6), areas of infilling or mounded fill material, and potential gasworks waste deposits, have been identified. Taking into account the distribution and thickness of the capping layer there appears to be an area of deep infilling around test-pits TP7 and TP10, which gradates out to an area with moderate infilling, which extends north in a band through the centre of the site (Figure 8). Based on the borelogs, a significant amount of gasworks waste was used to infill this area. There were no sampling points located on the mounded areas of the site, therefore the composition of these elevated landscaped areas is unknown. However, these areas can be managed in accordance with the agreed remediation option for the site.

Natural material consisted of yellow, orange, grey and white sands, silts and clays typical of the Brighton Group Sediments with occasional occurrence of Port Melbourne Sands as a discontinuous layer overlying the Brighton Group sediments. Cross-sections of the site are presented in Figures 4 and 5, at the locations depicted on Figure 3.

PID readings were collected in the field and recorded on the soil borelogs, and ranged to maximum of 320 ppm. High PID readings (100-320 ppm) were always noted in association with strong PAH odours and visible gasworks waste in the soil profile, however, in some locations odours and gasworks waste were noted with a low PID reading. These results indicate that the gasworks waste is composed of differing proportions of volatile CoPC, which have the potential to generate vapour.

Field pH was recorded as relatively neutral ranging between pH6 and pH8.5 with the following exceptions:

- pH 4 in natural material from boreholes BH6 (1.7-1.8), BH8 (1.4-1.5), and BH9 (1.4-1.5);
- pH4.5 in natural material from test-pits TP15 (2.4-2.5) and TP16 (2.0-2.1), and in fill material samples for TP17 (1.0-1.1), TP20 (0.6-0.7), and TP20 (0.8-0.9);
- pH5.0 in fill material from test-pits TP11 (1.2-1.3) and TP15 (0.0-0.1);
- pH9.0 in fill material from test-pits TP2 (0.95-1.0) and TP16 (1.0-1.1); and
- pH9.5 in fill material from test-pit TP3 (1.4-1.5).

8.4 Non-aqueous phase liquid

The only non-aqueous phase liquid (NAPL) encountered on the site was viscous tar in three sampling locations including:

- borehole BH13 (viscous tar observed with other pyrogenic waste at 0.9 m BGL);
- test-pit TP26 (minor amounts of viscous tar observed with other pyrogenic waste between 0.3 ~2.0 m BGL with impacts into natural material); and
- test-pit TP7 (solid tar mixed with other gasworks waste and rubble between 0.1-1.1 m BGL and semi-viscous tar encountered between 1.8-2.7 m BGL with discrete solid tar layer 1.9-2.0 m BGL).

In addition potentially perched water with hydrocarbon sheen was encountered in test-pit TP10 at 2.4 metres.

Solid tar was encountered in the following sampling locations:

- borehole BH11 (mixed with other pyrogenic gasworks waste between 0.5-0.9 m BGL);
- test-pit TP6 (in a discrete layer between 0.8-1.1m BGL); and
- test-pit TP11 (in a discrete layer between 1.4-1.6 m BGL).

8.5 Spent oxides

Blue spent oxides were observed mixed with other fill and gasworks waste in five sampling locations including:

- borehole BH4 (0.1-0.7 m BGL);
- test-pit TP4 (0.35-0.6 m BGL);
- test-pit TP6 (1.1-1.8 m BGL);
- test-pit TP18 (0.2-2.0 m BGL); and
- test-pit TP20 (0.8-1.0 m BGL).

9 LABORATORY ANALYSIS

The schedule for laboratory analysis was defined by our SAP (Environmental Earth Sciences VIC, 2010a) and letter 210074L1 *Revised site capping and NAPL investigation sampling and analysis plan for the South Melbourne Gasworks, Albert Park, Victoria* dated 8 December 2010 (Environmental Earth Sciences VIC, 2010b). Soil samples were selected for analysis on the basis of their location, stratigraphy, field observations such as colour and pH, location on the site relative to potential contamination sources (i.e. historic infrastructure) and sampling density.

9.1 Soil analytical program

A total of 144 discrete soil samples were collected across ‘Gasworks Arts Park’ and ‘Southport Community Nursing Home’ during the site capping investigation. Of these samples, 129 discrete soil samples (83 test pit samples and 46 borehole samples) were analysed for CoPC. Seven intra-laboratory triplicate samples and seven inter-laboratory duplicate samples were also collected and analysed for CoPC for QC purposes to ascertain the chemical status of the soil (refer to Appendix C for more detail of the sampling rationale).

Soil samples were selectively analysed for one or more of the following:

- heavy metals (As, Cd Cr, Cu, Pb, Ni, Hg and Zn);
- polycyclic aromatic hydrocarbons (PAHs);
- total petroleum hydrocarbons (TPHs)/total recoverable hydrocarbons (TRH);
- cyanide;
- phenols;
- ammonia;
- sulfates and sulfides; and
- benzene, toluene, ethyl benzene and xylene (BTEX).

Select samples were submitted for further laboratory analysis including:

- TPH speciation into aliphatic and aromatic species (11 samples);
- ASLP for select heavy metals (Pb, Hg, As, Ni, Zn); and
- ASLP for PAHs (14 samples).

All soil analysis was undertaken by Australian Laboratory Services (ALS) and SGS Australia, which are both NATA accredited for the methods used. Laboratory transcripts for soil samples are presented in Appendix B.

9.2 Quality control and quality assurance

Quality control is achieved by utilising NATA accredited laboratories, using standard methods supported by internal duplicates, the checking of high, abnormal or otherwise anomalous results against background and other chemical results for the sample concerned.

Quality assurance is achieved by confirming field or anticipated results based upon the comparison of field observations with laboratory results. In addition, the laboratory undertakes additional duplicate analysis as part of their internal quality assurance program.

Field observations are compared with laboratory results when they are not as expected and confirmation, re-sampling and re-analysis are undertaken if results cannot be correlated. In brief, field duplicate results were generally within the acceptable range of reproducibility and all duplicates and standards were within the acceptable reproducibility range.

Further to laboratory quality assurance, intra-laboratory comparison is achieved through comparison of analytical results of primary samples with their corresponding intra-laboratory duplicate.

Full laboratory transcripts and chain of custody forms are presented in Appendix B, while further discussion on QA/QC is provided in Appendix C.

10 RESULTS AND DISCUSSION

The results of the laboratory analysis are presented in Table 4 for SouthPort Nursing home, with the following exceedances of Tier 1 criteria noted (27 primary soil samples were analysed):

- lead – three samples exceeded HIL A criteria and one sample exceeded EIL criteria;
- arsenic – one sample exceeded HIL A criteria and four samples exceeded EIL criteria;
- copper – three samples exceed EIL criteria;
- mercury – four samples exceed EIL criteria;
- nickel – one sample exceed EIL criteria;
- sulfate – three samples exceed EIL criteria which is also the criteria for protection of concrete structures (buildings);
- sulfide – three samples exceed EIL criteria;
- cyanide – two samples exceed HIL A criteria;
- B(a)P – 20 samples exceed HIL A criteria and a maximum concentration of 97.6 mg/kg was reported for borehole BH8 (0.0-0.1m);
- total PAH – 16 samples exceed HIL A criteria and a maximum concentration of 1,744 mg/kg was reported for borehole BH8 (0.0-0.1m);
- naphthalene – three samples exceed HSL-A for the vapour intrusion pathway, none for direct soil contact (soil ingestion, dust inhalation and dermal contact), with a maximum concentration of 28.9 mg/kg at borehole BH8 (0.0-0.1m);

- TRH >C_{10}-C_{16} – four samples exceed HSL-A for the vapour intrusion pathway, none for direct soil contact, with a maximum concentration of 480 mg/kg at borehole BH4 (0.2-0.3m);
- TRH >C_{16}-C_{34} – four samples exceed HSL-A for the direct soil contact pathway, with a maximum concentration of 4,880 mg/kg at borehole BH4 (0.2-0.3m); and
- TRH >C_{34} – one soil sample exceeds HSL-A for direct soil contact (1,640 mg/kg at borehole BH4, 0.2-0.3m).

The results of the laboratory analysis are presented in Table 5 for Gasworks Park, with the following exceedances of Tier 1 criteria noted (105 primary samples were analysed):

- lead – two samples exceed HIL E criteria which is also the EIL criteria, and an outlier maximum concentration of 6,720 mg/kg was noted for test-pit TP18 (0.7-0.8);
- arsenic – 17 samples exceeded EIL criteria;
- copper – one sample exceed EIL criteria;
- mercury – six samples exceed EIL criteria;
- nickel – three samples exceed EIL criteria;
- zinc – ten samples exceed EIL criteria;
- sulfate (NEPM) – four samples exceed EIL criteria which is also the criteria for protection of concrete structures (buildings), and an outlier maximum concentration of 14,300 mg/kg was noted for test-pit TP18 (0.7-0.8);
- sulfide – seven samples exceed EIL criteria, and an outlier maximum concentration of 12,044 mg/kg was noted for test-pit TP18 (0.7-0.8);
- cyanide – one sample exceed HIL E criteria with an outlier maximum concentration of 4,240 mg/kg in sample TP20 (0.8-0.9);
- TRH (>C_{10}-C_{16}) – two samples exceed HSL C (HIL E equivalent) criteria, with a maximum concentration of 8,230 mg/kg detected (test-pit TP7, 1.75-1.8m);
- TRH (>C_{16}-C_{34}) – 16 samples exceed HSL C (HIL E equivalent) criteria, with a maximum concentration of 29,500 mg/kg detected (test-pit TP7, 1.75-1.8m);
- TRH (C_{34}-C_{40}) – 12 samples exceed HSL C (HIL E equivalent) criteria, with a maximum concentration of 4,460 mg/kg detected (test-pit TP7 1.75-1.8);
- B(a)P – 54 samples exceed HIL E criteria and a maximum concentration of 1,040 mg/kg was reported for borehole BH11 (0.5-0.6m);
- naphthalene – two samples exceed HSL C (equivalent HIL E) with a maximum concentration of 6,600 mg/kg reported for borehole BH11 (0.5-0.6m); and
- total PAH – 49 samples exceed HIL E criteria and a maximum concentration of 28,957 mg/kg was reported for borehole BH11 (0.5-0.6m).

Based on the results of TPH speciation into aromatic and aliphatic components for the >C16 fraction ranges, it has been assumed for the purposes of this assessment that 100% of TPH is aromatic in nature. This assumption (based on analysis of 11 samples as reported in Table 6 at the rear of this report) has also influenced guideline derivation (after Friebel and Nadebaum 2011). It is also important to note that non-speciated TPH results, as reported in Tables 4 and 5 and Appendix B of this report, are subject to potential ‘false positives’ as they haven’t had polar (natural) compounds removed via silica gel cleanup.

Reported concentrations for all other potential CoPC were below Tier 1 Screening criteria and therefore are not a concern for the site and are not considered further in this investigation. These include:

- cadmium, chromium;
- phenols and phenolic compounds;
- ammonia;
- TRH (C_6-C_{10}); and
- benzene, toluene, ethyl-benzene and total xylenes.

10.1 Statistical analysis

There were sufficient samples collected to be able to perform the 95% upper confidence limit (UCL) statistical analysis for different CoPC which exceed Tier 1 criteria, on a number of sample sub-populations including stratigraphic units (capping layer, gasworks waste layer and natural material) and depth below ground surface for Gasworks Park. There were insufficient samples collected from South Port Nursing home for depth below ground surface sub populations, however statistical analysis was able to be performed on stratigraphic unit subpopulations. CoPC that did not exceed Tier 1 criteria within the subpopulation did not have statistical analysis performed.

The outcomes of this statistical analysis are presented in Tables 9-12.

The distribution for the sub-populations was generally lognormal indicating positively skewed contamination concentration distributions and therefore in some cases, it is more appropriate to compare the soil sample results individually rather than using the statistical analysis, and this is applicable in the case of PAHs.

10.2 PAH fingerprinting and source identification

We have undertaken PAH chemical fingerprinting of the samples that fail the Tier 1 site criteria to assess their bioavailability. We have developed two methods (A and B) to predict the origin of PAHs on contaminated sites.

For method A, comparison is made between the correlation coefficients of the test PAH (i.e. from the site) and a reference set of PAH suites of known origin. A higher coefficient indicates a stronger correlation. We consider a result of 0.95 or greater a very good fit, a result of greater than 0.85 is considered a good fit and a result above 0.75 is considered reasonable. Any results below this value are considered to be poor fits.

For method B, both the test and the result and each reference PAH suite is normalised to pyrene. The absolute value of the difference between each pair of analytes (i.e. the site and the PAH suites of known origin) is then summed to determine a summed absolute of the difference at pyrene normalised data. A comparatively low result is considered to indicate a good correlation. So a result of 1 or less is considered a very good fit, a result of less than 2 is considered a good fit and a result below 3 is considered reasonable. Any results above this value are considered to be poor fits.

All sampling locations, except four, had sufficiently elevated PAH concentrations to perform PAH fingerprinting, with outputs from the PAH fingerprinting presented in Appendix F. Results for both methods are slightly varied as presented in Table 13, with most correlating to field observations of gas works waste. Nearly all samples analysed reported a PAH source of ash, coke and/or tar. The sole exceptions were PAH from spent oxides in borehole BH4 and test-pit TP20. Nearly half the samples analysed reported a tar chemical signature in conjunction with ash and/or coke. A number of samples with a black coal tar signature were not reported to have visible tar in the field observations.

The distribution of tar based PAHs is not strongly correlated with historic infrastructure suggesting that tar waste has been buried across the site. Test-pits TP5, TP7 and TP11 may be associated with historic tar and liquor wells. In most samples there appears to be a mixed signature, which indicates multiple sources consistent with field observations and disposal of mixed gasworks waste or the presence of other hydrocarbons making some of the PAHs more available to the extractant during testing.

To confirm the likely source of PAHs, additional lines of evidence were combined with the PAH fingerprinting methods including:

- field observations, including visual, olfactory and PID observations (tar contains more volatile PAHs which are odourous and register on a PID);
- co-occurrence with other CoPC (TPH for primary gas condensates, and cyanide, sulfate and heavy metals for secondary gas condensate, spent oxides);
- total PAH concentration:
    - pyrogenic residue typical concentrations in soil is <5 to <5,000 mg/kg; and
    - primary gas condensate typical concentrations in soil is 100 to 50,000 mg/kg.

The outcomes from this assessment are presented in Table 13 and indicate that:

- primary gas condensate (tar), in 17 sampling locations;
- secondary gas condensate (spent oxides) in four sampling locations; and
- pyrogenic residue (ash, coke, clinker and slag) was identified in every sampling location with elevated PAHs across the site.

It should be noted that without doing a further assessment such as bioavailability testing there will be insufficient justification for this approach in order to apply a literature value for bioavailability to PAHs. However, this can be managed by the proposed remediation options either to re-cap the entire site or apply the other mitigation measures detailed in the RAP.

10.3 TPH speciation

Speciation of TPH was undertaken on eleven samples to differentiate the aliphatic hydrocarbon concentrations from the more toxic aromatic hydrocarbon fraction (Table 6). This analysis reported only detectable aromatic hydrocarbons in all eleven samples. Based on these results it can be assumed that TPH detected in soil samples are predominantly aromatic hydrocarbons. This assumption has been used to derive Tier 1 criteria for TPH after Friebel and Nadebaum (2011).

10.4 PAHs

The PAH leachate analysis was performed a range of samples with differing stratigraphies and textures including:

- one sample from the loam capping layer;
- one sample from the re-worked sandy clay capping layer;
- twelve samples from mixed gasworks waste layers including:
  - four samples of coarse sand;
  - two samples of silty sand;
  - three samples of sandy clay; and
  - three samples of separate ash, coke and slag layers.

The PAH fingerprinting and field observations also identified a range of gasworks waste PAH sources in the selected samples including, black coal tar, ash and coke from black and brown coal.

There is no apparent correlation between bioavailability factor and the PAH source and a weak correlation between higher BF and sand or ash/coke matrix. In general the BF of the PAHs on-site is low, generally <1% including all B(a)P, with the highest BF recorded for:

- Naphthalene in sample TP14 (0.85-0.9) has a BF of 11.18%; and
- Fluorene in sample TP6 (1.75-1.8) has a BF of 7.22% and in sample TP16 (1.0-1.1) a BF of 4%..

This may be due to weathering of PAHs resulting in a higher proportion of recalcitrant, non-biodegradable PAHs remaining in the soil as more volatile and bio-available PAHs have already leached/volatilised from the soil or biodegraded.

It should be noted that the PAH ASLP was analysed outside the recommended holding times and therefore the calculated BF may be higher, but Environmental Earth Sciences is of the opinion that this data set can be considered as an initial screening tool and further assessment such as bioavailability testing would be required to provide greater certainty. In addition, it should be noted that no ASLP analysis was performed on samples collected from the Southport site. However, this can be managed by the proposed remediation options either to re-cap the entire site or apply the other mitigation measures detailed in the RAP.

10.4.1 Heavy metals

The leachate analysis for the few heavy metal samples yielded varying results:

- arsenic and mercury appear to be non-leachable and assumed to be non-bioavailable;
- lead had a BF of 8%;
- nickel had a BF of 4.2%; and
- zinc had a BF of 12.2%.

Only a few samples were analysed, as elevated heavy metals generally do not appear to pose a risk on this site.

It should be noted that without doing a further assessment such as bioavailability testing there will be insufficient justification for this approach in order to calculate the bioavailability factors. However, this can be managed by the proposed remediation options either to re-cap the entire site or apply other mitigation measures detailed in the RAP.

10.5 Cap coverage

Based on previous reports and visual observation during the field program, the thin layer of brown loam and the yellow-orange sandy clays, where they occur, constitute the capping layer placed over the site as part of the redevelopment (Section 4.3). The capping layer is generally at least 0.5m thick where the sandy clays occur (approximately half the site, Figure 7), but thins out to the brown loam layer across the outer edges of the site. The remainder of the site consists of the thin sandy gravel layer of the pathways, lain directly on top of impacted material, or is sealed beneath site buildings.

10.5.1 Surface loam layer

Samples were collected from the surface loam layer at every sampling location where it was observed and submitted for laboratory analysis, except for boreholes BH9, BH10, BH11 and BH16. There was insufficient sample of the loam layer in BH16 and no samples were collected from the loam layer at BH10 and BH11. A sample was collected from BH9, however was not analysed. We consider that the loam layer has been adequately characterised as 36 out of 41 samples in the loam layer were analysed and therefore the implication of not analysing the five loam samples (from BH9, BH10, BH11 and BH16) can be considered negligible..

Visible contamination with gasworks waste was only noted in the surface brown loam capping layer in sampling locations TP3 and BH8. Laboratory analysis reported total PAH concentrations ranging between non detectable to 1,744 mg/kg, and BaP concentrations ranging between non detectable to 97.6 mg/kg.

The following exceedances of Tier 1 criteria were noted in the loam cap on Southport Nursing home:

- seven samples reported B(a)P concentrations only that exceed HIL A criteria;
- five samples reported total PAH concentrations that exceed HIL A criteria; and
- borehole BH8 reported such significantly elevated concentrations it is considered an outlier.

The following exceedances of Tier 1 criteria were noted in the loam cap on Gasworks Park:

- ten samples reported B(a)P concentrations that exceed HIL E criteria; and
- seven samples reported total PAH concentrations that exceed HIL E criteria.

The remaining samples reported PAH concentrations, including B(a)P below adopted Tier 1 criteria. There does not appear to be any correlation between PAH concentration and spatial location with exceedances scattered densely across the site (Figure 10).

The 95%UCL was calculated for the loam capping layer, with results indicating the following concentrations: 9.33 mg/kg for B(a)P and 248.7 mg/kg for total PAHs.

There are no elevated sulfur compounds, cyanide or heavy metal concentrations noted for this stratigraphic unit with the following exceptions:

- one sample reported copper in excess of the EIL; and
- one sample reported arsenic in excess of the EIL.

10.5.2 Sandy clay cap layer

A total of 13 samples were collected from the re-worked Brighton Group sandy clays that formed part of the cap layer in Gasworks Park. Visible contamination with gasworks waste was noted in this material at every location except for borehole BH14, and test-pits TP4 and TP24. The occurrence of gasworks waste in this capping layer is attributed to cross contamination through mixing with underlying gasworks waste during capping, rather than importation to site.

Laboratory analysis of samples collected from this layer confirmed elevated PAH and TPH ($>C_{10}$-C_{36}), concentrations consistent with gasworks waste, even in samples which did not report visible contamination. Laboratory analysis reported total PAH concentrations ranging between non detectable to 379 mg/kg, B(a)P concentrations ranging between non detectable to 29.8 mg/kg and TPH ($>C_{10}$-C_{36}) concentrations ranging between non-detectable and 1,660 mg/kg. The following exceedances of Tier 1 criteria were noted:

- seven samples reported B(a)P concentrations that exceed HIL E criteria; and
- six samples (BH13) reported total PAH that exceeds HIL E;

The remaining three samples reported PAH concentrations, including B(a)P below adopted Tier 1 criteria. There does not appear to be any correlation between PAH concentration and spatial location with exceedances scattered densely across the site (Figure 11).

The 95%UCL calculated for the sandy clay capping layer is 12 mg/kg for B(a)P and 151 mg/kg for total PAHs (refer to Table 10).

There are no elevated sulfur compounds, cyanide or heavy metal concentrations noted for this stratigraphic unit with the following exceptions:

- one sample reported zinc in excess of the EIL;
- one sample reported nickel in excess of the EIL; and
- six samples reported arsenic in excess of the EIL.

It is the opinion of Environmental Earth Sciences that the arsenic concentrations are natural background levels given that arsenic:

- is characteristic of Brighton Group Sediments which have been reworked to create this layer; and
- has consistent concentrations in this layer across the site, just slightly elevated above EIL criteria (95%UCL of 33 mg/kg) that follow a statistical normal distribution pattern (no outliers indicating contamination).

10.5.3 South-eastern remediated corner

The firm brown clay beneath the thin loam capping layer on the south-eastern corner of the site, is thought to be a result of the historical excavation of 0.5 m of contaminated fill material and replacement with 0.3 m of "clean soil".

Laboratory analysis confirms visual field observations of contamination, reporting PAH concentrations ranging between non detectable to 75 mg/kg, and B(a)P concentrations ranging between non detectable to 5.9 mg/kg. The concentrations are generally lower than the loam and sandy clay capping layer thus corresponding to field observations that this clay does not form part of the capping layer.

There are no elevated sulfur compounds, cyanide or heavy metal concentrations noted for this stratigraphic unit. There were a few minor TPH (>C_{10}-C_{36}) concentrations but nothing above Tier 1 criteria. The following exceedances of Tier 1 criteria were noted:

- two samples reported total PAH and B(a)P concentrations that exceed HIL E criteria.

10.6 Gasworks waste

10.6.1 Organics

These layers were characterised in the field as layers of re-worked natural PMS and BGS mixed with visible mixed gasworks waste of spent oxides, coke, ash, clinker, slag and solid to semi-viscous tar. In a number of sampling locations the gasworks waste was noted to exist as a separate distinct layer.

For Gasworks Park, laboratory analysis reported total PAH concentrations ranging from 15 mg/kg to28,597 mg/kg, B(a)P concentrations ranging from 1.1 mg/kg to 1,040 mg/kg, and naphthalene concentrations ranging from non-detectable to 6,600 mg/kg.

TRH (>C_{10}-C_{16}) and TRH (>C_{16}-C_{34}) concentrations ranged between non-detectable and 8,230 mg/kg and 29,100 mg/kg, respectively in Gasworks Park.

For South Port Nursing home laboratory analysis reported total PAH concentrations ranging between 15 mg/kg to 1,724 mg/kg, B(a)P concentrations ranging between 1.1 mg/kg to 97.6 mg/kg and naphthalene concentrations ranging between non detectable to 28.9 mg/kg. TRH (>C_{10}-C_{40}) concentrations ranged between non-detectable and 6,830 mg/kg

The BTEX impacts are minimal, isolated and associated with much greater contamination of other organic CoPC including PAHs and TRH (>C_{10}-C_{34}). In particular elevated concentrations of benzene of 13.7 mg/kg and 21.6 mg/kg were noted in borehole BH11 (0.5-0.6) and test-pit TP7 (1.75-1.8), respectively. These samples also reported elevated volatile TPH (C_6-C_9) concentrations which are likely to be BTEX compounds. All concentrations are below the adopted Tier 1 criteria.

The 95% UCLs for BaP, total PAH and TRH >C_{16}-C_{34} in gas works waste on Gas Works Park exceeded Tier 1 criteria (Table 7). For the South Port Nursing home site, BaP and total PAH 95% UCLs exceed criteria (Table 8).

10.6.2 Heavy metals and cyanide

There were elevated cyanide and heavy metal concentrations noted for this stratigraphic unit, mostly above EILs for the latter except for:

- lead exceeded HIL A criteria in one sample on Southport Nursing home and HIL E criteria in two samples on Gasworks Park; and
- cyanide exceeded HIL A criteria in one sample on Southport Nursing home and HIL E criteria in one sample on Gasworks Park.

Laboratory analysis reported total cyanide concentrations on Gasworks Park ranging between non-detectable to 4,240 mg/kg, and lead concentrations ranging from non-detectable to6,720 mg/kg. The 95%UCL for the gasworks waste fill layers is 448 mg/kg for lead and 10,669 mg/kg for total cyanide. Total cyanide exceeds the adopted HIL E and EIL criteria.

Laboratory analysis reported total cyanide concentrations on Southport Nursing home ranging from non-detectable to 676 mg/kg, and lead concentrations ranging from non-detectable to 686 mg/kg. The 95%UCL for the gasworks waste fill layers for lead and total cyanide could not be calculated (Table 8).

Arsenic concentrations ranged from non-detectable to 136 mg/kg on Southport Nursing home or 63 mg/kg on Gasworks Park. The 95%UCL for the gasworks waste fill layers, is 97.9 mg/kg for South Port Nursing Home and 22.2 mg/kg for Gasworks Park, both of which are below adopted Tier 1 health criteria, however both scenarios exceeds the EIL criteria.

Copper concentrations ranged between non-detectable and 113 mg/kg on Gasworks Park or 456 mg/kg on South Port Nursing home. The 95%UCL for the gasworks waste fill layers, is 292.6 mg/kg for Southport Nursing Home and 24.8 mg/kg for Gasworks Park, both of which are below adopted Tier 1 criteria.

All 95%UCL for zinc, nickel and mercury were below adopted Tier 1 criteria for both Southport Nursing home and Gasworks Park.

The elevated heavy metals and cyanide (and sulfate, refer to Section 10.6.3 below) identified in boreholes BH4 and BH18, and test-pit TP20 are associated with spent oxides in the gasworks waste. Spent oxides were noted in 12% of sampling locations (BH4, TP18, TP20, TP4 and TP6) spread out across the site, most likely due to the heterogeneity of the gasworks waste. The detected spent oxides represent only 12% of sampling locations undertaken at the site. However, we acknowledge that spent oxides may be present in other locations within the gasworks fill due to the heterogeneity of the material onsite. However, this can be managed by the proposed remediation options either to re-cap the entire site or apply the other mitigation measures detailed in the RAP.

10.6.3 Sulfur and Sulfate

A total of 28 samples collected across the stratigraphic layers were submitted for sulfate, sulfide and total sulfur laboratory analysis. Of these samples eight were identified as containing elevated concentrations of sulfur compounds, all of which were collected from fill material impacted with gasworks waste.

Total sulfate was analysed using two methods, the Calcium Phosphate Soluble method recommended in NEPM (1999) and total sulfate by ICPAES. Results from the former method are lower as the method is less stringent in sulfate extraction as it accounts for bioavailable sulfate rather than total sulfate. Calcium phosphate soluble sulfate is therefore used when assessing against Tier 1 ecological criteria (NEPM EIL) of 2,000 mg/kg. Total sulfate concentrations by ICPAES methods are more accurate of total sulfate and used when assessing the beneficial use of 'Buildings and Structures' against the Tier 1 criteria of 2,000 mg/kg (AS3600-2009 *Concrete Structures*):

- calcium phosphate soluble sulfate reported a maximum concentration of 15,500 mg/kg (BH4) and seven samples reported concentrations exceeding EIL; and
- total sulfate reported a maximum concentration of 213,000 mg/kg (TP18) and eight samples reported concentrations which exceeded Tier 1 criteria for protection of "buildings and structures".

The percentage of total sulfur occurring as sulfides was analysed with results ranging from non-detectable to 1.84% This was calculated by converting total sulfur as %S to mg/kg and directly comparing this to the sulfate concentration (as a percentage). It is highly likely that sulfate is generated as a result of oxidation of sulfides in soils rather than the application of fertiliser with high sulfate content. Borehole BH4 is located near the historic sulfate store, which may account for some of the sulfate in this location.

To confirm the presence of organic vs inorganic sulfides, Environmental Earth Sciences converted the reported total sulfate to inorganic sulfide in consideration of the moisture content and reported total sulfur and then compared this with the reported sulfide (%). The summary of results has been presented in Tables 4 and 5. The results of the calculated inorganic sulfides were generally the same as the laboratory reported sulfides with a very minor difference (less than 10%) with the exception of two soil samples [TP20(0.8-0.9) – 68% difference and TP7(1.75-1.8) – 25% difference], suggesting that the majority of the reported sulfides were inorganic and can be considered as being representative of inorganic sulfur content for PASS assessment

It is apparent that oxidation of sulfides has already occurred to some degree given the high sulfate concentrations, with complete oxidation thought to have occurred in borehole BH3, and at TP11 (0.5-0.6m) and TP18 (0.7-0.8m), which have non-detectable sulfides but high sulfate concentrations. The soils being investigated also form part of the unsaturated zone above the water table and have soil moisture of <30% indicating that oxygen is present within the profile. It is important to note the positive correlation between detectable sulfide content and soil moisture.

The source of the sulfide/sulfate is likely to have come from one or both of the following sources:

- sulfides in fossil fuels: Australian coal is typically very low in sulfide content and the historical pyrogenic gasworks processes would remove sulfur from gasworks waste/ residue (ash, coke, slag, clinker) and vent as hydrogen sulfide gas (H_2S). This vented H_2S, however may have been captured by the spent oxides which were then buried on-site; and/or
- naturally occurring iron sulfides (mainly pyrite) and/or their precursors contained in the Port Melbourne Sands. It is also possible that some of the imported fill material at the site is Coode Island Silts (CIS), which are known to have both high sulfide (pyrite) and carbonate (calcium carbonate) concentrations.

The most elevated sulfate concentrations were noted in conjunction with spent oxides in borehole BH4, and test-pits TP18 and TP20. Test-pit TP18 (0.7-0.8) reported the maximum concentration of total sulfate, yet reported no detectable sulfides indicating sulfides had all oxidised to sulfate. Test-pit TP20 (0.8-0.9) reported the highest percentage of sulfur as sulfides at 1.84%.

Based on the photos and borelogs there is also strong evidence that sulfides may have at least partially originated from naturally occurring sulfides. A number of elevated sulfide/sulfate concentrations are associated with suspected reworked PMS material mixed with gasworks waste layers in BH4, BH5, TP7, TP18 and potentially TP20.

Regardless of the origin, the sulfides/sulfates at the site need to be evaluated with respect to their potential to generate sulfuric acid as the sulfides oxidise to sulfate when exposed to oxygen through soil disturbance or lowering of the watertable. This chemical process has implications for impacts to human and ecological health and the integrity of subsurface structures.

The preliminary risk assessment undertaken in Section 5.4.1 of this report indicates that the natural and disturbed natural soils may be prone to sulfide oxidation due to CASS occurrence.

The second stage of assessment consists of the field inspection, soil sampling and laboratory chemical analysis. The outcomes of this assessment confirm that:

- the site soil profile consistent with a Recent (Holocene) formation likely to contain elevated levels of sulfides within a clay/silt/sand matrix, particularly reworked PMS;
- water tables are not high, being located at 8-9 m BGS and there is no evidence of a swamp or estuarine environment (e.g. mangrove, *Melaleuca spp*., *Casuarina spp*, salt tolerant vegetation species, or acid tolerant species such as *Phragmites*);
- the soil was not noted to exude any sulfur (rotten egg gas) odour nor was shell or other carbonaceous material observable in the soil profile;
- in general field soil pH ranged between pH6.0 to pH8.5 which is not indicative of actual acid sulfate soils (AASS) or potential acid sulfate soil (PASS) with the following exceptions:
  - pH4 in natural material samples (PMS/BGS) for BH6 (1.7-1.8), BH8 (1.4-1.5), and BH9 (1.4-1.5);
  - pH4.5 in natural material samples (PMS/BGS) for TP15 (2.4-2.5) and TP16 (2.0-2.1), and in fill material samples for TP17 (1.0-1.1), TP20 (0.6-0.7), and TP20 (0.8-0.9);
- anecdotal evidence that growing grass was difficult and still occasional bare patches, however this could be due to elevated concentrations of other CoPC such as PAHs; and
- the percentage of total sulfur occurring as sulfides ranged from non-detectable to 1.84%.

To determine if further assessment of sulfides in soil is required, the action criteria from DSE (2010) have been referenced (Table 11). These criteria are dependent on the sample texture and the volume of potentially acid sulfate soil (PASS) that exists at the site.

It should be noted that estimating the acidity on the basis of total S%, sulfides and sulfate only provides a rough idea of the sulfur based acidity and does not include other salt or metallic compounds that contribute to the overall net acidity.

The results in Table 12 indicate that gasworks waste layers and potential underlying natural material are sufidic and have the potential to generate sulfuric acid if exposed to oxygen through soil disturbance or lowering of the watertable.

The soil classification would need to be confirmed through further soil testing including using the Chromium Reducible Sulfur (CRS) method to verify that the un-reacted sulfides are not false positives and assess the acid neutralising capacity (ANC) and retained acidity (S_{NAS}) if the soil is to be disturbed. However, this can be managed by the proposed remediation options either to re-cap the entire site or apply other mitigation measures detailed in the RAP and therefore a further assessment is not considered to be essential. However, consideration regarding PASS will have to be considered as part of the updated contaminant management plans.

10.7 Impacts within natural material

10.7.1 Inorganics

There are no elevated sulfur compounds, cyanide or heavy metal concentrations noted for natural material across both Gasworks Park and South Port nursing home with the following exceptions:

- three samples reported arsenic concentrations in excess of EIL;
- one sample reported copper concentrations in excess of EIL; and
- one potential CASS sample in natural material at test-pit TP26 (1.8-1.9), refer to Section 10.6.3 above.

The 95%UCL for all heavy metals are below all adopted Tier 1 criteria and it is considered likely that the arsenic concentrations are natural background levels characteristic of the Brighton Group Sediments.

10.7.2 Organics

The underlying natural material does not appear to have been significantly impacted by the overlying gasworks waste with most of the 14 samples analysed reporting non-detectable concentrations of TRH ($>C_{10}$-C_{40}), B(a)P and total PAHs. All detectable concentrations were below adopted Tier 1 health criteria and therefore 95% UCL were not calculated.

10.8 Vertical delineation of impacts

Impacts from gasworks waste were not delineated vertically due to refusal in fill material at 12 sampling locations. As the objective of this investigation was to assess the extent and coverage of any capping materials at the site, the focus was on the sampling and laboratory analysis of soil samples from the surface fill material. Consequently samples collected from the underlying material in a number of sampling locations were not submitted for laboratory analysis. Natural material was not reached in test-pits TP7 and TP23 due to depth of fill, although the deepest fill sample collected from each location did not report any Tier 1 exceedances.

It is noted that the vertical delineation of impacts was not undertaken during the soil capping investigation. However, this can be considered not significant at this stage as the residual contamination can be managed by the proposed remediation options either to re-cap the entire site or apply other mitigation measures detailed in the RAP.

10.9 Identified chemicals of potential concern

10.9.1 Heavy metals and cyanide

Although there are some isolated samples that report heavy metal concentrations in excess of EILs, and HIL A for lead and total cyanide, the 95%UCL indicate that only total cyanide is found to exceed the health criteria. However, this can be considered not significant of concern as it's not leachable and not considered to be widespread. In addition, the residual contamination can be managed by the proposed remediation options either to re-cap the entire site or apply other mitigation measures detailed in the RAP.

10.9.2 Sulfur compounds

Sulfur containing compounds are not generally directly toxic to human health and ecosystems but rather the oxidation of metal sulfides to sulfate results in the production of acid and salinity. This issue has been addressed in Section 10.6.3 above and is not considered further in this investigation.

10.9.3 TRH

The volatile TRH (C_6-C_{10}) fraction is comprised partly of BTEX compounds as discussed in Section 10.9.5. TRH (C_6-C_{10}) was detected in five samples, in the Gasworks Park only, however were below the adopted health criteria.

The semi-volatile components of TRH (C10-C16, C16-C34 and C34 to C40) fractions generally comprised of aromatic hydrocarbons and were detected below the adopted guidelines with the exception of the following:

Southport Nursing Community

- three of 27 soil samples exceeding TRH(C_{10}-C_{16}) fractions;
- four of 27 soil samples exceeding TRH(C_{16}-C_{34}) fractions; and
- one of 27 soil samples exceeding TRH(C_{34}-C_{40}) fractions

Based on the 95% statistical analysis, only TRH (C_{16}-C_{34}) exceeded the criteria which can be considered a large proportion of which are likely to be PAHs. This elevated concentration can be dealt with as part of the proposed RAP.

Gasworks Site

- three of 105 soil samples exceeding TRH(C_{10}-C_{16}) fractions;
- twenty seven of 105 soil samples exceeding TRH(C_{16}-C_{34}) fractions; and
- twelve of 105 soil samples exceeding TRH(C_{34}-C_{40}) fractions

Based on the 95% statistical analysis, only TRH (C_{16}-C_{34}) and TRH (C_{34}-C_{40}) exceeded the criteria which can be considered a large proportion of which are likely to be PAHs. These elevated concentrations can be dealt with as part of the proposed RAP.

10.9.4 PAH

PAHs (including naphthalene, BaP and total PAH) are the main CoPC detected on this site, in particular B(a)P which is a known carcinogen. Naphthalene was found to exceed the NEPM HIL A criteria, but not the Tier 1 criteria for direct contact in the Southport site. There were two exceedences of the Tier 1 criteria at the Gasworks Park at TP7(1.75-1.8) and BH11(0.5-0.6).

Furthermore, based on the calculated 95%UCL, total PAH were found to exceed the adopted criteria at both the Southport and Gasworks Park sites. These CoPC require either further risk assessment or to be managed as part of the proposed remediation options at the site.

10.9.5 BTEX

Although there were detectable concentrations of BTEX compounds, they were all below Tier 1 criteria, and only detected in samples heavily contaminated with PAHs and TRH s, the risk assessment of which will decide whether these areas will require remediation. Therefore it was deemed unnecessary to also conduct a risk assessment of BTEX compounds.

11 RISK ASSESSMENT

11.1 Framework for the risk assessment

In order to target the health and ecological risk assessment to the most important chemicals of concern and exposure routes we intend to adopt a hierarchical approach. This will include three tiers of assessment in increasing levels of effort and expense as follows:

- **Tier 1:** This initial level of assessment is to utilise published criteria from reputable sources. The initial Tier1 screening criteria used in this investigation is outlined in Section 6.2 of this report. In instances where the level of contamination is less than these criteria then there is no need to assess the risk further or develop site specific criteria;
- **Tier 2:** If substances fail the Tier 1 criteria then an adjustment may be made to the criteria based on assessment of the assumptions used in development of those Tier 1 criteria; and
- **Tier 3:** For some substances the most appropriate method of defining a suitable site criteria will be to model the fate and transport mechanisms between the source of the contaminant and the receptor that is to be protected.

11.2 EnHealth Model

EnHealth 2004, *Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards* presents a national approach to health risk assessment. The EnHealth model includes four key phases of assessment:

- Issue Identification: This stage provides crucial background and reasoning for carrying out the risk assessment. It essentially sets the context for the risk assessment through identifying: what the concern is, what is causing the concern, why the concern is an issue, and whether risk assessment is an appropriate means of addressing the issue;

Hazard assessment: This phase includes two components; hazard identification and dose response assessment. The objective of the hazard assessment is to determine what the likely adverse health effects might be and the timeframe and severity of those effects. This phase is largely dependent on literature research;

- Exposure assessment: This provides an assessment of the likely frequency, extent duration and character of exposure to the agent of concern and relies of assumptions and modelling where actual data is not available; and
- Risk Characterisation: The final step in the risk assessment process is to provide a qualitative and/or quantitative estimate of the nature, severity and potential incidence of effects based on the hazard assessment and the exposure scenarios. The risk characterisation should also assess uncertainties in the conclusions.

11.3 NEPC model

11.3.1 Health risk assessment

In addition to the EnHealth approach, Section 4 of Schedule B(4) of *National Environment Protection (Assessment of Site Contamination) Measure* (NEPM, 1999), provides guidance for risk assessment and states that "the process of risk assessment is intended to…determine a tolerable level of contaminants that can remain in place with adequate protection of public health" amongst other objectives.

Similarly to the EnHealth approach Schedule B(4) of NEPM (1999) refer to a risk assessment model, which comprises:

- problem or issue identification;
- data collection and evaluation of the chemical condition of the site, including identification and quantification of the chemicals of potential concern (CoPC) and their lateral and vertical extent;
- toxicity assessment of identified CoPC;
- exposure assessment for potential receptor population/s on or near the site via source-receptor pathway/s (receptor identification); and
- risk characterisation.

11.3.2 Ecological risk assessment

Schedule B(5) of NEPC (1999) states that "Ecological Risk Assessment (ERA) is a set of formal, scientific methods for defining and estimating the probabilities and magnitudes of adverse impacts on plants, animals and/or the ecology of a specified area posed by a particular stressor(s) and frequency of exposure to the stressor(s)". It defines the EIL as the concentration of a contaminant above which further investigation is required and an Ecological Response Level as the concentration of a contaminant above which some response is needed to protect ecological values.

The NEPC framework for an ERA also comprises a staged process of three levels of complexity though slightly different to that used in this assessment. The levels of an ERA and their components are summarised below:

- Level 1 – Comparison of existing soil EILs with contaminant concentrations from the area of study;
- Level 2 – A desktop study to increase the detail of components of the ERA and the derivation of site specific EILs; and
- Level 3 – Detailed site specific information gathered and the derivation of site specific EILs taking into account the local ecological values at the site.

The level of assessment required depends on various factors such as “the statutory requirements, the type of contaminant, the degree of contamination, the availability of appropriate receptors, exposure and toxicity data, the sensitivity of ecological values and the economic value of the site”. Assessment at a higher level is based on knowledge gained from the previous level.

Specifically this study includes components that would fall within Level 1 or Level 2 ERA as defined in NEPC 1999. That is, no site specific biological surveys were conducted (which forms part of a Level 3 ERA).
As NEPC 1999 does not report Tier 1 ecological criteria for TPH/TRH or PAHs, values presented in Verbruggen *et al*. (2001) (RIVM 2001) have been referenced for PAH compounds, whilst the direct contact human health value for the TRH >C_{16}-C_{34} aromatic fraction range (2,520 mg/kg) has been used based on the absence of other criteria and the assumption that fauna are a more sensitive receptor than site flora. The BaP value from RIVM (2001) is 7 mg/kg, whilst naphthalene is 17 mg/kg.

Schedule B(5) identifies the basic five component which form part of an ERA, irrespective of the level to which the assessment is conducted:

- problem identification;
- receptor identification;
- exposure assessment;
- toxicity assessment; and
- risk characterisation.

11.4 Issue identification

Due to the identified chemicals of potential concern (CoPC) at the site that exceed Tier 1 published criteria (discussion and summary provided in Section 10.9 – PAHs and TRH >C_{16}-C_{34}) in soil, it can be concluded that the site has been impacted by past activities and some degree of remediation and/or further management and monitoring may be necessary for continued residential and open space land-use.

11.4.1 Human health

Where we deviate from published criteria in developing site specific health based remediation criteria we have considered the following:

- the potential onsite users, both future and present:
  - direct exposure to soil under a variety of scenarios and taking into consideration the chemical form of the substances; whilst
  - exposure to volatile substances via migration of vapour and accumulation in buildings (and in open areas and trenches) has been addressed, and is also covered under a separate vapour investigation;
- as impacted groundwater is captured by the sewer system (Environmental Earth Sciences, 2011b version 3), it has not been considered in this risk assessment, except as soil impacts that act as a source of ongoing groundwater contamination.

11.4.2 Potential ecological receptors

There is a perceived possibility that chemicals of potential concern could leach out of the soil at sufficient concentration to have an adverse effect on protected environmental values for soil, its pore water, and exchange positions associated with vegetation growth (phytotoxic effects). As groundwater impacted from soil contamination is captured by the surrounding sewer system, managed under a Trade Waste Agreement, and does not appear to discharge to Port Phillip Bay, the environmental values for groundwater and surface water are not considered relevant for this assessment.

Once available, contaminants may be subject to uptake by fauna through dermal contact or ingestion of contaminated plants. Therefore the risk assessment for soil will evaluate the results of leachability testing to determine whether CoPC in soil are sufficiently available to potentially cause phytotoxic effects on vegetation.

This methodology will ensure that all of the required Victorian SEPP land beneficial uses are protected:

- ecosystems (modified and highly modified);
- human health;
- buildings and structures;
- aesthetics; and
- production of food, flora and fibre.

11.4.3 Chemicals for which further risk assessment (Tier 2 or Tier 3) is necessary

In accordance with the overarching framework (Section 11.1), where chemical concentrations to date have been below the Tier 1 criteria we do not propose to develop Tier 2 or Tier 3 criteria. Tier 1 criteria will remain as the site criteria for these chemicals.

In addition, if there are minor exceedances of Tier 1 criteria, or the instances of Tier 1 exceedance is localised and easily dealt with during remedial works, then these chemicals also will not be subject to development of Tier 2 or 3 criteria.

Table 16 provides lists of chemicals for which Tier 2 health-based assessment will be carried out for soil. The table includes a summary of the intended approach to Tier 2 modifications and rational for various chemicals or chemical classes not being subject to further assessment. However, it should be noted that Tier 2 or further risk assessment is only required if the proposed remediation options such as re-capping and/or mitigation measures cannot be applied.

11.5 Physical and chemical characteristics of Tier 2 chemicals

11.5.1 Total petroleum hydrocarbons

Hydrocarbons comprise the majority of the components in most petroleum products and are the compounds that are primarily (but not always) measured as TPH. The hydrocarbon constituents can be grouped into saturated hydrocarbons, unsaturated hydrocarbons, and aromatics.

Petroleum hydrocarbons are organic compounds comprised of carbon and hydrogen atoms arranged in varying structural configurations. Generally, they are divided into two families, aliphatics (saturated hydrocarbons) and aromatics (unsaturated hydrocarbons). Aliphatics are further divided into three main classes, alkanes, alkenes and cycloalkanes.

Aliphatic hydrocarbons are the primary class of compounds found in petroleum and most petroleum products. They are comprised of single C-C bonds (with all other remaining bonds saturated with H atoms). TPH speciation undertaken on eleven impacted samples (Section 10.3) indicate that only aromatic hydrocarbons are present on the site, and are therefore the focus of this risk assessment. Aliphatic hydrocarbons are not considered any further.

Aromatic compounds are a special class of unsaturated hydrocarbons. These compounds are based on one or more benzene rings as structural components. The benzene ring contains six carbons. Each carbon in the ring binds with one hydrogen atom, not typically shown in structural diagrams. Single benzene ring structures are known as monocyclic aromatic hydrocarbon (MAHs). The benzene molecule can have one or more hydrogens substituted with side chains resulting in alkyl benzenes, or there may be two or more aromatic rings fused together resulting in PAHs, which are discussed further in Section 11.5.2 below.

When petroleum products are released into the environment, changes in product composition take place. Collectively, these changes are referred to as weathering. The main weathering processes are dissolution in water, volatilization and biodegradation. Each of the weathering processes affects hydrocarbon families differently. Aromatics tend to be more water soluble and less volatile than aliphatics. When hydrocarbons are released into the environment, the principal water contaminants are likely to be aromatics while aliphatics will be the principal air contaminants. Solubility, volatility and amenability to biodegradation of all compounds generally decrease with an increase in molecular weight.

11.5.2 Polycyclic aromatic hydrocarbons

General PAH properties

Polycyclic aromatic hydrocarbons (PAHs) are a class of organic contaminants that comprise multiple fused aromatic rings. Sixteen priority PAHs have been identified by USEPA.

PAHs are one of the most ubiquitous contaminants and occur both naturally and through anthropogenic processes. PAHs generally form through petrogenic processes, being found naturally in fossil fuels, and through pyrogenic processes, either as gas condensates from the heating of fossil fuels (e.g. those associated with tar and creosote) or as pyrogenic residues from the incomplete combustion of carbon based materials (such as those associated with coke and ash).

Table 18 summarises physical and chemical characteristics of the key PAHs. In general PAHs are denser than water (with the exception of acenaphthylene) with low to very low solubility in water. PAHs have high Koc values indicating they have a high affinity with soil organic matter. Volatility varies widely with naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene and anthracene considered to be volatile substances and the remaining being non volatile. A substance is defined as volatile if it's Henry's Law Constant (H) is >1.0 x 10^{-5} atm-m^3/mol and it has a molecular weight <200 g/mol (US EPA 2004).

Source identification PAH fingerprinting methodology

The source of PAHs in the environment has a strong bearing on the bioavailability of the PAHs. Table 17 (from Mulvey and McKay, 2006a) provides a classification system for types of PAH bearing materials based on the source type. It explains the various characteristics of those sources, the chemical bonding mechanisms and the toxicity risk in the form of the Bioavailable Toxicity Equivalence Factor (BTEF). PAHs "tend to strongly adhere to soil" (Mulvey and Elliot 2000), with bonding dependent upon whether they are introduced to the soil as a liquid or a solid (Mulvey and McKay 2006b). This is also true for other organic compounds such as TPHs and phenols.

PAHs added as liquid bind strongly within the structure of soil and organic matter, residing within macro- (>50 nm), meso- (2-50 nm) and micro-pores (<2 nm), with increased strength of adsorption occurring over time. Once adsorbed, desorption is only readily possible from macro- and some meso-pores (Mulvey and Stuckey 2006). Organic matter holds PAHs in soil by four different bonding types: free; fast diffusion; slow diffusion; and specifically held (i.e. never released).

Liquid PAHs are able to displace water and form co-valent bonds with interstitial cations within the clay lattice, a process that can occur quickly but that is only slowly to sparingly reversible. Desorption from clay can be assisted by rehydration by chemicals such as surfactants (Mulvey and McKay 2006b). Solid PAH compounds (e.g. ash, coke, charcoal, clinker, activated carbon), while containing pores, do not readily react with soil or organic matter but provide adsorption sites for liquid PAHs (and other organic compounds). Coke and charcoal are reported to have very few micro-pores (Mulvey and Stuckey 2006). Hence, liquid PAHs (condensates) are generally more toxic than solid PAH structures (residues).

Primary gas condensates (tar, benzol, naphtha oil) and secondary gas condensates (material collected in spent oxides & ammonical liquors) are usually present at elevated concentrations in soil (100 to 50 000 mg/kg), are available, toxic and readily bioremediatable. In contrast pyrogenic residues such as activated carbon, coke, clinker, charcoal, cinders and ash contain PAHs that may also be at high concentrations, but are immobile, unavailable, non toxic and not bioremediatable due to being chemically and physically held within a vitrified carbonaceous and siliceous matrix.

Results of chemical fingerprinting

As discussed in Section 10.2 we have undertaken PAH chemical fingerprinting of the samples that fail the Tier 1 site criteria to assess their bioavailability.

Outputs from the PAH fingerprinting are presented in Table 15 and Appendix F. Nearly all samples analysed reported a PAH source of ash, coke and/or tar consistent with Gasworks waste. The sole exceptions were PAH from spent oxides (still Gasworks waste) in borehole BH4 and test-pit TP20.

In most samples there appears to be a mixed signature, which indicates multiple sources. The presence of other hydrocarbons (TPH) may make some of the PAHs more available to the extractant during testing and/or the weathering of PAHs may have altered the chemical signature. A mixed signature, however, is consistent with field observations and anecdotal evidence of disposal of mixed gasworks waste

The process of signature analysis does show that PAH containing materials are likely to have mixed bioavailability as they are sourced from ash, coke, clinker and tar.

It should be noted that without doing a further assessment such as bioavailability testing there will be insufficient justification for this approach. Further, as the PAH ASLP analysis was conducted outside the recommended holding times, the calculated BF may be higher. Environmental Earth Sciences is of the opinion that this calculation can still be considered as a valid screening tool, however further assessment is required to provide greater certainty. However, as the proposed remediation options are to either re-cap the entire site and/or by applying other mitigation measures, then the uncertainty of this approach can be dealt with as part of the proposed remediation options (such as additional capping and/or other mitigation measures).

11.6 Hazard (toxicity) assessment

We have carried out a toxicity assessment for each of the identified CoPC. The information is intended to be of an introductory level only. This is considered sufficient for this risk assessment as we do not intend to modify the toxicity components of the compounds, just the exposure scenarios and bioavailability based on site specific data.

The toxicity assessment for the CoPC in relation to this site (TRH and PAHs) has been based on published and peer reviewed data for impacts on human health and the environment. Further detail on chemical toxicity is provided in the references cited in Section 15 of this report.

Detailed discussion has not been included in this assessment due to the fact that ecological and health risk is focussing on adjusting existing criteria based on site specific bioavailability or exposure scenarios rather than deriving new criteria based upon baseline studies.

11.6.1 TPH

An estimate of acceptable daily intake (ADI) levels of chemicals over an extended period of time (i.e. lifetime) without suffering deleterious health effects is quantified as milligrams per kilogram of body weight that can be safely consumed per day (mg/kg-bw/day). For air toxicity (including dust inhalation), reference concentration (RfC) is the measure of non-cancer hazard, which is usually expressed in micrograms per cubic metre of air (or dust) inhaled (µg/m^3). RfCs can be converted to ADI based on a 70kg adult inhaling 20 m^3/day.

For TRH >C_{16}-C_{34} aromatic fractions, the dust inhalation ADI is 0.057 mg/kg/day, the oral ingestion ADI is 0.03 mg/kg/day, and the dermal contact ADI is 0.024 mg/kg/day.

11.6.2 Polycyclic aromatic hydrocarbons

Humans

As with many toxic substances, the health effects of PAH's is largely dependent on the length, duration and pathway of exposure. The health effects of short term acute exposure to PAH's remains relatively unknown, and most studies of the compounds have been conducted following prolonged occupational exposure. In these cases, inhalation has caused eye irritation, nausea, vomiting, diarrhoea and confusion. Long term exposure to PAH's is likely to cause cataracts, kidney and liver damage and jaundice.

Of the 16 PAHs classified as priority pollutants by the US EPA, benzo(a)pyrene (BaP) is perhaps one of the most commonly encountered on polluted sites. Short term health effects of exposure to BaP can include skin and eye irritation, vomiting and nausea. Long term effects in animal studies have shown that BaP can have carcinogenic effects, especially in the lungs and stomach. Toxicity studies in humans have also noted higher cancer rates in those exposed to BaP in the workplace, lung abnormalities and asthma are also common effects however these studies are not definitive as people are usually exposed to other unknown carcinogens.

As with other toxic substances, young children, the elderly and pregnant women have shown a higher susceptibility to effects of exposure. For children this can be due to a smaller body mass and hence lower tolerance, while declining organ function in the elderly can reduce their tolerance. PAH's are readily absorbed and easily transported through the bloodstream, putting unborn children at a particular risk if the mother is to be exposed to such substances. One of the greatest sources of exposure to PAH's is the inhalation of tobacco smoke, although they are often found in soils and can be ingested by children.

For the "direct contact" pathways (oral ingestion, dust inhalation and dermal contact) the toxicity of PAHs to humans is usually quantified by extrapolation from the BaP ADI, which is 8E-05 mg/kg-bw/day. Each of the other 15 PAH compounds are assigned a BaP Toxicity Equivalence Factor (TEF), and the sum of the 16 BaP TEFs is the BaP Toxicity Equivalence Quotient (TEQ).

Fauna

PAHs are generally toxic to animals, having carcinogenic effects and causing a variety of defects in both birth and reproductive systems, respiratory systems and major organs. Insufficient data is available for the acute and chronic effects of PAHs on land animals however they are generally known to have a highly acute toxic effect on aquatic animals and birds.

Flora

Phytotoxicity is largely dependent on the PAH and specific plant in question. Studies have shown that phytotoxicity has occurred in soils contaminated with PAHs such as pyrene, naphthalene and phenanthrene, and the observed phytotoxicity increased when the number of rings in the hydrocarbon rings increased. To date, limited data is available on the phytotoxic effects of PAHs however it is generally considered to be rare, certain plants are able to metabolise PAHs and others can contain substances which can protect against the effects of PAH toxicity (Baek, *et al*. 2004 and Kapustka, 2004)

Based on anecdotal evidence of the difficulties establishing grass and vegetative cover on the site in the 1990's, PAH concentrations at the site may be sufficient to cause phytotoxicity.

11.6.3 Possible effects on ecology and the environment

Direct deleterious effects to ecosystems occur when vulnerable systems are exposed to toxic compounds. This can result in virtual eradication of some important species within the primary food chain. As vulnerable species are threatened by toxic effects of contamination this pressure is also exerted up the food chain to less sensitive organisms that nevertheless rely on the presence of organisms in the lower tiers of the food chain.

The food chain can also be threatened by bioaccumulation of many compounds. These may not be at toxic levels to species at the bottom of the food chain but due to concentration within the food chain, can be expressed as chronic effects in organisms at the top of the food chain.

Indirect effects of contamination on the environment can occur when ecological changes result in other environmental issues developing. For example if a contaminant exists at phytotoxic concentrations few if any plants may grow on that portion of the site. These areas then the lack vegetation and are vulnerable to erosion – thereby transporting contaminated sediment to other ecosystems where further direct or indirect effects on the environment may occur.

11.7 Exposure assessment for human health

The exposure assessment has focused on the future use of the site, its consequent potential exposure to the most sensitive receptors on the site (assumed to be a 2.5 year old child, weighing 14 kg), and the ecological environment surrounding the site.

11.7.1 Exposure pathways

The two predominant transport mechanisms for TRH and PAHs that are directed by a chemical's partitioning in the sub-surface soil are leaching to groundwater and volatilization to air. Given the TRH and PAHs on-site are heavier compounds (primarily >C_{16}-C_{34}) from tar, coke, and ash it is expected the primary transport mechanism will be leaching to groundwater and not volatilisation, with the possible exception of naphthalene.

The risk of potential vapour generation from contaminated soil and groundwater and accumulation within buildings onsite has been determined to be a potential risk at the South Port nursing home site for naphthalene only. Whilst concentrations of naphthalene detected in soil comply statistically to criteria for extrapolation to indoor air (see Table 10), some individual samples do exceed the criteria (see Table 4), and sub-slab sampling was not undertaken.

For this reason, indoor air quality (IAQ) monitoring was undertaken in 13 locations across Gasworks Park and Southport nursing home between 17-19 July 2011, and 29 January and 1 February 2012. Please refer to Environmental Earth Sciences report titled "Indoor Ambient Air Vapour Investigation at Former South Melbourne Gasworks" (2012) for further details. The conclusion of the report indicates that any sub-surface vapour intrusion at the site appears to be negligible and unlikely to result in a chronic unacceptable health risk to building users.

The open space area of Gas Works park has been assessed for potential outdoor exposure to vapours, and the risk has been found to be acceptable for both recreational visitors and trench workers (after Friebel and Nadebaum 2011 - adjusted HSLs). The criteria for direct contact for the open space portion of the site is therefore also protective of vapour exposure, and as all volatile chemicals comply with this criteria, the risk is deemed acceptable. Note that the dust inhalation direct contact pathway is considered insignificant and will not be considered further.

As any on site groundwater impacted from soil contamination is captured by the sewer system as it flows off-site (Environmental Earth Sciences, 2011b version 3), it has not been considered in this risk assessment. Therefore, only direct contact with soil is considered relevant.

11.7.2 Gasworks Park

Potential receptors of Gasworks Park include:

- office workers in Gasworks Park Administration area and gatehouse building, in addition to café workers in Gasworks café;
- artists in studio buildings and staff/participants in classes and workshops within the Former Gasworks buildings;
- performers and site visitors for performing arts in the Theatre area;
- recreational uses of open space parkland (includes festivals and weekly farmer's market); and
- site maintenance and construction workers.

These receptors are all protected under an open space parkland exposure scenario, as long as "direct contact" to the gasworks waste layer does not occur. As this site is managed, it is expected that public exposure should not occur, and that site maintenance/ construction activities will control workers exposure via OHS procedures (particularly personal hygiene). See Section 11.7.4 below for a further discussion on site capping mitigation.

11.7.3 SouthPort nursing home

Potential receptors of SouthPort nursing home include:

- aged care residents,
- aged care workers;
- visitors to the nursing home; and
- site maintenance workers, including gardeners.

These receptors are all protected under a standard residential exposure scenario.

11.7.4 Site capping mitigation

Further to the above, ANZECC (1992) states "well maintained grass will cause a substantial reduction in exposure to contaminants in surface soil and may therefore provide an effective barrier in particular situations. The reduction in exposure from well-maintained grass is at least 80%" (i.e. an exposure ratio from a standard residential scenario of 0.2, or from a standard open space ratio of 0.5 to 0.1). A grass cover exists across most of Gasworks Park and SouthPort Nursing home, except for the pathways, buildings and the administration area.

The grassed parts of the site have been identified as being covered by a minimum 0.1 metres of loam cap with the remainder of the site covered by 0.2 metres of sandy gravel (pathways) or sealed beneath concrete or buildings. A sandy clay cap also exists in the central area of the site, however it and parts of the overlying loam layer (e.g. borehole BH8) have been cross-contaminated with impacted subsurface soils during the capping process.

Nevertheless the capping layers have resulted in significantly less severe impacts in the surface layers than is reported for the underlying gasworks waste layers.

Based on this, the proposed exposure ratio for soil in open space that is covered by vegetation or gravelly sand, and/ or an average 0.3 -0.5m thick 'cap' is 0.1, and for soil in the residential area is 0.2.

11.7.5 Background exposure

PAHs are a large group of organic compounds with two or more fused aromatic rings made up of carbon and hydrogen atoms. PAHs are formed from incomplete combustion of organic materials such as the processing of coal, crude oil, combustion of natural gas, refuse, vehicle emissions, heating, cooking and tobacco smoking, as well as natural processes including carbonisation. Food is considered to be the major source of human exposure to PAH, due to their formation during cooking or from atmospheric deposition of PAHs on grains, fruits and vegetables (WHO 1998). There are several hundred PAHs, including derivatives of PAHs. The best known (and studied) is BaP, as it is a genotoxic carcinogen.

Intakes of BaP from sources other than soil have been considered by Fitzgerald (2004) to range from 0.166 to 1.6 µg/day (US EPA 1980) with intakes derived from food identified as the most significant. More detailed reviews are available on potential intakes of BaP (CCME 2008). However, background intakes are not considered in the derivation of an HIL for BaP, as a non-threshold approach has been adopted.

11.8 Pathways of exposure for ecosystems

Most of the Gasworks Park and South Port Nursing home exist as garden areas and public open space. As such, appropriate risk based criteria are required to evaluate the effectiveness of the remedial works and existing cap for the protection of surface ecological receptors (i.e. fauna and flora).

Given the site location and setting, along with existing and continuing use, ecological receptors to chemicals in soil and groundwater include (but are not necessarily limited to):

- vegetation growing on-site (native and introduced) – soil only; and
- fauna, including native and introduced, and local and transitory – soil only.

As noted previously, ecosystems at point of groundwater discharge (Port Phillip Bay) are not considered relevant as groundwater is captured by local sewer system and re-directed.

Heemsbergen *et al*. (2008) identifies four main exposure pathways from CoPC in soil to ecological receptors, which are summarised in Table 19. Based on the information presented, the exposure pathways identified as relevant to the local ecological values are direct toxicity (ingestion, plant absorption) and biomagnification, with direct contact (ingestion) likely to be the major potential pathway for fauna.

In accordance with the protocol, any Tier 2 assessment would involve modifications to the Tier 1 criteria based on leachability (used to determine bioavailability factor [BF]) and/ or exposure scenarios (exposure ratio [ER]).

$$Tier\ 2\ Criteria = \frac{Tier\ 1\ Criteria}{BF}$$ Equation 1

11.9 Risk characterisation

Following on from the above exposure and toxicity assessments, risk characterisation can be undertaken for the CoPC at this site (TRH >C_{16}-C_{34} aromatics and PAHs).

Human Health
As a result of the recent inception of NEPC (2013), which uses a cancer slope factor (CSF) and toxicity reference value (TRV) approach, rather than tolerable daily intakes (TDI), risk characterisation for BaP, total PAHs, naphthalene and BaP TEQ has defaulted to NEPC (2013, Schedule B7, Appendix A2).

For the TPH >C_{16}-C_{34} aromatic fractions, the open space exposure ratio (ER) of 0.1 is proposed to be applied for the direct contact pathway to account for reduced exposure at the ground surface (not taken into account in the original criteria derivation).

Ecological receptors
It is expected that potential faunal receptors include birds, reptiles, frogs and mammals. A greater level of exposure would be expected for small mammals, reptiles and frogs that habitat the site as they would be in regular contact with soil and would be likely to have a limited territory that could be wholly on the site. Native fauna (e.g. kangaroos, emus) have been excluded due to the location of the site. Those sensitive species identified are likely to be predominantly insectivores, whilst some species may burrow through the capping layer into the gas works waste layer. As such, dermal contact and incidental soil ingestion are expected to be the major potential exposure routes.

Ingestion of flora growing on the site by herbivores is expected to be a less significant exposure route. This is due to these species being unlikely to predominate, the shallow rooting nature of most site grasses (i.e. unlikely to extend roots into gas works waste), and the expected lower bioavailability of PAH and TPH compounds to plant uptake than direct absorption in the stomach following incidental soil ingestion and/ or dermal contact.

12 SOIL BENEFICIAL USES

Based on our discussions with City of Port Phillip (CoPP), we understand that the future land-use of both Gasworks Park is likely to remain '*Recreation / Open Space'*, and the Southport site to remain a nursing home or developed into another community use sometime in the future, classified as '*Sensitive Use – Other*' under the SEPP (2002).

12.1 Land beneficial uses

In accordance with the SEPP *Prevention and Management of Contamination of Land*, and the most likely future land use outlined above, the following beneficial uses are to be protected.

- modified and highly modified ecosystems;
- human health;
- buildings and structures;
- aesthetics; and
- production of food, flora and fibre (SouthPort Nursing home only) .

Please note that the maintenance of natural ecosystems has been considered however it is not a relevant beneficial use for this site and will not be discussed further.

12.1.1 Production of food and fibre

In consideration of the production of food and fibre, applicable sections of the SEPP *Prevention and Management of Contamination of Land* state that '*contamination of land must not: adversely affect produce quality or yield.'* Likely onsite production would be limited to the production of shallow rooting food plants (vegetable garden) and chickens on the South Port Nursing home, with no market production of food.

As there were multiple exceedances of EILs and likely some salinity and acid impacts on soil at the site, production of food, fibre and flora can be considered precluded. However, this can be managed by the proposed RAP and updated contaminant management plan.

A site specific risk assessment may be required should this beneficial use be realised as part of the upgrade of the park and topsoil, organic material or chemical amelioration may need to be added to effectively grow vegetables and other plants.

12.1.2 Maintenance of highly modified ecosystems

Modified ecosystems may include areas that have been disturbed by human activity but allow an altered ecosystem usually with a lower diversity to exist (e.g. residential allotments, bike and walking tracks). As such, species that are associated with domestic gardens (societal), significant native trees and plants that may be important to wildlife (ecological) and pasture species of economic importance need to be protected.

The slightly modified nature of the site also precludes the use of Tier 1 EIL guidelines in this assessment and therefore if the proposed capping or other mitigation measures cannot be applied then consideration to the development of the Tier 2 ecological soil criteria should be undertaken.

12.1.3 Human health

The beneficial use of human health relates to the need for people to be able to make use of land without suffering adverse impacts on their health due to land contamination. The people who visit, work or live at the site need to be protected.

Exceedences in BaP, total PAHs, cyanide and TRH concentrations were identified within the Gasworks Park and South Port Nursing Home and therefore this beneficial use can be considered precluded. However, this can be managed by the proposed remediation options either to re-cap the entire site or apply other mitigation measures detailed in the RAP.

In addition, the Indoor Ambient Air Vapour Investigation (Environmental Earth Sciences, 2012) was undertaken at the site concludes that any sub-surface vapour intrusion at the site appears to be negligible and unlikely to result in a chronic unacceptable health risk to building users.

12.1.4 Buildings and structures

Land may interact with buildings, footings and structures, such as support piers and underground services. For example, land that is acidic or corrosive can degrade concrete structures leading to collapse. Therefore, these need to be protected.

Objectives for buildings and structures as outlined within the SEPP Prevention and Management of Contamination of Land are that *'contamination must not cause the land to be corrosive to or adversely affect the integrity of structures or building materials'*.

As discussed in this report, further data needs to be collected to adequately quantify soil impacts as a result of natural or gas-works sourced sulfide oxidation. This impact relates to acid generation and sulfate (salinity) precipitation. Therefore Environmental Earth Sciences considers that, until additional data collection is undertaken, buildings and structures may be precluded. Note also however that site buildings are unlikely to have footings that extend any considerable distance into the soil profile.

12.1.5 Aesthetics

Aesthetics refers to visual and odorous components of land. This beneficial use ensures the community lives in an aesthetically pleasing environment that is not degraded due to the effects of land contamination.

Objectives for aesthetics as outlined within the SEPP *Prevention and Management of Contamination of Land* are that *'contamination must not cause the land to be offensive to the senses of human beings'*.

As noted in Section 8.1.1, areas of patchy grass cover were noted in parts of the grassed centre of the site, however grass coverage was at least 70% in these areas and no visible staining, discolouration, gasworks waste or asbestos was observed at the surface of the site. There was hydrocarbon odour noted at various times during the inspection, however a specific location could not be identified, or directly attributed to the gasworks site or soil.

This aesthetic issue will be addressed as part of the proposed remediation options at the site.

13 CONCLUSION

Environmental Earth Sciences undertook the systematic grid based soil sampling between 18 and 21 January 2011. A total of 41 locations were completed across the site at an approximate density of 12.6 points/ha.

The main objective of this investigation was to characterise the site cap and extent of contamination in soil to quantify the risks posed to beneficial users of the site.

Site Capping Characterisation

Based on previous reports and visual observations during the field program, the thin layer of brown loam and the yellow-orange sandy clays, where they occur, constitute the capping layer placed over the site as part of the redevelopment (Section 4.3). The capping layer was observed to be at least 0.5m thick where the sandy clays occur (approximately half the site, refer to Figure 7), but thins out to the brown loam layer across the outer edges of the site. The remainder of the site consists of the thin sandy gravel layer of the pathways, lain directly on top of impacted material, or is sealed beneath site buildings. It is likely that the thin layer of brown loam and the yellow orange sandy clays, where they occur, constitute the capping layer, generally >0.5m thick, placed over the site as part of the redevelopment. There was visible contamination of this capping layer, with gasworks waste in most sampling locations, which is attributed to cross contamination through mixing with the existing underlying impacted fill material, rather than importation to site.

The capping layer was found to be irregular (less than 0.5m deep) and contaminated with gasworks waste and polycyclic aromatic hydrocarbons and therefore the existing site capping can be considered in-adequate.
The firm brown clay on the south-eastern corner of the site is thought to be a result of the excavation of 0.5 m of contaminated fill material and replacement with 0.3m of “clean soil” rather than part of the capping layer. It should be noted that this does not match the historical records of 0.5m of clean backfill.

Contaminant Characterisation

Based on the results of this assessment, chemicals of potential concern in soil have been assessed with respect to their potential to adversely (acute or chronic) impact on potential receptors to the direct soil contact and vapour migration pathway exposure routes.

Comparison of results to Tier 1 published criteria and modified SSTL (including statistical analysis of identified soil populations based on elevated chemicals of concern and depth of impact below the ground surface) indicates that the PAHs including BaP and Naphthalene, TRH (C_{16}-C_{34}), TRH (C_{34}-C_{40}) exceeded the criteria. In addition, the distribution of contamination was observed to be widespread and thus visually identifying and delineating the areas of contamination can be considered difficult.

For the Southport site, undertaking examination of the data-set (Table 4 data compared to Table 15 source apportionment) indicates that only soil from boreholes BH5 (0.2-0.7m) and BH8 (0.0-0.1m) exceeded the criteria. However, as the distribution of contamination was observed to be widespread and thus visually identifying and delineating the areas of contamination can be considered difficult and therefore the presence of elevated chemicals of concern in other areas of the Southport site cannot be discounted.

As the detected TRH impacts at the site were generally $>C_{16}$, the potential pathway could be via direct contact only. In addition, the outcome of the IAQ assessment indicated that any sub-surface vapour intrusion at the site appears to be negligible and unlikely to result in a chronic unacceptable health risk to building users.

14 RECOMMENDATIONS

Based on the above conclusions, several areas of concern with elevated concentrations of CoPC have been identified and given the distribution of contamination is widespread and thus visually identifying and delineating the areas of contamination can be considered difficult and several soil samples were observed above the Tier 1 published criteria and modified SSTL, it is recommended that the site will have to be capped to restrict direct contact.

During the actual capping and isolation works, if none of the proposed mitigation measures can be applied (e.g structural integrity issue or significant amount of vegetation or trees with high retention values) then those areas will have to be further assessed with a combination of targeted and grid sampling to check if the existing ground surface may remain without an unacceptable risk to both human health and environment. Refer to the Remediation Action Plan Report prepared by Environmental Earth Sciences (2014_v4) for further details.

It is also recommended that the two Interim Contamination Management Plans (ICMPs) for the site be updated to provide the current site status and framework for addressing the required management for the residual soil contamination within the site.

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FIGURES