Air Quality Assessment

Remediation of Former Macdonaldtown Gasworks

Incoll Management Pty Ltd

On behalf of
Rail Corporation NSW

Former Macdonaldtown Gasworks
Burren St
Erskineville, NSW

August 2011
JBS40913-15136 Revision H

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List of Abbreviations

A list of the common abbreviations used throughout this report is provided below.

- As Arsenic
- Cd Cadmium
- Cr Chromium
- Cu Copper
- BTEX Benzene, Toluene, Ethylbenzene and Xylenes
- B(a)P Benzo (a) pyrene
- DCE Cis-1,2-dichloroethene
- DECC NSW Department of Environment and Climate Change
- DoP NSW Department of Planning
- DP Deposited Plan
- DQO Data Quality Objectives
- DWE NSW Department of Water and Energy
- EPA NSW Environment Protection Authority
- Hg Mercury
- HIL Health Based Investigation Level
- LOR Limit of Reporting
- MAH Monocyclic Aromatic Hydrocarbon
- Ni Nickel
- OCP Organochlorine Pesticide
- PCE Tetrachloroethene
- SAR Site Audit Report
- SAS Site Audit Statement
- PAH Polycyclic Aromatic Hydrocarbons
- Pb Lead
- PIL Phytotoxicity Based Investigation Level
- PCB Polychlorinated Biphenyls
- PQL Practical Quantitation Limit
- QA/QC Quality Assurance/Quality Control
- RPD Relative Percentage Difference
- TCE Trichloroethene
- TPH Total Petroleum Hydrocarbons (C_6-C_9 and C_{10}-C_{36})
- VC Vinyl Chloride
- VOC Volatile Organic Compound
- Zn Zinc

Executive Summary

JBS Environmental Pty Ltd (JBS) was engaged by Incoll Management Pty Ltd (Incoll) on behalf of the Rail Corporation NSW Environmental Projects Unit (RailCorp) to prepare an air quality study to accompany an Environmental Assessment for the proposed remediation of the former Macdonaldtown Gasworks located at Burren St Erskineville NSW.

The objectives of this air quality assessment are to:

- Estimate potential air emissions including particulates, potential chemical constituents and odours from the proposed remediation works;
- Identify the requirement and type of air emission controls required;
- Undertake dispersion modelling of air emissions to determine potential impacts to nearby receptors and adjoining properties to assess the effectiveness of proposed air emission controls;
- Undertake a health risk assessment to determine potential health impacts of speciated chemical constituents identified as occurring from the works to nearby receptors and adjoining properties;
- Based on results of air modelling, assess compliance with relevant NSW Office of Environment and Heritage (OEH) and National Environmental Protection Council (NEPC) published criteria; and
- Estimate the greenhouse contribution of the proposed works.

A range of activities that may be undertaken with the gasworks remediation has been considered in the air quality assessment including:

- Excavation, handling and stockpiling of low level contaminated soils;
- Excavation , handling and stockpiling of coal tar contaminated soils;
- Movement of site vehicles over non-paved site haulage roads;
- Treatment of coal tar contaminated soils on-site by bioremediation;
- Dewatering of coal tar impacted groundwater from excavations and operation of a water treatment plant;
- Potential pooling and evaporation of coal tar impacted groundwater within site excavations; and
- Backfilling of excavations and compaction.

The assessment has been completed by undertaking air modelling to determine the impacts at a range of representative receptor locations in close proximity of the site. A number of conservative assumptions have been assumed in the air modelling to determine of the nature air quality controls required. Modelling results have been compared to OEH published and endorsed air quality criteria. On the basis of the assessment, a number of air quality controls have been designed to reduce the air emissions from the proposed works to an acceptable level. These include:

The assessment has been initially completed by undertaking air modelling to determine worst case impacts for a range of representative receptor locations in close proximity of the site. A number of conservative assumptions, including the complete absence of any air quality controls, has been assumed in the air modelling to allow the identification of all

site activities that will require air quality controls. Modelling results have been compared to OEH published and endorsed air quality criteria.

A number of air quality controls have been designed to reduce the air emissions from the proposed works. These include:

- Excavation Works: Water will be applied to disturbed areas at least hourly within the remediation site. Areas of coal tar impacted soil excavation will require addition of an odour suppression agent to the water sprays. Notwithstanding this recommendation, any works involving the excavation or handling of potential asbestos contaminated soils shall be undertaken subject to constant water application;
- Enclosure of Remediation Works: The excavation of soils impacted with high levels of coal tar anticipated in proximity of the northern gasholder and the former tar wells to the north of the gasholder shall require encapsulation within a ventilation controlled enclosure. Air discharges from the enclosure shall be through a controlled air filtering system designed to remove malodorous emissions and particulates;
- Soils Treatment on Site: Where treatment of coal tar impacted soils (as defined by the soil criteria summarised in **Table ES.1**) is proposed to occur on site this shall also be required to occur within a ventilation controlled enclosure. The enclosure shall be sufficiently sized to accommodate both the soil treatment works and the associated stockpiling;
- Odour Control: The presence of the coal tar impacted soils and groundwater on the site causes them to be highly malodorous on exposure during excavation and when stockpiled. A number of measures require implementation to minimise the impacts of odours including, in some sections of the site, enclosure of any excavation and soil handling works with treatment of air emissions to remove odours. In areas unsuited to the enclosure of soil handling activities, control measures shall include the minimisation of areas of exposed soils by works staging and covering of stockpiles, covering of tippers used to transport materials on the site, enclosure and controlled ventilation of any areas of splash filling the water treatment plant, installation and operation of an odour suppression system on the site boundary, application of odour suppression agents with dust control sprays during excavation and soil handling works and prevention of the exposure of contaminated groundwater saturated soils by control of water levels in open excavations. Materials with chemical concentrations exceeding those stipulated in **Table ES.1** shall not be stockpiled outside of enclosure without odour controls;
- Air Treatment System Monitoring: daily monitoring of volatile constituents will be required in emissions from the carbon filter forming part of the treatment system for the enclosure. When the measured concentrations exceed the nominated screening level the filter requires replacement and work within the enclosure shall be halted until a new filter has been installed;
- Site Monitoring: Site monitoring will be required, including assessment for particles less than 10 micron in diameter (PM_{10}), malodorous emissions, levels of volatile organic compounds, respirable fibres and dust deposition. Where site monitoring identifies potential exceedances of acceptable levels of dust or odour, site practices shall be reviewed, or the particular dust / odour

generating activity ceased until more favourable meteorological conditions occur or revised mitigation practices are adopted;

- Deep Excavations: Infiltrating coal tar impacted groundwater is to be prevented from accumulating within excavations by removing any ponded groundwater generated during the remediation works; and
- Monitoring: An atmospheric monitoring program requires to be implemented at the site boundary and adjoining residential areas to continually assess levels of airborne pollutants and offensive odours being generated by the works. Monitoring shall include dust and particulate, odour, asbestos and volatile constituents.

Table ES.1: Summary of Maximum Allowable Levels of Malodorous Constituents

Constituent	Criteria (mg/kg)	Comments
Benzene	2.5	-
Ethylbenzene	5	-
Toluene	10	-
Xylene (total)	10	-
Cresols	_	Non volatile, no limits requiring covering from odour potential
Acenaphthene	35	-
Naphthalene	25	-
Phenol	40	-

Notwithstanding the implementation of these air quality controls, it is considered likely that localised detections of coal tar odours will occur in close proximity of the site for the duration of the works. However the level of impact has been demonstrated by the air quality impact assessment not to be offensive, and is unavoidable in achieving the environmental rehabilitation of the site.

An Air Quality Management Plan (AQMP) detailing the requirements for the aforementioned controls and monitoring requirements has been prepared for the remediation program. The proposed controls are considered to be best practice for the proposed remediation works. The recommended controls above are identified as having a 'High' relative effectiveness (USEPA, 1991). Enclosure of soil handling works, with collection and treatment of air emissions, has been demonstrated as effective in protecting the surrounding community on other sites heavily impacted with tar (USEPA 1992).

1 Introduction

1.1 Introduction and Background

JBS Environmental Pty Ltd (JBS) was engaged by Incoll Management Pty Ltd (Incoll) on behalf of the Rail Corporation NSW Environmental Projects Unit (RailCorp) to prepare an air quality assessment to accompany an Environmental Assessment for the proposed remediation of the former Macdonaldtown Gasworks located at Burren St Erskineville NSW. The air quality assessment was required to determine the management procedures necessary to control potential air emissions from the remediation works proposed for the site.

In August 2000 the Site was found by the (former) NSW Environment Protection Authority (EPA) to pose a Significant Risk of Harm (SRoH) to human health and the environment. The finding was made in consideration of the concentrations of contaminants in the soil and groundwater reported in previous site investigations.

It is understood that RailCorp wish to remediate the site to a condition that:

- Results in the removal of the SRoH finding;
- Reduces health risks to future commercial / industrial site users to an acceptable level;
- Reduces the potential risks to the surrounding environment to an acceptable level; and
- Facilitates the beneficial use of the site for a future commercial / industrial use as consistent with rail activities.

The air quality assessment has been undertaken in accordance with the guidelines made or endorsed by the OEH, NEPC and enHealth including:

- NSW DEC (August 2005) 'Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales';
- NSW DEC (November 2006) 'Technical Framework Assessment and management of odour from stationary sources in NSW';
- NEPC (1999) 'National Environment Protection (Assessment of Site Contamination) Measure'; and
- enHealth (2004) 'Environmental Health Risk Assessment Guidelines for assessing human health risks from environmental hazards'.

1.2 Objectives

In developing an approach for the assessment it has been acknowledged that two types of air emissions will potentially occur from the site;

- Particulate/dust emission as associated with the handling of soils; and
- Odour/chemical emissions as associated with environmentally impacted materials which have driven the need for remediation works.

The chemical constituents impacting soils on the site are considered to be highly malodourous. Malodourous impacts are commonly found to precede potential toxicological impacts.

Dust controls for excavation / soil handling works are relatively widely used and easily identifiable for the proposed works on the site. Notwithstanding this, controls put in place to controls the potential chemical/malodourous emissions will also reduce potential dust emissions from the site. The controls developed discussed and modelled within this report are considered effective and feasible and have been included in the Air Quality Management Plan (AQMP) and Environmental Management Plan (EMP) prepared for the site.

On this basis, the assessment has been undertaken by the following approach:

- Describing the site, environmental condition of materials to be handled and assessment of existing air quality (**Section 2**);
- Description of the nature and scope of the proposed works and identification of the potential sources of air emissions and identification of best practice air quality controls (**Section 3**);
- Identification of air quality criteria to be protective of potential receptors in proximity of the site works (**Section 4**);
- Detailed descriptions of sources of odour emissions and quantification of anticipated rates of release of particulates, odours and associated chemical emissions (**Section 5**);
- Derivation of levels of potentially volatile constituents in soils where malodourous impacts are not anticipated to occur. The derivation of these criteria are used to facilitate the definition of malodourous soils throughout the remainder of the assessment (**Section 6**);
- Estimation of air quality impacts of the proposed remediation works on the basis of the air emission rates identified for each activity and the best practice air quality control as nominated (**Section 7**);
- Detailed description of the extent and proposed application of the range of air quality controls, and associated monitoring requirements to inform the preparation of the Air Quality management Plan (AQMP) (**Section 8**);
- An estimate of the greenhouse gas contribution of the proposed works (**Section 9**); and
- An estimate of the potential chronic health risk associated with the potential exposure of adjoining and nearby properties to chemical emissions from the works (**Section 10**).

2 Site Condition & Surrounding Environment

2.1 Site Identification

The site is located between Erskineville and Macdonaldtown railway stations. The site is roughly triangular in shape, being part of the area referred to as the Macdonaldtown Triangle. The site location is shown in **Figure 1**. The site details are summarised in **Table 2.1** and described in more detail in the following sections.

Table 2.1 Summary Site Details

Lot/DP	Part Lot 50 in DP1004167
Address	Burren Street, Erskineville NSW
Geographical Coordinates	624700N; 343200E
Local Government Authority	City of Sydney
Site Zoning	Railways as per SREP 26
Current Use	Vacant
Site Area	7,732m^2

A site plan showing the site is shown on **Figure 2**.

2.1.1 Proposed Future Use

RailCorp has advised that the site is to be remediated to a condition that facilitates commercial / industrial use of the site.

2.2 Current Site Condition

A site inspection was completed on the 25th March 2010 by JBS. The site was found to be overgrown with vegetation. Several stockpiles of predominantly soil and ballast based materials were located over the eastern portion of the site, which were being removed during the site inspection. It was reported by RailCorp representatives that the observed works were being undertaken to remove all stockpiled materials. The northern most former gasholder was observed as a circular area of exposed brickwork. The southern most gasholder was observed to be substantially intact. Some brick and metallic debris, presumably associated with the former operation of the site as a gasworks, was distributed throughout the remainder of the property.

The site has been previously delineated into eight areas by CH2M Hill (March 2007) 'Delineation & Characterisation Sampling and review of Remedial Options' (CH2M Hill 2007a). These areas are shown on **Figure 3** and include:

- Gasholders: encompasses both Gasholder structures adjoining the western boundary. The Southern Gasholder remains intact with the superstructure standing approximately 12 metres above the ground surface. The above ground structure of the Northern Gasholder has been demolished, however the brick annulus structure remains intact beneath the ground;
- Retort: encompasses the footprint of the former Retort House, Tar Wells, Condensers, Coal and Shale Storage areas and other building structures associated with the gasworks operations (office, amenities, etc). These buildings and structures have been demolished and associated structures are no longer visible above the ground surface. However some underground

structures remain in place, including the two Tar Wells, pipework, brick flooring and foundations and concrete slabs;

- Gas Purifier: encompasses the footprint of the former Purifier Beds, Scrubbers and Gas Meters. Similar to the Retort Area, structures only remain buried below the ground surface, with no above ground structures remaining;
- Northeast: includes the majority of the northeast section of the Site;
- South Central: includes the portion along the central southeast boundary;
- Southwest: includes the majority of the southern area of the Site;
- Retaining Wall: includes the filled area embankment along the northern site boundary; and
- Western Lot: includes the small rectangular section of land that extends west to Burren Street.

2.3 Surrounding Landuse

Surrounding land-uses include:

- North – Covered rail sidings are present adjoining the northern boundary of the former gasworks. Further north is located Macdonaldtown station and associated rail corridor;
- South-east – A noise barrier and access roadway is located adjoining the south-eastern boundary of the site. Further south is the rail corridor associated with the Illawarra and south-west rail corridor; and
- West – Residences fronting Burren St Erskineville are located adjoining the eastern boundary of the site. Residences consist of detached and semi attached low and medium density dwellings and small yard areas. Further west is located the residential area of Erskineville.

2.4 Topography

The site topography has been defined in CH2M Hill (December 2007) 'Remedial Action Plan Former Macdonaldtown Gasworks – Burren Street, Erskineville, NSW' (CH2M Hill 2007b). The Site is generally flat with a gentle grade that falls toward the south east. Along the western boundary that adjoins residential properties, the ground level falls off sharply to the backyards of the residential homes forming an embankment. This is considerable in the southern corner where there is a surface level difference of approximately four metres.

The ground surface of the adjoining northern property (Stabling Yards) is approximately 2m higher than the gasworks site, and this surface elevation extends into the gasworks site up to five metres in some places, where an old retaining wall was constructed (CH2M Hill 2007b).

2.5 Geology

The Sydney Geological Series Sheet 9130 (C. Herbert, 1999) indicates that the geological formation underlying the Site is the Wianamatta Group Ashfield Shale comprising black to dark-grey shale and laminite.

The Sydney Soil Landscape Series Sheet 9130 (G. A. Chapman et. Al, 1999) indicates that the Site soils are of the Residual Blacktown Grouping, consisting of:

- Landscape – gently undulating rises on Wianamatta Group shales and Hawkesbury shale. Local relief to 30m, slopes are usually <5%. Broad rounded crests and ridges with gently inclined slopes. Cleared woodland and tall open-forest;
- Soils – shallow to moderately deep (<100cm) Red and Brown Podzolic Soils (Dr3.21, Dr3.11, Db2.11) on crests, upper slopes and well-drained areas; deep (150-300cm) Yellow Podzolic soils and Soloths (Dy2.11, Dy3.11) on lower slopes and areas of poor drainage; and
- Limitations – moderately reactive highly plastic subsoil, low soil fertility, poor soil drainage.

Previous investigations on the site as reported in CH2M Hill (2007b) have identified three general soil types on the site including fill materials, natural soils and tar impacted fill and natural soils. Each is described in more detail in **Section 2.8**.

2.6 Meteorology

The Sydney area has a humid to temperate climate with a seasonal rainfall maximum during the summer and autumn months. The average rainfall for Sydney Airport Station is 1107mm. Rainfall ranges from 522-2025mm for Sydney Airport (DLWC, 2000).

The area has a history of droughts, which are broken by periods of heavy rainfall resulting in significant recharges to groundwater resources. The 1940's and 1980's and the current decade are observed to be dry periods, while the early 1970's and 1990's were wet periods.

Summer winds are northeasterly with southerly thunderstorms common. Winter winds are westerly. An assessment of the site specific meteorology is detailed with the preparation of meteorological data for the site in **Appendix A**.

2.7 Air Quality

Air quality in the Sydney region is impacted by a range of air pollution emissions sources including major industry, motor vehicles, commercial operations and leaking pipes and tanks as well as from domestic activities such as solid fuel heaters. A description of each of the major pollutants that may potentially be emitted by the proposed remediation works is provided in the following sections.

2.7.1 Fine particles

Particles (or particulate matter) in the atmosphere come from a wide variety of sources, including soil (dust), vegetation (pollens and fungi), sea salt, fossil fuel combustion, biomass burning and industrial activities. Particles in the atmosphere typically exhibit a bi-modal size distribution with a peak in the range of 0.1-2.5µm and a second peak in the range 2.5-50µm. As a result, particles with a diameter of up to 2.5µm ($PM_{2.5}$) are

commonly referred to as fine particles. There is also a distinction in the health effects of different sized particles. Particles up to about 10µm (PM_{10}) diameter are inhaled, whereas larger particles are not. On this basis, the term 'fine particles' is often used to refer to PM_{10}.

Air monitoring results have been reviewed for each of the OEH air monitoring stations in proximity of the site to determine a typical background level of fine particulates. Air monitoring stations include:

- Randwick monitoring station located approximately 4km south-east of the site;
- Earlwood monitoring station located approximately 8km south-west of the site; and
- Rozelle monitoring station located in closest proximity to the site, being approximately 4.5km to the north-west of the site.

Levels of fine particulates, reported as PM_{10}, as recorded at each of the three stations are summarised in **Table 2.2** following for the most recent published monitoring available. Particulate levels are reported to be based on measurements using an oscillating microbalance and corrected to 0°C.

Table 2.2: Summary of PM_{10} Background Concentrations (µg/m^3)

Monitoring Station	24h Maximum	Monthly average	Source / Comments
Rozelle	37	17-22	January – March 2007[1]
	53	13-21	April – June 2007[2]
	31	13-18	July – September 2007[3]
	40	16-25	October – November – December 2007[4]
Randwick	45	18-24	January – March 2007[1]
	70	14-20	April – June 2007[2]
	31	13-18	July – September 2007[3]
	36	16-24	October – November – December 2007[4]
Earlwood	42	18-24	January – March 2007[1]
	67	15-26	April – June 2007[2]
	33	16-20	July – September 2007[3]
	49	16-29	October – November – December 2007[4]

Notes: 1. DECC (2007) 'Air Quality Monitoring Report 2007 Part A DEC Data January – February – March 2007'
2. DECC (2007) 'Air Quality Monitoring Report 2007 Part A DEC Data April – May – June 2007'
3. DECC (2007) 'Air Quality Monitoring Report 2007 Part A DEC Data July – August – September 2007'
4. DECC (2007) 'Air Quality Monitoring Report 2007 Part A DEC Data October – November – December 2007'

Based on **Table 2.2**, the maximum 24h level of PM_{10} recorded in proximity of the site using the most recent available monitoring data was 70µg/m^3, and monthly averages, approximately equivalent to the anticipated level of an annual average have been reported at 13 to 29µg/m^3.

2.7.2 Coarse Particles

Coarse particles remain in the air for relatively short periods of time and are therefore generally not carried long distances. As a result coarse particles tend to be a local rather than a regional problem, occurring close to industrial sources such as metal processing plants and mining operations. The level of particles in the atmosphere is determined by measurement of their mass. In the greater metropolitan area two methods of measurement are commonly used, total suspended particulates (TSP) and dust deposition rates (DDR). While the mass determined by these measures will include fine particles, these will generally only make a small contribution. Therefore measurements of TSP and DDR are used to provide an indication of the level of coarse particulates in the atmosphere.

Concerns about coarse particles are generally more in terms of nuisance such as damage to or soiling of materials, or adverse effects on sensitive vegetation through surface coating.

As per the discussion provided to **Section 2.7.1** the most recent data for the closest air quality monitoring stations has been reviewed to determine levels of total particulates as may be present in background air. It has been assumed that coarse particulates are present at 50% of the level of total particulates. This is a common assumption in several guidelines. Total particulates data has been summarised in **Table 2.3** following.

Table 2.3: Summary of Estimated TSP Background Concentrations (µg/m^3)

Monitoring Station	24h Maximum	Monthly average	Source / Comments
Rozelle	74	34-44	January – March 2007
	106	26-42	April – June 2007
	62	26-36	July – September 2007
	80	32-50	October – November – December 2007
Randwick	90	36-48	January – March 2007
	140	28-40	April – June 2007
	62	26-36	July – September 2007
	72	32-48	October – November – December 2007
Earlwood	64	36-48	January – March 2007
	134	30-52	April – June 2007
	66	32-40	July – September 2007
	98	32-58	October – November – December 2007

2.7.3 Air Toxins

Another group of air pollutants which can be hazardous to human health, even at low levels, are toxic compounds known as air toxins. This group includes chemicals such as benzene, formaldehyde, chlorinated hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and dioxins. Trace amounts of many of these chemicals have been detected in air in urban environments in a number of areas around the world.

In recent years there has been increasing community concern about air toxins in ambient air and the associated health effects. These compounds may cause cancer, gene mutation, reproductive malfunction, affect foetal development, or have neurotoxic effects. While the levels that endanger public health have not been established, it is believed that even very low levels, particularly under long term exposure, could have adverse effects. Many air toxins are highly volatile and evaporate readily into the air following inhalation.

Background levels of a range of air toxins that may be present in emissions from the Macdonaldtown remediation works have been assessed and reported in:

- NSW DEC (December 2004) 'Ambient Air Quality Research Project (1996-2001) Internal working paper no. 2 Ambient concentrations of toxic organic compounds in NSW';
- NSW DEC (December 2004) 'Ambient Air Quality Research Project (1996-2001) Internal; working paper no. 3 Ambient Concentrations of Polycyclic Aromatic Hydrocarbon Species in NSW'; and
- NSW DEC (December 2004) 'Ambient Air Quality Research Project (1996-2001) Internal working paper no. 4 Ambient concentrations of heavy metals in NSW'.

Airborne levels have generally been reported for the Sydney CBD, or the wider Sydney area. These levels are reported in **Table 2.4** following for each constituent that will be anticipated to be present in emissions from the site.

Table 2.4: Background Levels of Air Toxins in Sydney

Constituent	Background Concentration
Arsenic	0.51 ng/m^3 (1)
Cadmium	0.28 ng/m^3 (1)
Chromium	No data
Lead	48 ng/m^3
Nickel	No data
Cyanide	No data
Total petroleum hydrocarbons	No data
Benzene	2.3 ppb[1] (7.7µg/m^3)
Toluene	4.2 ppb[1] (15.4µg/m^3)
Ethylbenzene	0.5 ppb[1] (2.2µg/m^3)
Xylene	3.0 ppb[1] (13.1µg/m^3)
PAHs (total)	3.90 ng/m^3 (2)
Benzo(a)pyrene	0.40 ng/m^3 (2)
Phenols	No data
Asbestos	Nil

Note: 1. DECC (December 2004) overall average for Sydney CBD
2. DECC average of mean summer (Sydney) and winter (Sydney CBD) concentrations

2.7.4 Odour

Odour is measured using panels of people who are presented with samples of odorous gas diluted with decreasing quantities of clean odour-free air. The panellists report when the smell becomes detectable. Odour in air is quantified in terms of "odour units" which is the number of dilutions required to bring the odour to a level at which 50% of the panellists can just detect the odour. This process is known as olfactometry.

Background levels of odour in the environment can vary enormously based on a range of factors.

2.8 Previous Environmental Site Assessments

A range of previous environmental assessments have been completed for the site. These include:

- Rail Services Australia (November 1999) '*Eveleigh Gasworks – Site History*';
- CH2M Hill (June 2000) '*Phase I & II Environmental Site Assessments*';
- CH2M Hill (November 2000) '*Vegetable, Soil and Sediment Sampling – Letter Report*';
- CH2M Hill (December 2001) '*Soil and Groundwater Investigations of the former Gasworks Area and Offsite*';
- Australian Railway Historical Society (June 2003) '*A Brief History of NSW Railway Gasworks*';
- Banksia Heritage & Archaeology *'Macdonaldtown Station Works – Archaeological Assessment'*;
- GHD (September 2005) '*Macdonaldtown Triangle (Former Cleaning Sheds) – Delineation and Classification Sampling'*;
- Sinclair Knight Merz (April 2006) '*Macdonaldtown Triangle (Former Gasworks Site) – Human Health and Ecological Risk Assessment*';
- Heritage Concepts (November 2006) '*Archaeological Assessment and Remediation Management Strategy*';
- CH2M Hill (March 2007) *'Delineation & Characterisation Sampling and review of Remedial Options'*; and

- CH2M Hill (December 2007) '*Remedial Action Plan*'.

On the basis of a review of these assessments, CH2M Hill (December 2007) characterised the contamination status of the site. The characterisation is detailed in the following sections for each of the media of soils, groundwater, surface water and vapours.

2.9 Contamination Status - Soils

Previous investigations on the site as reported in CH2M Hill (2007b) have identified three general soil types on the site including fill materials, natural soils and tar impacted fill and natural soils. The findings of contamination assessments are summarised following. Reference should be made to **Figure 4** which shows the former operational areas of the gasworks.

2.9.1 Fill Material

Based on the findings of previous investigations as reported in CH2M Hill (2007b), the fill materials identified at the Site can be grouped as follows:

- Ash and Coke Gravels – observed across the majority of the Site in surface and near surface layers from ground level to approximately 0.5m depth;
- Reworked Clays – observed in subsurface layers in some site areas between 0.5m depth to approximately 1.5m depth. This material was observed in the majority of areas as general filling;
- Sands and Gravels – observed in subsurface layers in some site areas between 0.5m depth to approximately 1.5m depth. This material was observed in the North East, South Central and Gas Purifier areas;
- Gravelly Sand and Clay with Minor Ash – observed in surface and subsurface layers in some site areas from ground level to approximately 3.5m depth. This material was predominantly observed in the South West area of the Site as general filling; and
- Gravel, Sand and Demolition Wastes – observed in the fill embankment of the Retaining Wall and inside the annulus of the Northern Gasholder. This material was observed to mainly consist of sandy gravels and some ash gravels. It also consisted of demolition wastes and rubble including bricks, metal pipes, tiles, fibro-cement sheeting and Asbestos Containing Material (ACM) and other building rubble in a gravely sand matrix.

Organic Compounds

CH2M Hill (December 2007) reported that contaminants including polycyclic aromatic hydrocarbons (PAHs) including benzo(a)pyrene (B(a)P), semi- and non-volatile total petroleum hydrocarbons (TPH C_{10}-C_{36}), benzene and xylenes were reported as being present in a high number of samples at levels that exceeded the relevant commercial/industrial land use criteria.

PAH and B(a)P impacts were reported to be governed by the presence of tar in fill material proximal to source areas including underground tar pipes, the Retort area, Tar Wells and the Gas Purifier. The other major source of PAH and B(a)P impacts is a layer of ash/coke material covering the majority of the Site surface to a depth of approximately 0.5m.

TPH impacts were reported to be attributed to the presence of PAH, considering analytical results indicate that the main constituents of the TPH impacts comprise aromatic compounds.

Benzene and xylene impacts were reported to be related to the presence of tar in fill material proximal to source areas and also to the surface ash/coke fill layer.

The remainder of the organic contaminants were present in relatively low concentrations that meet the relevant land use criteria.

Inorganic Compounds

The majority of metal contaminants were reported in CH2M Hill (December 2007) to be at concentrations that meet the adopted land use criteria, with the exception of three samples that exceed the criterion for lead (Pb). This included samples collected from the fill present inside the annulus of the Northern Gasholder and the surface fill material in an area south of the Southern Gasholder.

Asbestos

All fibrous cement fragment samples collected from the surface and subsurface layers were reported in CH2M Hill (December 2007) to indicate the presence of asbestos. Fill samples collected from inside the Northern Gasholder and from the Retaining Wall indicated the presence of asbestos in this material.

The asbestos was reported to be present in these samples within a bonded matrix.

2.9.2 Natural Soils

Based on the findings of previous investigations as reported in CH2M Hill (2007b), the natural soil materials identified at the Site can be grouped as follows:

- Silty Clay – observed generally from between 1.5m depth to approximately 2.5m depth. This material exists across the majority of Site areas. This horizon was predominantly a saturated zone, which sustained the perched groundwater system;
- Red/Grey Mottled Clay – observed generally from between 2.5m depth to approximately 4.0-6.0m depth. The soil profile is consistent with a Red Podzolic soil, being moderately to highly plastic, stiff to very stiff, moist and mottled red/grey; and
- Weathered Shale – observed underlying the natural clay. This material grades from extremely weathered to moderately weathered at depths of up to 10m depth. At depths beyond 6m, fracturing of the material is common.

Organic Compounds

CH2M Hill (December 2007) reported that the results of the analysis of the natural soils indicated similar high numbers of samples that exceeded the relevant land use criteria for the same organic compounds as reported to be present in fill materials.

In particular, the volatile compounds benzene, xylenes and TPH (C_6-C_9) were reported to have higher ratio of samples exceeding the adopted assessment criteria as compared to the fill material. The reasons for this occurrence were considered by CH2M Hill (December 2007) to most likely to be a combination of:

- Higher solubility rates of shorter chained hydrocarbons that become mobile with infiltrating water or migrating groundwater;

- Volatilisation of these compounds from shallower fill materials;
- Higher impacts from leakage of tarry wastes from deep subsurface storage areas, especially from the Tar Wells and the Gasholders; and
- Vertical fracturing of natural clays and weathered shales, which provide a preferential pathway into deeper soils.

The remainder of the organic contaminants were reported to be at relatively low concentrations that met the relevant land use assessment criteria.

Inorganic Compounds

Metal and cyanide contaminants were reported at relatively low concentrations that meet the relevant adopted land use assessment criteria.

2.9.3 Tar Impacted Fill Material and Soils

A number of areas of fill/natural soil materials were observed to be impacted by tar and were summarized in CH2M Hill (2007b). The tar impacts have been categorised as follows:

- Soil/fill impacted by free tar – consisting of soil and fill materials impacted to a high degree with black ooze, highly odorous, liquor type material;
- Tarry soils – consisting of soil and fill materials with minor tar impacts and moderate odours; and
- Dark Stained Impacts – this material was observed as dark brown to black staining in the deep soils and Weathered Shale within the soil pores and shale fractures zones underneath the Southern Gasholder. This material was also moderately odorous.

Soil/fill impacted by free tar is material was reported by CH2M Hill (2007b) to be predominately associated with former gasworks infrastructure, which include the:

- Tar Wells – shallow subsurface and deep natural soils immediately adjacent to these two structures;
- Northern Gasholder – deep natural soils immediately adjacent to the brick base annulus; and
- Old gasworks pipework – inside pipes and immediately adjacent fill/natural soils.

Tarry soils are present at similar locations, however there is spatial separation between former gasworks infrastructure and tarry soils given tars have not migrated significant distances from gasworks infrastructure. Therefore there is a layer of highly impacted soils (free tar impacts) surrounding these structures followed by less impacted tarry soils. Tarry soils are located in the following areas:

- Tar Wells, Northern Gasholder and Gas Purifier – soil and fill surrounding these source areas in surface/subsurface fill and deeper natural soils;
- Retort – fill and deep soil across the majority of this area;
- Gas Purifier – Sandy fill and deeper soils; and
- Localised impacted fill – observed in one localised pocket in the Northeast Area.

Dark stained impacts were also reported in CH2M Hill (2007b) to be associated with deep soils below the base of the annulus of the southern gasholder. The dark stained impacts were considered likely to be secondary sources within the strata in localised areas associated with the Southern Gasholder.

Soil/fill impacted by free tar

Tar source material was reported to have been able to be collected from a former tar well and two buried pipes. Results of analysis have reported high levels of PAHs, TPH and BTEX.

Tarry Soils

Tar material was reported in CH2M Hill (December 2007) to be present within the fill/natural soil matrix and prevalent in areas proximal to the former gasworks structures and specific site areas including:

- The Tar Wells (Retort area);
- The network of underground pipes;
- The base annulus of the Northern Gasholder (Gasholder area); and
- The Retort and Gas Purifier areas – where tar exists in soil pores and soil fractures.

Contaminants including PAHs, TPH, benzene, toluene, ethylbenzene and xylene (collectively referred to as BTEX) were reported to be present in the tar impacted areas.

Tar impacts were reported to be limited to the former gasworks footprint area (i.e. Gasholders, Retort, Gas Purifier) and were considered unlikely to persist in areas away from the former gasworks footprint, such as in the Northeast, South Central, Southwest, Retaining Wall or the Western Lot site areas.

CH2M Hill (December 2007) further reported that the presence of a localised tar impact in the Northeast Area of the Site, at sample location TP16, indicates the potential for other areas of localised impact where tarry material may have been dumped or buried on site. It was further reported that the network of gasworks related pipework has only been partially delineated in the previous investigations. On this basis it was noted that in areas that pipework has not been delineated have the potential for additional tar impacts.

Dark Stained Soils and Fill Material

Dark stained material was reported by CH2M Hill (December 2007) to be observed as dark brown to black staining in the deep soils and Weathered Shale within the soil pores and shale fractures zones underneath the Southern Gasholder. This material appears different in nature to the tars observed at the base of the annulus of the Northern Gasholder. Dark stained materials were only observed underneath the Southern Gasholder.

Minimal contamination impacts were reported to be present beneath the Southern Gasholder including benzene impacts at 10m depth at a concentration of 1.6mg/kg.

Leaching Potential

Neutral water leaching tests were reported in CH2M Hill (December 2007) to have been conducted on three deeper natural soil samples collected from between 7.0m and 8.5m depth from areas below the Southern Gasholder, below the Northern Gasholder, and below the Gas Purifier area.

The results indicate that contaminants will leach under neutral conditions from the Northern Gasholder and Retort (deep tar impacted soil) source areas. The results show the contaminants that are likely to leach include benzene, xylene, naphthalene and C_{10}-C_{14} fraction TPH (from aromatic compounds).

2.10 Contamination Status - Groundwater

Previous investigations on the site as summarized in CH2M Hill (December 2007) have included the installation of groundwater monitoring wells on the Site and off site on RailCorp owned land down gradient of the Site.

Groundwater has been reported to occur as a shallow perched aquifer and deeper groundwater. Elevated concentrations of inorganic and organic contaminants have been reported in both groundwater systems. Concentrations of PAH, TPH (predominantly C_{10}-C_{36}), metals, phenols and BTEX exceed the adopted assessment criteria. The concentration of TPH in the C_6-C_9 range was also considered by CH2M Hill (December 2007) to exceed the solubility limit in water, in the deep groundwater system in the vicinity of the Gasholders. However no light-nonaqueous-phase-liquids (LNAPL) have been encountered in any groundwater monitoring wells on the site. It was further reported that there has been no identification of dense-nonaqueous-phase-liquid (DNAPL) in any groundwater monitoring wells.

Concentrations of contaminants have been reported to be lower in the shallow groundwater compared to the deeper groundwater.

The shallow groundwater contamination plume has been reported to extend 75m to the south and 50m to the east of the Site, while the deep groundwater contamination plume has been reported to extend 160m to the south and 50m to the east. Off site monitoring of groundwater has determined that the plumes are limited to RailCorp owned land.

The background water quality at the site is also reported to be impacted by some heavy metals, including cadmium, copper, nickel and zinc.

2.11 Contamination Status - Surface Water

Previous sample results reported by CH2M Hill (2007b) indicated that water accumulated in the site structures are impacted to varying degrees with both organic and inorganic contaminants.

These structures constitute the main sources of surface water at the Site and include the Tar Wells, the Northern and Southern Gasholders, and shallow fill material. Generally the organic contaminants were found to include the more soluble compounds including naphthalene and BTEX. The waters also showed moderate to high concentrations of TPH. Metal impacts were reported to include cadmium, copper, lead nickel and zinc.

2.12 Contamination Status - Vapours

The measured levels and results of modelling of soil vapour were reported in CH2M Hill (2007b). The results of soil vapour analysis were reported to indicate:

- Concentrations of benzene, ethylbenzene and xylenes below the LORs;
- Concentrations of toluene ranging from below the LOR to 28mg/m^3;
- Concentrations of PAH below the LORs; and
- Concentrations of naphthalene ranging from below the LOR to 0.00541mg/m^3.

It is reported to have been concluded in the SKM (2006) assessment that "*All test results measured concentrations of BTEX and PAHs well below the WorkCover Exposure Guidelines.*"……and……"*These results suggest there may be a low risk that soil-gas vapours at the former gasworks site are an environmental media of concern*."

Soil vapour levels as predicted by modelling were found to be substantially higher than measured levels.

2.13 Constituents of Potential Concern

On the basis of the review of the previous site assessments, CH2M Hill (December 2007) identified constituents of potential concern (COPCs) for each of the media as assessed on the site. This included:

Soils

- Monocyclic aromatic hydrocarbons (MAH), being benzene, toluene, ethylbenzene & xylenes (BTEX));
- Polycyclic aromatic hydrocarbons (PAH);
- Phenolic compounds (phenol and cresol isomers);
- Heavy metals (localised fill materials); and
- Asbestos.

Surface Water and Groundwater

- Monocyclic aromatic hydrocarbons (MAH), being benzene, toluene, ethylbenzene & xylenes (BTEX));
- Polycyclic aromatic hydrocarbons (PAH);
- Phenolic compounds (phenol and cresol isomers);
- Heavy metals including arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni) and zinc (Zn); and
- Cyanides

Soil Gas

- BTEX compounds and naphthalene as based on outcomes of computer simulation only.

TPH was excluded from the list of COPCs proposed by CH2M Hill (2007b) on the basis that the main components of TPH are aromatic compounds, as based on the consideration of the total concentrations of BTEX, PAH and phenolic compounds compared to total TPH concentrations. This is consistent with the enHealth (2001) '*Health-based Soil Investigation Levels*' approach to assessing TPH.

2.14 Areas of Environmental Concern

Areas of environmental concern were identified by CH2M Hill (2007b) and included:

- Tar in the Tar Wells;
- Tar residues in the network of underground pipework;
- Tar residues in the base annulus of the Northern Gasholder;
- Tar in soil pores and soil fractures in former gasworks areas;

- Potential tar residues in the base annulus of the Southern Gasholder as based on the historical use of this gasholder and the marginally elevated levels of contaminants in proximity;
- Demolition wastes including asbestos containing materials; and
- Ash and Coke fill materials across the majority of the Site in the surface and shallow subsurface layers

Each of these areas requires remediation.

3 Summary of Proposed Works

The information provided in the following sections has been summarised from the RAP (CH2M Hill 2007) prepared for the site. Further details on the proposed scope of works are also provided in the Remedial Strategy (JBS 2011) document prepared for the site. **Table 3.1** summarises the proposed scope of works and should be viewed in conjunction with **Figures 3** and **5** to **8**, which nominate the anticipated remediation areas/depths and likely locations for the associated infrastructure.

Table 3.1: Summary of Remediation Works

Stage	Task	Comments
Preliminary	Project planning and licensing	-
Site Establishment I	Setup of site offices, sediment and erosion controls	-
Remediation Stage I	1A – assessment/soil sampling of northern boundary retaining wall 1B- construction of internal turning circle, vegetation removal	1A - Blue area as shown on **Figure 5** 1B – Orange turning circle as shown on **Figure 5**
	1C – excavation/validation of the top 0.5m of fill material of the entire site surface. Transfer of excavated soil to Chullora for treatment prior to disposal to landfill	Purple shaded areas on **Figure 5** (ash & coke gravel fill) do not have a malodorous potential. These soils will be excavated by standard excavation practice to typical depth of 0.5m
	1D – excavation/validation of four hotspots to depths of 1-2m	Hot-spot at north-east of the site (**Figure 5)** in proximity of former sample location BH14. Benzene impact. Hot-spot at eastern of the site (**Figure 5)** in proximity of former sample location TP16. Free tar impact. Hot-spot at central southern boundary of the site (**Figure 5)** in proximity of former sample location MW04 (**Figure 3** Benzene impact. Hot-spot at south-western of the site (**Figure 5)** in proximity of former sample location MW13. Ash and coke impacts
Site Establishment II	Installation of temporary enclosure, associated air extraction/treatment system and water treatment system	Proposed locations shown on **Figure 6**.
Remediation Stage II	2A- commission air and water treatment system	-
	2B – excavate/validate areas within enclosure. Transfer of excavated soil to Chullora for treatment prior to disposal to landfill	Blue areas on **Figure 6** as present within the boundaries of the enclosure
	2C – reinstate enclosure excavation with imported Virgin Excavated Natural Material (VENM) or Excavated Natural material (ENM)	-
Remediation Stage III	3A – excavate/validate areas external the enclosure. Excavated material unsuitable for onsite bioremediation within enclosure to be transferred to Chullora for treatment prior to disposal to landfill	Orange areas on **Figure 8** as present external to the boundaries of the enclosure
	3B –Material assessed as suitable for remediation by bioremediation to be stockpiled for treatment within enclosure	-

Stage	Task	Comments
	3C – reinstatement of site using VENM or ENM, landscaping as required	-
Disestablishment	Decommissioning of air and water treatment plants, disestablishment of enclosure and site offices	-

The approximate quantities of materials associated with the above program of remediation, based on CH2M Hill (March 2007) are summarised in **Table 3.2** following. The handling / storage options associated with each of these material types is based on its waste classification, as per DECC (2009) '*Waste Classification Guidelines*'. The anticipated waste classification of material sourced from each excavation is also provided in **Table 3.2**.

Table 3.2: Summary of Remediation Volumes

Area	Volume	Description	Indicative Waste Classification
Surface soils	2,950m^3	Ash and coke fill. Excluding surface fill materials impacted with tar	General Solid
Contamination hot-spot at BH14	100m^3	Soils impacted with benzene	General Solid
Contamination hot-spot at TP16	115m^3	Soils impacted with coal tar. Potentially malodorous.	Restricted Solid / Hazardous
Contamination hot-spot at MW04	100m^3	Soils impacted with PAHs and TPH $C_{>10}$	General Solid
Contamination hot-spot at MW13	140m^3	Soils impacted with benzene	General Solid
Fill Behind Retaining Wall	1,765m^3	Soils impacted with PAHs, TPH $C_{>10}$, heavy metals and demolition wastes	General Solid
Fill Within Northern Gasholder to 4m bgl	1,900m^3	Soils impacted with PAHs, TPH $C_{>10}$, heavy metals, asbestos containing materials and demolition wastes	Restricted Solid
Fill and materials within Northern Gasholder >4m bgl	3,060m^3 (2,100m^3 tar impacted materials) (640m^3 tar impacted water) (320m^3 tar)	Tar impacted soils, free tar, tar impacted water. Potentially malodorous.	Hazardous
Former gasworks area	12,700m^3 (9,225m^3 shallow soils, i.e. <4m bgl) (2,375m^3 deeper soils, >4m bgl) (1,000m^3 tar impacted soils in tar wells) (100m^3 tar in tar wells)	Tar impacted soils, free tar, tar impacted water. Potentially malodorous.	Restricted solid / hazardous

3.1 Proposed Hours of Operation

Given the presence of commercial and residential properties in the vicinity of the site, personnel will only be on site during normal working hours. The expected hours for site works are therefore:

Monday to Friday: 7:00 am - 6:00 pm

Saturdays: 8:00 am – 1:00 pm

Sundays: No work permitted.

It is noted that some items of machinery, such as dewatering pumps, shall be required to operate continually. For modelling of air emissions it has been assumed that a standard ten hour day occurs on site, based on the standard allowable construction site hours, commencing at 7:00am. Meteorological data for air modelling is provided as hourly records. On this basis, and to maintain conservatism, it is assumed that the 10 hour period occurs between 7am and 5pm, to correlate to the hourly meteorological records within the meteorological data used for modelling, meteorological conditions conducive to poor dispersion of air pollutants occur in early morning periods (i.e. 7am records), are included in the modelling.

The use of a 10 hour day for the modelling period is considered appropriate given that the bulk of potential air emissions will occur during the standard working hours. Air emissions that will occur outside these standard hours will be related to fugitive emissions from static sources. The values of these fugitive emissions are likely to be a small percentage of the normal daytime emissions and are considered not to significantly impact air quality.

3.2 Identification of Sources of Air Emissions

The proposed scope of remediation works has been reviewed to identify potential sources of air emissions. Based on the site conditions described in **Section 2** and remediation scope of works described in **Section 3**, it is considered that the following works will require air emission controls:

- Excavation and handling of tar impacted soils wherever they should be encountered on the site to control potentially offensive odour emissions at receptor locations;
- Excavation and handling of tar impacted soils wherever they should be encountered on the site to control potential particulate emissions to receptor locations;
- Excavation and handling of tar impacted soils wherever they should be encountered on the site to control potential emissions of air toxins at receptor locations;
- Excavation and handling of all other soils excavated to control potential particulate emissions to receptor locations;
- Excavation and handling of all other soils excavated to control potential emissions of air toxins at receptor locations;
- On site treatment of tar impacted soils to control potentially offensive odour emissions, particulate and air toxin emissions at receptor locations; and

- Management of perched water seeping into excavations and the operation of the groundwater treatment system to prevent the release of unacceptable concentrations of air toxins.

The above works generally relate to control of odours during handling of tar impacted soils. In order to optimise the management of air emissions from the site, **Section 4** has been included to define 'tar impact' in soils in terms of odour potential. As such soils compliant with the criteria provided in **Section 4** will not require specific odour control measures, while those materials not compliant will be subject to the controls for reduction in duration of odour as described below.

3.3 Proposed Air Emissions Controls

The proposed air quality controls for each of the above works are summarised in the following sections. It is noted that air dispersion modelling is required for the detailed design of some of the air quality controls. Further to the outcomes of this modelling, the detailed design of the controls is summarised in **Section 7**. All the air quality controls have been documented in an Air Quality Management Plan (**Appendix B**).

3.3.1 Particulate Emission Controls

Water will need to be regularly applied to disturbed areas within the remediation site. It is reported by Midwest Research Institute that watering of surfaces at 2 hourly intervals reduces dust emissions by 61%, and watering at hourly intervals reduces dust emissions by 74%. It is recommended that all disturbed surfaces are watered by water cart at hourly intervals throughout the remediation works. This shall include:

- Areas of excavation;
- Areas of stockpiling;
- Areas of exposed soils where fugitive dusts may occur; and
- Haulage roads.

3.3.2 Controls for Reduction in Duration of Odour

The following measures are proposed to minimise the potential impact of tar impacted materials:

- Enclosure of excavation works in areas of significant coal tar impact where it may be practically implemented; and
- Enclosure of any soil treatment works to be conducted on the site.

Where lower levels of widespread coal tar impact are present enclosure of works is not required, however excavation and stockpiling in these areas should be managed excavation such that:

- No more than 400m^2 of *in-situ* materials are exposed in surface soil excavations;
- No more than 25m^2 of *in-situ* materials are exposed in retaining wall fill excavations; and
- Stockpiled materials to be left uncovered for an extended period outside of the enclosure must be demonstrated to comply with the site specific odour based criteria provided in **Section 8**.

- For works required outside of the enclosure, infiltrating groundwater should be prevented from accumulating within excavations present on the site; and
- Any areas of splash filling associated with the water treatment plant require to be enclosed to control emissions. Emissions within the enclosed area require to be filtered through GAC filters.

The maximum areas of 400 m^2 and 25 m^2 described above for exposed surface soil and retaining wall excavations were derived from dispersion modelling of worst case and controlled conditions. Details regarding this modelling scenario are provided in **Section 5**.

3.3.3 Enclosure of Odour Generating Works

The enclosure shall be constructed and operated in such a way that it is maintained under negative pressure. Air emissions from the enclosure will require treatment through bag filters to remove particulates and granular activated carbon (GAC) filters to remove potential malodorous emissions.

3.3.4 Soil Treatment on Site

For soils assessed to be suitable for treatment on site by bioremediation, treatment and associated soil stockpiling and handling activities shall occur within the enclosure. The enclosure shall be constructed and operated as described in **Section 7** and **Appendix B**.

Alternately, treatment of malodorous materials may potentially be undertaken at the RailCorp nominated off-site facility at Chullora.

3.3.5 Deep Excavations

Infiltrating groundwater should be prevented from accumulating within excavations present on the site. This will be achieved by continual extraction as required to prevent ponding of water within the excavations.

4 Air Quality Criteria

Air quality criteria are provided and endorsed by the OEH and are provided in DEC (2005) 'Approved Methods and Guidance for the Modelling and Assessment of Air Pollutants in NSW'. This document specifies a range of impact assessment criteria for toxic and malodorous air pollutants. The impact assessment criteria for these pollutants associated with the proposed remediation works are summarised in **Table 4.1**.

In addition to assessment of results to the OEH endorsed air quality criteria for each of the principal contaminants recorded on the Macdonaldtown Site, estimation of incremental risk and hazard index of the proposed air quality impacts from the site works has been undertaken. This is detailed in the Health Impact Assessment as detailed in **Section 10**.

Table 4.1: OEH Air Quality Impact Assessment Criteria

Pollutant	Concentration		Averaging Period
	ppm	µg/m3	
PM10	-	50	24 hour
	-	30	Annual
Total Suspended Particulates	-	90	Annual
Benzene	0.009	29	1 hour
Benzo(a)pyrene	-	0.4	1 hour

The air quality impact assessment criteria require to be assessed at each of the nearest potentially affected off-site properties.

Dust deposition criteria are also provided by DEC (2005). A maximum increase of dust deposition of 2 g/m^2/month requires to be adopted for the proposed works at Macdonaldtown, based on the strong likelihood that existing levels of dust deposition currently exceed 2 g/m^2/month.

4.1 Ambient Air Quality Criteria

The relevant ambient air standards and goals are provided in NEPC (1998) 'National Environment Protection (Ambient Air Quality) Measure' and DEC (2006) 'Action for Air – the NSW Government's 25-year Air Quality Management Plan'. The air quality goals contained within these guidelines are designed for use in assessing regional air quality and are generally not intended for use as boundary or atmospheric dispersion modelling criteria. Although the proposed remediation works have not been assessed directly against these guidelines it should be noted that the maximum concentrations in these guidelines for PM_{10} are identical to the OEH criteria in **Table 4.1**.

4.2 Odour Impact Assessment Criteria

Odour performance criteria are provided in DEC (2006) 'Assessment and management of odour from stationary sources in NSW'. The detection of an odour is a sensory property that refers to the theoretical minimum concentration that produces an olfactory response or sensation. The point at which an odour is detected is called the 'odour threshold' and defined as 1 odour unit (1 OU).

In practice the character of a particular odour can be judged by the receiver's reaction to it. DEC (2006) advises the level at which an odour is perceived to be of nuisance can range from 2OU to 10OU depending on a combination of a number of factors including: odour quality; odour intensity; odour frequency, timing and duration; population sensitivity; background level; public expectation; source characteristics; and health effects. DEC (2006) provides a range of odour assessment criteria for various population densities. The lowest of the available criteria of 2 odour units (2 OU) has been adopted for this study. The peak concentration of odour, calculated as a 1 second average using the guidance provided in DEC (2005), requires to be complied with at each of the nearest potentially affected off-site properties.

DEC (2006) advises the use of peak to mean ratios to convert modelled odour levels at one hour averaging to times to maximum 1 second concentrations, consistent with olfactory detection times. Peak to mean ratios are summarised following for each source of odour emissions included in the modelling:

- Area source – 2.3 (E and F stability classes where maximum levels occur)

5 Sources of Air Emissions

Table 5.1 summarises the following potential air emissions arising from the proposed remediation program.

Table 5.1: Summary of Air Emissions

Works	Air Emissions
Excavation and handling of soils	Particulates, Air toxins, Odours, Greenhouse gases
Haulage of soils across site roads	Particulates, Greenhouse gases
Stockpiling of soils	Particulates, Air toxins, Odours, Greenhouse gases
Treatment of soils	Particulates, Air toxins, Odours, Greenhouse gases
Fugitive dust emissions from exposed surfaces	Particulates, Air toxins (where contaminated soil exposed), Odours
Volatilisation of impact in groundwater	Potentially Volatile Groundwater Contaminants, Odours
Dewatering and transfer of groundwater	Potentially Volatile Groundwater Contaminants, Odours
Infiltration and pooling of contaminated groundwater within deep open excavations	Potentially Volatile Groundwater Contaminants, Odours

Details of the methods used to estimate the emissions from each of the above sources is discussed in the following sections, including, where appropriate, the value used to incorporate the effect of the relevant control measures described in **Section 3**.

Due to the nature of the emissions, greenhouse gas emissions are considered separately in **Section 9.**

5.1 Excavation of Soils

Soil excavation is required to remove contaminated soils. **Table 5.1** includes the quantities of soils that are anticipated to require removal. Anticipated excavation rates are required to allow air emission rates to be estimated. The following excavation rates are anticipated to occur during remediation works:

- Surface soils and contamination hot-spots – 500m^3/day;
- Fill materials behind the northern retaining wall – 300m^3/day;
- Fill materials from within northern gasholder – 100m^3/day; and
- Impacted soils across former gasworks area (tar impacted soils) – 200m^3/day.

In applying these rates it has been assumed that only one area will be subject to excavation at any given time.

A reduced excavation rate is proposed for the tar impacted materials as significant treatment / handling works will be required on excavation. The handling requirements will control the rate at which the soils can be excavated.

An emission factor for excavation and loading of soils is provided in NEPC (2001).

$EF = k * 0.0016 * (U / 2.2)^{1.3} * (M/2)^{-1.4}$

where: EF – Emission factor (kg/t)

U – Wind speed (m/s)

M – Moisture content

k – 0.74 for TSP, 0.35 for PM_{10}

It is noted that groundwater is present at a shallow depth in many of the impacted areas requiring excavation. Materials excavated from below the depth of groundwater will be in a saturated condition and are not anticipated to generate dust. However it has been assumed in modelling that all materials will be equally likely to generate dust (saturated in addition to non-saturated).

The soils on the site are found to be typically clay based. Based on a brief review of the laboratory analysis of soil samples from the site a moisture content of 0.1 has been adopted.

It is noted that volatile and semi-volatile constituents present in soils may be rapidly volatilised during soil excavation works. The potential release of chemical vapours during soil handling and stockpiling works has been assessed in **Appendix C**.

Additionally the effect of the proposed hourly watering of disturbed areas on mitigating emissions from excavation of soil has been included by reducing the emission factor by 74% consistent with the literature review described in **Section 3.3.1**.

5.2 Haulage Across Site Roads

In the time between remediating and reinstating the site, soils will be transported across site roads and more than likely be removed from the site. Departure from site will be via the site access/egress located at the south-west of the site. A paved access road moves from this point into Swanson Rd, Erskineville. Environmental controls (i.e. wheel wash / vehicle decontamination) will be present at the south-west of the Macdonaldtown site, prior to vehicle movement onto the paved road. These will restrict dust emissions associated with vehicle movement over roads to the dimensions of the Macdonaldtown site as shown on **Figure 6**. An emission factor for paved roads is provided in NEPC (1999a).

$EF = k_{iu} * (s/12)^A * (AW/3)^B / (M/0.2)^C$

where: EF_{iu} – Emission factor for particle size category 'i' and unpaved roads (kg/km)

K_{iu} – Empirical factor for particle size category 'i' and unpaved roads (0.35 for PM_{10} and 0.74 for TSP)

s – Surface material silt content (%)

AW – Average weight of vehicles, tonnes

M – Surface material moisture content (%)

A, B and C are empirical constants (A = 0.8, B=0.5 and C=0.4 for TSP and A=0.8, B=0.4 and C=0.3 for PM_{10})

It is noted that gravelly sands that have been identified as surface soils over the majority of the site have relatively low silt contents. It has been assumed that surface soils on the site, as may be present on site roadways, will have a silt content of 5%. This would be

anticipated to decrease in the most likely scenario where imported materials (i.e. crushed stone) are used to pave roadways on the site.

Movement over unpaved roads would typically be by 10T tippers transporting soils. Excavator movement would be anticipated to be insignificant in comparison.

Additionally the effect of the proposed hourly watering of disturbed areas on mitigating emissions from excavation of soil has been included by reducing the emission factor by 74% consistent with the literature review described in **Section 3.3.1**.

5.3 Fugitive Dust

Exposed surfaces will be anticipated to generate dust by wind movement and erosion of surface particles. The excavated areas of the site and the proposed area of stockpiling have been considered as having an unlimited wind erosion potential subsequent to the completion of excavation works. This is characterised as being a smooth field, lacking any vegetation and covered with loose sandy soil. The site immediately subsequent to excavation works may be characterised as this. A general emission factor of 0.85 tonnes/ha.year is provided in NEPC (1999b) for this scenario.

This worst case emission factor, reduced by a factor of 74% to account for hourly watering, has been used to predict emission rates from stockpiled soils as will be present on the site.

5.4 Stockpiling and Handling of Soils

Stockpiling and handling of soils will principally be undertaken in each of the areas of proposed excavation works. Localised stockpiling will generally occur adjoining the area of excavation prior to loading of materials onto road tippers for off-site disposal, on-site treatment or off-site treatment.

The greatest potential for the release of air pollutants from the stockpiles will be during handling of soils. The emission factor provided for excavation is considered to be sufficient to allow estimation during this activity.

The emission factor for fugitive dust is considered suitably conservative to estimate the fugitive emissions at other times from the stockpiled soils. The worst case emission factor has been used to predict emission rates from stockpiled soils as will be present on the site within the enclosure. The worst case emission factor has been reduced by a factor of 74% for stockpiles external to the site enclosure to account for the impact of hourly watering on reducing proposed emissions.

5.5 On-Site Treatment of Soils - Bioremediation

Bioremediation of soils will typically be undertaken by stockpiling of soils. This will occur on the site as uncovered stockpiles within the controlled ventilation conditions of the enclosure. Modelling has assumed the uncovered spreading and stockpiling of soils only. Covered bioremediation areas would not be anticipated to release particulates. Emissions of chemical and malodorous constituents would be anticipated to be the same for each scenario. Emissions for the bioremediation areas would be anticipated to be similar to those predicted for soil stockpiling in **Section 4.4**. The same emission factors will be adopted for bioremediation.

5.6 Sorbed Impact to Soils

Elevated levels of several contaminants have been identified in soils underlying the site. Particulates generated by these soils will be anticipated to be similarly subject to contamination. Consequently, levels of contaminants in generated dusts must also be considered. It has been assumed for this calculation that soil contaminants are present at the same concentrations within particles as present in soils.

5.7 Groundwater Exposure

Groundwater will be anticipated to enter deeper excavations as placed across the site, more than likely necessitating dewatering works. This groundwater is proposed to be dewatered and transferred to holding tanks. Volatile and semi-volatile constituents present in groundwater will volatilise out of groundwater. This will most likely be most significant where groundwater is discharged into the holding tanks. It has been assumed that the area of water transfer is open to the atmosphere.

Volatilisation of impact present in this transferred water is able to be estimated using the shower model as provided in NZ Ministry for the Environment (1999). Details of calculations using this model are provided in **Appendix C**.

Groundwater is also anticipated to potentially pool in each of the deeper excavations on the site. It is likely that groundwater will be impacted with dissolved contamination as recorded in groundwater monitoring wells and by tar in highly impacted areas of the site. The pooled water would be anticipated to evaporate, causing releases of dissolved impact present within the water. The following equation is presented in US EPA (2004) 'Methods for Estimating Fugitive Air Emissions of Radionuclides from Diffuse Sources at DoE Facilities' to estimate releases by evapo-transpiration.

$R = (20.73 * P_S * A^{0.9} * U^{0.8} * a * 3600) / T^{1.47}$

where: R – emission rate (g/hr);

P_S – vapour pressure of water at ambient temperature (assumed to be 20°C, 293 K, equal to 17.5 mm Hg)

A – surface area of pooled water

U – wind speed at pooled water surface (m/s)

T – Ambient temperature (K)

a – concentration of constituent in water (g/g)

5.8 Constituents Present in Soils and Groundwater

Soil and groundwater data has been analysed in CH2M Hill (March 2007). Statistical analysis of the levels of principal constituents of potential concern (COPCs) identified by CH2M Hill as benzo(a)pyrene and benzene, have been detailed for a range of material types on the site. Of the constituents identified at significant levels, benzene and benzo(a)pyrene are found to be most potentially toxic. Benzene is also found to have a significant volatilisation potential. This is detailed in **Table 5.2** following.

Total PAHs have also been detailed for materials that have been identified as potentially malodorous. These are used in **Section 5.9** to estimate potential odour emissions from tar impacted soils.

Table 5.2: Summary of Levels of Principal COPCs in Site Soils

Site Area	Constituent	Mean Concentration	Maximum Concentration
Surface soils, ash and coke gravels	Benzo(a)pyrene	31.2	339
	Benzene	0.24	4.2
Reworked clays / fill materials (including hot-spots and areas of free tar)	Benzo(a)pyrene	21	444
	Benzene	0.25	4.6
	PAHs (total)	674	15,238
Silty clays (near surface depths, including hot-spots and areas of free tar)	Benzo(a)pyrene	19.0	178
	Benzene	0.73	4
	PAHs (total)	589	5,302
Gravel, Sand & Demolition Wastes (behind retaining wall and within northern gasholder)	Benzo(a)pyrene	18.26	150
	Benzene	1.2	15
Red / Grey Clays (deeper soils, including hot-spots and areas of free tars)	Benzo(a)pyrene	2.2	13.9
	Benzene	1.4	20
	PAHs (total)	85.4	516
Weathered Shales (deeper depths at vertical extent of excavation, including free tars)	Benzo(a)pyrene	0.6	17.6
	Benzene	1.3	7.5
	PAHs (total)	96	1,906

Tar impacted water as present in a tar well on the site has also been characterised by previous sampling and analysis in CH2M Hill (March 2007). Levels of impact in the water are summarised in **Table 5.3**. These levels would also be indicative of the highest levels of impact that would be anticipated in infiltrating seepage water that will occur in excavation of highly impacted soils.

Table 5.3: Summary of Maximum Concentrations of Impact in Tar Impacted Water on Site (mg/l)

Constituent	Maximum Concentration
Acenaphthene	0.215
Acenaphthylene	1.45
Anthracene	0.482
Benz(a)anthracene	0.357
Benzo(a)pyrene	0.277
Benzo(b)fluoranthene	0.259
Benzo(g,h,i)perylene	0.124
Benzo(k)fluoranthene	0.0771
Chrysene	0.288
Dibenz(a,h)anthracene	0.0336
Fluoranthene	0.622
Fluorene	0.75

Constituent	Maximum Concentration
Indeno(1,2,3-c,d)pyrene	0.0979
Naphthalene	20.9
Phenanthrene	1.52
Pyrene	0.651
Benzene	1.36
Ethylbenzene	0.16
Toluene	1.26
Xylenes	1.903

From review of **Table 5.3**, it can be observed that benzene is present at significant concentrations within the water, as compared to the other constituents, and benzo(a)pyrene, a known animal carcinogen is also present, despite being detected at a lower concentrations. Consequently, assessment of potential impacts of chemical constituents will be appropriately undertaken by assessment to these two constituents, as adopted for the assessment of soil impact.

Specific sampling and analysis of coal tar has also been undertaken. This represents the maximum concentrations of constituents that may occur in materials as excavated from the site. Maximum levels of constituents are summarised in **Table 5.4** following.

Table 5.4: Summary of Maximum Concentrations of Impact in Coal Tar (mg/kg)

Constituent	Maximum Concentration
Acenaphthene	355
Acenaphthylene	2,260
Anthracene	1,380
Benz(a)anthracene	921
Benzo(a)pyrene	595
Benzo(b)fluoranthene	364
Benzo(g,h,i)perylene	250
Benzo(k)fluoranthene	545
Chrysene	765
Dibenz(a,h)anthracene	99.3
Fluoranthene	1,770
Fluorene	1,720
Indeno(1,2,3-c,d)pyrene	241
Naphthalene	9,750
Phenanthrene	3,920
Pyrene	1,870
Total PAHs	26,805
Benzene	576

Constituent	Maximum Concentration
Ethylbenzene	156
Toluene	1,210
Xylenes	1,506
Phenol	2,060
2-methylphenol	1,730
3- and 4-methylphenol	3,590
2,4-dimethylphenol	2,490
2,6-dichlorophenol	2.4

Benzene and benzo(a)pyrene can be observed from review of **Table 5.4** to constitute a significant proportion of the constituents of coal tar. As with impacted soil and water, potential chemical impacts will be assessed by consideration of benzene and benzo(a)pyrene only.

5.9 Odour Emissions

Some of the hydrocarbon constituents identified in soils and groundwater underlying the site, and which will be potentially released from the site during the remediation works, are observed to be potentially malodorous. As discussed within the previous CH2M Hill assessments and the characterisation of contamination on the site, the source of hydrocarbon contamination is found to be coal tar. Previous odour analysis of coal tar has been undertaken in Egis Consulting (August 2001) '*Thiess Services Notice of Intention for Demolition and Earthworks Former Platypus Site Neutral Bay, North Sydney*'. Coal tar has been found to have an odour strength of 290 OU/m^2.s. This odour strength has been used in modelling of potential worse case odour impacts of the excavation and soil handling works.

The majority of excavation works will not comprise the excavation and handling of 'pure' coal tar. Instead coal tar impacted soils will be stored and handled for the majority of the works. The odour generating potential of these materials is considered to be reduced as a function of the decreasing coal tar content. The extent of coal tar impact in these soils has been estimated by the comparison of total PAH levels in the sample of coal tar from the site and total PAHs in the site soils. On this basis, the following odour emission rates have been determined as summarised in **Table 5.5**.

Table 5.5: Summary of Odour Emission Rates

Site Activity / Source	Odour Emission Rate	Basis of Estimation
Excavation / handling of free tar	290 OU/m^2.s	Maximum odour emission rate for coal tar
Pooled tar impacted water	0.3 OU/m^2.s	Comparison of weight % of PAHs in tar impacted water and free tar
Stockpiled / homogenised soils Open Excavations on Site	7.3 OU/m^2	Comparison of highest mean total PAH concentration in site soil type and PAH concentration in free tar. Applicable to areas of Figure 4 shown shaded in orange and pink.

5.10 Deposition

Dust deposition has also been calculated for the site. The particle size distribution as recommended for mechanically generated aggregate in US EPA (1986) 'Generalised Particle Size Distributions for Use in Preparing Site Specific Particulate Emission Inventories' has been used to characterise particulates as may be emitted from the site activities. To remain conservative, it has assumed that wet depletion of particulates does not occur. The adopted mass fractions include:

- Particles <2.5µm – 15%;
- Particles 2.5-6µm – 34%; and
- Particles 6-10µm – 51%.

5.11 Treatment Plant Emissions and Works within the Temporary Enclosure

Separate air and water treatment systems will be run on the site, and emissions from both systems will require treatment through a granular activated carbon (GAC) filter. The USEPA (1991) review of air emission mitigation technologies reported that enclosures were successfully used in '*preventing the escape of any air emissions*'. While this may be interpreted as meaning the enclosure was 100% effective, the modelling has assumed the enclosure and associated extraction/treatment system will be capable of reducing emissions from all internal activities by 99% (US EPA 1997[1]).

For simulation of the emissions from the air treatment system GAC filter the modelling has assumed 99% effectiveness in reducing of all of the air emissions generated within the enclosure.

For simulation of the emissions from the water treatment system GAC filter the modelling has assumed 99% effectiveness in reducing of all of the air emissions generated by the pooled water for treatment.

The adopted 99% efficiency is considered to be sufficient to be protective of both the emissions from the filters during treatment the intermittent releases from the enclosure that may occur over the course of a work day when doors are briefly opened to allow for plant /personnel entry and exit.

5.12 Summary of Air Emission Rates

Air emission rates have been calculated for each of the air emission sources in the preceding sections. These are summarised in **Table 5.6** following. Chemical constituent emission rates can be observed to be related to rates of particulate emissions and as vapour emissions by volatilisation from the soil matrix. Detailed discussion of the derivation of the emission estimates for the chemical constituents is summarised in **Appendix C**.

[1] U.S. Environmental Protection Agency (1997) *Capsule Report; Sources and Air Emission Control Technologies at Waste Management Facilities*, US EPA / 625/R-97/002. Performance of activated carbon filters/adsorbers reported as '*Carbon adsorbers can achieve control efficiencies of at least 95 percent, and control levels of 99 percent have been demonstrated in many applications*'.

Table 5.6: Summary of Emission Rates

Source / control to be adopted	Constituent	Emission Factor under worst case conditions (i.e. no controls)	Comments
Excavation and Stockpiling – Surface Soils / hourly watering	TSP	$2.81*10^{-2}*U^{1.3}$ kg/t	An excavation rate of 500m^3/day has been adopted in the modelling and the worst case emission factor has been reduced by 74% to account for control measures.
	PM_{10}	$1.33*10^{-2}*U^{1.3}$ kg/t	An excavation rate of 500m^3/day has been adopted in the modelling and the worst case emission factor has been reduced by 74% to account for control measures.
	Benzene	$1.18*10^{-8}*U^{1.3}$ kg/t (max) $6.74*10^{-9}*U^{1.3}$ kg/t (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzene concentration recorded for surface soils, ash, coke and gravels and the worst case emission factors have been reduced by 74% to account for control measures.
	Benzo(a)pyrene	$9.53*10^{-6}*U^{1.3}$ kg/t (max) $8.77*10^{-7}*U^{1.3}$ kg/t (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzo(a)pyrene concentration recorded for surface soils, ash, coke and gravels and the worst case emission factors have been reduced by 74% to account for control measures.
Excavation and Stockpiling – Fill Materials behind Northern Retaining Wall / hourly watering	TSP	$2.81*10^{-2}*U^{1.3}$ kg/t	An excavation rate of 300m^3/day has been adopted in the modelling and the worst case emission factor has been reduced by 74% to account for control measures.
	PM_{10}	$1.33*10^{-2}*U^{1.3}$ kg/t	An excavation rate of 300m^3/day has been adopted in the modelling and the worst case emission factor has been reduced by 74% to account for control measures.
	Benzene	$4.22*10^{-7}*U^{1.3}$ kg/t (max) $3.37*10^{-8}*U^{1.3}$ kg/t (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzene concentration recorded for gravels, sand and demolition wastes and the worst case emission factors have been reduced by 74% to account for control measures.
	Benzo(a)pyrene	$4.22*10^{-6}*U^{1.3}$ kg/t (max) $5.14*10^{-7}*U^{1.3}$ kg/t (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzo(a)pyrene concentration recorded for gravels, sand and demolition wastes and the worst case emission factors have been reduced by 74% to account for control measures.
	Odour	7.3 OU/m^2.s	Based on comparison of impacted soils to coal tar in **Section 5.9**

Source / control to be adopted	Constituent	Emission Factor under worst case conditions (i.e. no controls)	Comments
Excavation and Stockpiling – Northern Gasholder / works within temporary enclosure with capture of and GAC filter treatment of emissions	TSP	$2.81*10^{-2}*U^{1.3}$ kg/t	An excavation rate of 100m^3/day has been adopted in the modelling and the worst case emission factor has been reduced by 99% to account for control measures.
	PM_{10}	$1.33*10^{-2}*U^{1.3}$ kg/t	An excavation rate of 100m^3/day has been adopted in the modelling and the worst case emission factor has been reduced by 99% to account for control measures.
	Benzene	$4.22*10^{-7}*U^{1.3}$ kg/t (max) $3.37*10^{-8}*U^{1.3}$ kg/t (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzene concentration recorded for gravels, sand and demolition wastes and the worst case emission factor has been reduced by 99% to account for control measures.
	Benzo(a)pyrene	$4.22*10^{-6}*U^{1.3}$ kg/t (max) $5.14*10^{-7}*U^{1.3}$ kg/t (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzo(a)pyrene concentration recorded for gravels, sand and demolition wastes and the worst case emission factors have been reduced by 99% to account for control measures.
	Odour	7.3 OU/m^2.s	Based on comparison of impacted soils to coal tar in **Section 5.9** and the worst case emission factors have been reduced by 99% to account for control measures.
Excavation and Stockpiling – Former Gasworks Area / works within temporary enclosure with capture of and GAC filter treatment of emissions	TSP	$2.81*10^{-2}*U^{1.3}$ kg/t	An excavation rate of 200m^3/day has been adopted in the modelling and the worst case emission factor has been reduced by 99% to account for control measures.
	PM_{10}	$1.33*10^{-2}*U^{1.3}$ kg/t	An excavation rate of 200m^3/day has been adopted in the modelling and the worst case emission factor has been reduced by 99% to account for control measures.
	Benzene	$5.62*10^{-7}*U^{1.3}$ kg/t (max) $3.93*10^{-8}*U^{1.3}$ kg/t (mean) Vapour emission rate as per **Appendix C**	Using the highest of the maximum and mean benzene concentration recorded for each of the soil types assessed for the site and the worst case emission factors have been reduced by 99% to account for control measures.
	Benzo(a)pyrene	$1.25*10^{-5}*U^{1.3}$ kg/t (max) $5.90*10^{-7}*U^{1.3}$ kg/t (mean) Vapour emission rate as per **Appendix C**	Using the highest of the maximum and mean benzo(a)pyrene concentration recorded for each of the soil types assessed for the site and the worst case emission factors have been reduced by 99% to account for control measures.
	Odour	7.3 OU/m^2.s	Based on comparison of impacted soils to coal tar in **Section 5.9**

Source / control to be adopted	Constituent	Emission Factor under worst case conditions (i.e. no controls)	Comments
Haulage Site Roads/ hourly watering	TSP	0.177 kg/km (loaded trucks) 0.109 kg/km (unloaded trucks)	Maximum excavation rate will result in 65 return trips over longest length of roadway during a 10 hour day. A roadway length of 65m has been adopted for the modelling, with roadway use distributed over the duration of the modelling and the worst case emission factors have been reduced by 74% to account for control measures.
	PM_{10}	0.105 kg/km (loaded trucks) $7.09*10^{-2}$ kg/km (unloaded trucks)	Maximum excavation rate will result in 65 return trips over longest length of roadway during a 10 hour day. A roadway length of 65m has been adopted for the modelling, with roadway use distributed over the duration of the modelling and the worst case emission factors have been reduced by 74% to account for control measures.
Stockpiles (Fugitive Emissions) Surface Soil and Hotspots Remediation / hourly watering	TSP	0.85 tonnes/ha.year	Requires to be based on likely extent of stockpiling with this stage. This has been assumed to be an area of 10m * 10m for the purposes of modelling and the worst case emission factor has been reduced by 74% to account for control measures. Surplus soils would generally be rapidly removed from the site.
	PM_{10}	0.43 tonnes/ha.year	Requires to be based on likely extent of stockpiling with this stage. This has been assumed to be an area of 10m * 10m for the purposes of modelling and the worst case emission factor has been reduced by 74% to account for control measures. Surplus soils would generally be rapidly removed from the site.
	Benzene	$3.57*10^{-6}$ tonnes/ha.year (max) $2.04*10^{-7}$ tonnes/ha.year (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzene concentration recorded for surface soils, ash, coke and gravels and the worst case emission factors have been reduced by 74% to account for control measures.
	Benzo(a)pyrene	$2.88*10^{-4}$ tonnes/ha.year (max) $2.65*10^{-5}$ tonnes/ha.year (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzo(a)pyrene concentration recorded for surface soils, ash, coke and gravels and the worst case emission factors have been reduced by 74% to account for control measures.
Stockpiles (fugitive emissions) – Fill Materials behind Northern Retaining Wall / hourly watering	TSP	0.85 tonnes/ha.year	Requires to be based on likely extent of stockpiling with this stage. This has been assumed to be an area of 10m * 10m for the purposes of modelling and the worst case emission factor has been reduced by 74% to account for control measures. Surplus soils would generally be rapidly removed from the site.
	PM_{10}	0.43 tonnes/ha.year	Requires to be based on likely extent of stockpiling with this stage. This has been assumed to be an area of 10m * 10m for the purposes of modelling and the worst case emission factor has been reduced by 74% to account for control measures.

Source / control to be adopted	Constituent	Emission Factor under worst case conditions (i.e. no controls)	Comments
			Surplus soils would generally be rapidly removed from the site.
	Benzene	$1.26*10^{-5}$ tonnes/ha.year (max) $1.02*10^{-6}$ tonnes/ha.year (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzene concentration recorded for gravels, sand and demolition wastes. Worst case emission factors have been reduced by 74% to account for control measures.
	Benzo(a)pyrene	$1.28*10^{-4}$ tonnes/ha.year (max) $1.55*10^{-5}$ tonnes/ha.year (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzo(a)pyrene concentration recorded for gravels, sand and demolition wastes. Worst case emission factors have been reduced by 74% to account for control measures.
	Odour	7.3 $OU/m^2.s$	Requires to be based on likely extent of stockpiling with this stage. This can be assumed to be 10m * 10m. Based on comparison of impacted soils to coal tar in **Section 5.9**.
Stockpiles (fugitive emissions) – Northern Gasholder / works within temporary enclosure with capture of and GAC filter treatment of emissions	TSP	0.85 tonnes/ha.year	Requires to be based on likely extent of stockpiling with this stage. This has been assumed to be an area of 10m * 10m for the purposes of modelling and the worst case emission factor has been reduced by 99% to account for control measures. Surplus soils would generally be rapidly removed from the site.
	PM_{10}	0.43 tonnes/ha.year	Requires to be based on likely extent of stockpiling with this stage. This has been assumed to be an area of 10m * 10m for the purposes of modelling and the worst case emission factor has been reduced by 99% to account for control measures. Surplus soils would generally be rapidly removed from the site.
	Benzene	$1.26*10^{-5}$ tonnes/ha.year (max) $1.02*10^{-6}$ tonnes/ha.year (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzene concentration recorded for gravels, sand and demolition wastes. Worst case emission factors have been reduced by 99% to account for control measures.
	Benzo(a)pyrene	$1.28*10^{-4}$ tonnes/ha.year (max) $1.55*10^{-5}$ tonnes/ha.year (mean) Vapour emission rate as per **Appendix C**	Using the maximum and mean benzo(a)pyrene concentration recorded for gravels, sand and demolition wastes. Worst case emission factors have been reduced by 99% to account for control measures.
	Odour	7.3 $OU/m^2.s$	Requires to be based on likely extent of stockpiling with this stage. This can be assumed to be 10m * 10m. Based on comparison of impacted soils to coal tar in

Source / control to be adopted	Constituent	Emission Factor under worst case conditions (i.e. no controls)	Comments
			Section 5.9 and the worst case emission factors have been reduced by 99% to account for control measures.
Stockpiles (fugitive emissions) – Former Gasworks Area / works within temporary enclosure with capture of and GAC filter treatment of emissions	TSP	0.85 tonnes/ha.year	Requires to be based on likely extent of stockpiling with this stage. This has been assumed to be an area of 10m * 10m for the purposes of modelling and the worst case emission factor has been reduced by 99% to account for control measures. Surplus soils would generally be rapidly removed from the site.
	PM_{10}	0.43 tonnes/ha.year	Requires to be based on likely extent of stockpiling with this stage. This has been assumed to be an area of 10m * 10m for the purposes of modelling and the worst case emission factor has been reduced by 99% to account for control measures. Surplus soils would generally be rapidly removed from the site.
	Benzene	$1.70*10^{-5}$ tonnes/ha.year (max) $1.19*10^{-6}$ tonnes/ha.year (mean) Vapour emission rate as per **Appendix C**	Using the highest of the maximum and mean benzene concentration recorded for each of the soil types assessed for the site. Worst case emission factors have been reduced by 99% to account for control measures.
	Benzo(a)pyrene	$3.77*10^{-4}$ tonnes/ha.year (max) $1.79*10^{-5}$ tonnes/ha.year (mean) Vapour emission rate as per **Appendix C**	Using the highest of the maximum and mean benzo(a)pyrene concentration recorded for each of the soil types assessed for the site. Worst case emission factors have been reduced by 99% to account for control measures.
	Odour	7.3 $OU/m^2.s$	Requires to be based on likely extent of stockpiling with this stage. This can be assumed to be 10m * 10m. Based on comparison of impacted soils to coal tar in **Section 5.9** and the worst case emission factors have been reduced by 99% to account for control measures.
Bioremediation of Soils / works within temporary enclosure with capture of and GAC filter treatment of emissions	TSP	0.85 tonnes/ha.year	Requires to be based on likely extent of stockpiling within the temporary enclosure. This has been assumed to be an area of $1,000m^2$ in the western portion of the site for the purposes of modelling. Worst case emission factors have been reduced by 99% to account for control measures.
	PM_{10}	0.43 tonnes/ha.year	Requires to be based on likely extent of stockpiling within the temporary enclosure. This has been assumed to be an area of $1,000m^2$ in the western portion of the site for the purposes of modelling. Worst case emission factors have been reduced by 99% to account for control measures.
	Benzene	$1.70*10^{-5}$ tonnes/ha.year (max) $1.19*10^{-6}$ tonnes/ha.year (mean)	Using the highest of the maximum and mean benzene concentration recorded for each of the soil types assessed for the site. Worst case emission factors have been

Source / control to be adopted	Constituent	Emission Factor under worst case conditions (i.e. no controls)	Comments
		Vapour emission rate as per **Appendix C**	reduced by 99% to account for control measures.
	Benzo(a)pyrene	$3.77*10^{-4}$ tonnes/ha.year (max) $1.79*10^{-5}$ tonnes/ha.year (mean) Vapour emission rate as per **Appendix C**	Using the highest of the maximum and mean benzo(a)pyrene concentration recorded for each of the soil types assessed for the site. Worst case emission factors have been reduced by 99% to account for control measures.
	Odour	7.3 $OU/m^2.s$	Requires to be based on likely extent of stockpiling with this stage. This has been assumed to be an area of 1,000m^2 in the western portion of the site for the purposes of modelling. Based on comparison of impacted soils to coal tar in **Section 5.9**.
Groundwater Treatment and Transfer / capture of and GAC filter treatment of emissions	Odour	0.3 $OU/m^2.s$	As per estimate rate for pooled water. Area of water column exposed to air needs to be considered. Conservative assumption is 1m^2. Worst case emission factor has been reduced by 99% to account for control measures.
	Benzene	Vapour emission rate as per **Appendix C**	Calculated in **Appendix C**.
	Benzo(a)pyrene	Vapour emission rate as per **Appendix C**	Calculated in **Appendix C**.
Pooled Groundwater / works within temporary enclosure with capture of and GAC filter treatment of emissions	Odour	0.3 $OU/m^2.s$	As per estimated rate for pooled water. Pooled water assumed to be present across area of the northern gasholder (20m * 20m) for the purposes of modelling. Worst case emission factor has been reduced by 99% to account for control measures.
	Benzene	Vapour emission rate as per **Appendix C**	Calculated in **Appendix C**.
	Benzo(a)pyrene	Vapour emission rate as per **Appendix C**	Calculated in **Appendix C**.

6 Derivation of Soil Criteria Protective of Potential Malodorous Effects

As part of the Air Quality Management Plan (**Appendix B**) to be adopted at the site, a set of odour based criteria have been derived for materials to be stockpiled external to the storage area without cover. These criteria, for use only during remediation works, provide an objective system for assessing whether temporarily stockpiled materials have the potential to generate offensive odours at the boundary. Put simply, these criteria are used to define malodourous materials on the site, for the purposes of identifying the requirement for odour controls. The criteria are only specific to activities associated with the above ground stockpiling/storage of soils. All subsurface areas that are potentially tar impacted require specific air quality controls during all excavation works, as described in **Section 5**.

As such soils compliant with the criteria derived within this section will not require specific odour control measures, while those materials not compliant will be subject to the controls for reduction in duration of odour.

6.1 Characterisation of Constituents of Coal Tar

With respect to the subsurface materials present on the site, the malodourous constituents of soil are consequent of the occurrence of coal/tar based impact. Analysis of free coal tar was reported in CH2M Hill (March 2007) 'Delineation & Characterisation Sampling and Review of Remedial Options Former Macdonaldtown Gasworks – Burren Street, Erskineville NSW' (CH2M Hill 2007). The coal tar was sampled from coal identified within a pipe on the former Macdonaldtown gasworks being assessed.

The results of analysis are summarised following for each substance reported above laboratory detection limits at a significant concentration.

Table 6.1: Summary of Published Coal Tar Constituents

Coal Tar Constituent	Reported Concentration (W%)
Phenol	0.206%
2-Methylphenol	0.173%
3- & 4-Methylphenol	0.359%
2,4-Dimethylphenol	0.249%
Naphthalene	0.975%
Acenaphthylene	0.226%
Acenaphthene	0.0355%
Fluorene	0.172%
Phenanthrene	0.392%
Anthracene	0.138%
Fluoranthene	0.177%
Pyrene	0.187%
Benz(a)anthracene	0.0921%
Chrysene	0.0765%
Benzo(b)fluoranthene	0.0364%
Benzo(k)fluoranthene	0.0545%
Benzo(a)pyrene	0.0595%
Indeno(1,2,3-c,d)pyrene	0.0241%
Dibenz(a,h)anthracene	0.0099%
Benzo(g,h,i)perylene	0.025%
Benzene	0.0576%
Toluene	0.121%
Ethylbenzene	0.0156%
Xylene	0.151%
TPH C_6-C_9	0.377%
TPH C_{10}-C_{14}	40.2%
TPH C_{15}-C_{28}	65.4%
TPH C_{29}-C_{36}	12.4%

By review of **Table 6.1**, 4% of the constituents of coal tar have been speciated.

6.2 Estimation of Rate of Release of Volatile and Semi-Volatile Constituents

Rates of volatilisation from soils will be chemical specific and based on several physical parameters that control volatilisation of chemical constituents from soils. The flux of volatile constituents that will potentially volatilise from soils stockpiled and handled on the site has been estimated on the basis of the physical properties of the constituents. The potential emissions of constituents from contaminated soils into outdoor air can be predicted by the RISC modelling package. RISC provides estimates of vapour emission on the basis of:

- The depth at which the volatile constituents occur;
- The levels (i.e. concentrations) at which volatile constituents are present;
- Soil properties; and
- Chemical parameters related to the potential volatility of the constituents.

Two scenarios have been identified to characterise the potential release of volatile constituents from stockpiles on the site including:

- Evaporation / volatilisation of constituents from soils during tipping / bulk movement of the soils; and
- Evaporation / volatilisation of constituents from soils as soils are left exposed on the site surface during remediation.

It is anticipated that an increased rate of volatilisation would occur during the bulk handling of soils. However, this would be short term in nature and restricted in extent based on the extent of soils that may be dumped from a tipper.

It has been assumed that all constituents are present at a depth of 0.1 m for volatilisation from spread soils, and present at a shallower depth of 0.01 m for volatilisation from soils as they are tipped and handled in the filling / stockpile area. This is a conservative assumption, as the rates of vapour migration and discharge from the soil decrease with increasing depth of the constituents from the soil surface. Similar modelling as performed in NZ Ministry for the Environment (1999) '*Users Guide Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand*' has recommended a minimum diffusion distance of 0.1 m be used for the characterisation of excavation surfaces.

Modelling scenarios have been undertaken on the basis of a unit concentration of each constituent identified as potentially volatile. Vapour flux rates are reported by RISC from the source of impact in units of $g/cm^2/s$.

Soil properties for the modelling have been adopted as per the recommended soil properties provided to US EPA (19 June 2003) '*User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings*'. Soil values for sand have been used as an overall average noting that soils that may be stockpiled on the site range from gravelly fill materials to natural silty clay and weathered shale. Noting the hourly site watering required with the proposed dust controls, the highest of the recommended range of water filled porosities has been adopted in the modelling of area based sources. The median water filled porosity has been adopted to characterise soils at the time of placement and handling, noting that dust controls may not be applied to these soils immediately. The soil properties used in the modelling are summarised in **Table 6.2** following.

Table 6.2: Summary of Soil Properties Adopted for Modelling of Volatilisation of Constituents

Soil Property	Adopted Value	Comments

Total porosity	0.375	Sand, as per US EPA (2003)
Water filled porosity (tipped / handled soils)	0.053	Sand, as per US EPA (2003). Median value adopted for soils as received as fill material. Used for characterising water filled porosity of soils received and handled as fill, presumably for period prior to full implementation of dust controls
Water filled porosity (exposed areas)	0.253	Value for capillary fringe sands adopted on the basis of surfaces being regularly watered in model assumptions. Value as per US EPA (2003). Adopted for exposed areas of soils
Fraction organic carbon	0.3	Assumed, consistent with site measurements
Soil bulk density	1.66	Sand, as per US EPA (2003). Based on density of materials once the compaction standard has been achieved, noted to be greater than density adopted for loose / bulked soils as imported to the site.

The results of flux calculations for the fugitive emissions and handling emissions is summarised **Table 6.3** following. RISC model outputs for each of the constituents assessed are provided attached as **Appendix G**. Rates have only been calculated for those contaminants within coal assessed to be volatile and it is noted that only some of these contaminants are considered to be malodourus.

Table 6.3: Summary of Predicted Rates of Volatilisation Based on Unit Concentration of Constituents

Constituent	Rate of Volatilisation from Handled Soils ($g/cm^2/s$)	Rate of Volatilisation from Spread / Compacted Soils ($g/cm^2/s$)
Acenaphthene	$4.09*10^{-12}$	$2.00*10^{-14}$
Benzene	$6.43*10^{-9}$	$2.16*10^{-11}$
Ethylbenzene	$2.51*10^{-9}$	$9.37*10^{-12}$
Naphthalene	$3.81*10^{-11}$	$1.59*10^{-13}$
Toluene	$4.36*10^{-9}$	$1.55*10^{-11}$
Xylenes	$2.39*10^{-9}$	$8.79*10^{-12}$
TPH C_6-C_8 (aliphatic)	$3.79*10^{-10}$	$3.79*10^{-11}$
TPH $C_{>8}$-C_{16} (aliphatic)	$2.73*10^{-11}$	$2.73*10^{-12}$
TPH $C_{>8}$-C_{16} (aromatic)	$3.01*10^{-12}$	$3.01*10^{-13}$

6.2.1 Odour Thresholds of Volatile and Semi-Volatile Constituents

Odour thresholds of the most significant potentially malodorous constituents that may be present in fill materials stockpiled on the site have been summarised in **Table 6.4**. This has been undertaken as per a literature review of several available sources for each constituent. Each of the constituents in **Table 6.1** has been considered in this review.

Table 6.4: Summary of Odour Thresholds

Constituent	Odour Threshold	Source / Comments
Naphthalene	0.05 – 5.34 mg/m^3 0.0095 – 1.02 ppm Mean: 0.038 ppm	US EPA (1990) '*Reference Guide to Odour Thresholds for Hazardous Air Pollutants Listed in the Clean Air Act Amendments of 1990.*' A series of values are given reflecting various studies. The mean value is given as the geometric mean or recommended best estimate.
	0.44 mg/m^3	US EPA Air Toxics Web Site (2000) 'Naphthalene 91-20-3'. Thresholds derived from ATSDR Toxicological Profile and Journal of Applied Toxicology article (1983).
	0.44 mg/m^3 0.021 mg/L (water)	ATSDR (2005) 'Naphthalene, 1-methylnaphthalene and 2-methylnaphthalene'.
	0.0075 - 0.42 mg/m3	WHO (2010) '*WHO Guidelines for Indoor Air Pollutants – Selected Pollutants*'. Values taken from review of external studies.
	<0.3 ppm	CDC NIOSH (1978) '*Occupational Health Guideline for Naphthalene*'.
	<0.3 ppm	NTP (1992) '*NTP Technical Report on the Toxicology and Carcinogenesis Studies of Naphthalene in BC63F Mice*'.
	0.038 ppm	ScienceLab (2010) '*Material Safety Data Sheet: Naphthalene MSDS*'.
	2.5 ug/l	Young et al (1996) '*Taste and Odour Thresholds Concentrations of Potential Potable Water Contaminants*', Water Research Vol 30.2. Study indicated the odour threshold for contaminants present in water
	0.35 mg/m^3	Nagata, 1990 '*Measurement of Odor Threshold by Triangle Odor Bag Method*'
Adopted	*0.35 mg/m^3*	
Total Petroleum	No values provided	WHO (2004) '*Rolling Revision of the WHO*

Constituent	Odour Threshold	Source / Comments
Hydrocarbons		*Guidelines for Drinking-Water Quality*'. No specific value given – states that drinking water may be unacceptable below guideline values due to odour and taste thresholds.
Benzene	1.5 ppm (5 mg/m^3)	US EPA Air Toxics Web Site (2000) 'Benzene 71-43-2'.
	1.5 ppm (5 mg/m^3)	US EPA '*National Air Toxics Program: The Integrated Urban Strategy Report to Congress*'.
	34-119 ppm	ATSDR (2007) 'Toxicological Profile for Benzene'. From AIHA 1989 source.
	4.68 ppm (4.9 mg/m^3), 2.0 mg/L (water)	ToxNet (2005) 'Benzene CASRN 71-43-2' HSCB (2010) 'Benzene 71-43-2'
	8.6 mg/m^3	Nagata, 1990 '*Measurement of Odor Threshold by Triangle Odor Bag Method*'
Adopted	*5 mg/m^3*	
Toluene	1 mg/m^3	WHO (2000) '*Air Quality Guidelines for Europe*'.
	40 – 120 µg/l	WHO (1993) '*Guidelines for Drinking Water quality*'.
	2.9 ppm	US EPA Air Toxics Web Site (2000) 'Toluene 108-88-3'.
	2.9 ppm	Von Burg, (1993) 'Toxicology Update: Toluene', Journal of Applied Toxicology.
	8 ppm, 0.04-1 ppm (water)	ATSDR (2000) 'Toxicological Profile for toluene'.
	2.14 ppm (8 mg/m^3)	ToxNet (2006) 'Toluene CASRN 108-88-3'
	1.2 mg/m^3	Nagata, 1990 '*Measurement of Odor Threshold by Triangle Odor Bag Method*'
Adopted	*1 mg/m^3*	
Ethylbenzene	2 - 130 µg/l	WHO (1993) 'Guidelines for Drinking Water quality'
	2.3 ppm	US EPA Air Toxics Web Site (2000) 'Ethylbenzene 100-41-4'
	20-100 ppb	Von Burg, (1992) 'Toxicology Update: Toluene', Journal of Applied Toxicology Vol 12.1
	2.3 ppm ,2-2.6 ppm, 0.029 mg/L (water), 0.14 mg/L (water)	ATSDR (200) 'Toxicological Profile for Ethylbenzene'. Four sources cited for varying values
	140 ppm, 0.4 mg/m^3, 8.7 mg/m^3	ToxNet (2005) 'Ethylbenzene 100-41-4'.
	0.8 mg/m^3	Nagata, 1990 '*Measurement of Odor Threshold by Triangle Odor Bag Method*'
Adopted	*0.8 mg/m^3*	
Xylenes	20-1800 µg/L	WHO (1993) '*Guidelines for Drinking Water quality*'.
	100 mg/m^3	AIHA (1997) '*Odor Thresholds for Chemicals with Established Occupational Health Standards*'
	1.1 ppm	US EPA Air Toxics Web Site (2000) 'Xylenes (Mixed Isomers)'. M-xylene only
	1 ppm (mixed xylenes), 0.05 ppm (m-, p- or o-xylene)	ATSDR (2007) 'Toxicological Profile for Xylene'.
	6 mg/m^3	ToxNet (2001) 'Xylenes CASRN 1330-20-7'.
	0.2-1.7 mg/m^3	Nagata, 1990 '*Measurement of Odor Threshold by Triangle Odor Bag Method*'
Adopted	*0.2 mg/m^3*	
Acenaphthene	0.08 mg/l	Gemert & Nettenbreijer, (2003) '*Odour Thresholds – Compilation of Odour Threshold Values in Air, Water, and Other Media*'.
	0.08 ppm, 0.02-0.22 ppm, 0.51 ppm	ToxNet (2001) 'Acenaphthene CASRN 83-32-9'.
	0.08 ppm	Speclab (2001) '*Chemical Fact Sheet – Acenaphthene*'.
Adopted	*0.5 mg/m^3*	
Phenol	0.04 ppm	US EPA Air Toxics Web Site (2000) 'Phenol 108-95-2'.
	0.040 ppm, 7.9 ppm (water), 1 ppm (water)	ATSDR (2006) 'Toxicological Profile for Phenol'.
	0.022-0.094 mg/m^3 (0.006-0.024 ppm 0.047-0.5 ppm	ToxNet 'Phenol CASRN 108-95-2'
	0.02 mg/m^3	Nagata, 1990 'Measurement of Odor Threshold by Triangle Odor Bag Method'
Adopted	*0.02 mg/m^3*	
Cresol	0.00024-0.00044 mg/m^3 (0.0003 mg/m^3 adopted)	Nagata, 1990 '*Measurement of Odor Threshold by Triangle Odor Bag Method*'

With reference to the results of the analysis of a tar sample in **Table 6.1**, it is likely that malodorous constituents will occur together as mixtures. Several of these compounds are