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StateRail

Macdonaldtown Triangle (Former Gasworks Site) Human Health & Ecological Risk Assessment

- Final
- 12/04/2006

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Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
1.0	19.10.05	Ian Swane	Ian Swane	19.10.05	Draft
2.0	12.04.06	Ian Swane	Ian Swane	12.04.06	Final

Distribution of copies

Revision	Copy no	Quantity	Issued to
1		Electronic	StateRail, Site Auditor
2	1 - 2	Hard copy, electronic	StateRail, Site Auditor
2	3	Hard copy	SKM

Printed:	12 April 2006
Last saved:	12 April 2006 01:22 PM
File name:	I:\ENVR\Projects\EN01669\Deliverables\Report\Former Gas Works Site\Final\Former Gas Works Site - Final.doc
Author:	Louise MacDonald / Ian Swane
Project manager:	Matthew Nation
Name of organisation:	RailCorp
Name of project:	Macdonaldtown Triangle Health & Ecological Risk Assessment
Name of document:	Human Health & Ecological Risk Assessment – Former Gasworks Site
Document version:	Final
Project number:	EN01669

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1 Executive Summary

Background

This report presents the results of a human health and ecological risk assessment for the Former Gasworks Site of the property known as the Macdonaldtown Triangle, Erskineville, NSW (hereafter referred to as 'the Site'). The risk assessment has identified the potential issues that should be addressed in respect to contamination on the Site. Ground contamination that is present at the neighbouring former cleaning sheds site has been addressed in a separate risk assessment prepared by SKM (Macdonaldtown Triangle, Former Cleaning Shed Site, Human Health & Ecological Risk Assessment, August 2005).

The main tasks that have been undertaken as part of this assessment are as follows:

- An assessment of site conditions, which involved an evaluation of the main features of the site and its history;
- A review of previous investigations;
- Development of a site investigation methodology and quality assurance and quality control protocols;
- A preliminary assessment of the risks posed by ground contamination at the Site and identification of environmental investigation levels for assessing soil contamination, groundwater contamination, aesthetics, and soil-gas quality;
- A site-specific health and ecological risk assessment, which has involved hazard identification, toxicological assessment, human health exposure assessment and ecological risk characterisation; and
- Provision of conclusions and recommendations.

The Former Gasworks site along with the adjacent Former Cleaning Shed site is referred to as "The Macdonaldtown Triangle" and forms a 1.53 ha parcel of land. The Site is identified as Lot 50 in Deposited Plan 1001467 in the Local Government Area of City of Sydney Council, Parish of Petersham and County of Cumberland. The Site is generally bounded by railway and rail related activities to the north and east, the former gasworks site immediately to the south of the Site and Burren Street to the west.

Soil Contamination

The site-specific risk assessment involved the assessment of soil contamination data provided by previous investigations together with some additional data that targeted data gaps. The study has found that the fill layer is mainly contaminated with high levels of PAHs and TPH C10-C36 distributed over much of the site. In the fill layer, hot-spots were found to be contaminated by benzene and xylenes in addition to PAHs and TPH C10-C36. Contamination in the fill layer was found to be highest in samples located near to the former tar tanks/gasholders, retorts/gas converter and the gas scrubbers.

The study found that the natural soils generally have lower levels of contamination compared to the fill layer and fewer hot-spots. Contamination in the natural soils was also found to be highest in samples located near to the former tar tanks/gasholders, retorts/gas convertor and the gas scrubbers.

Soil-Gas

The site-specific risk assessment involved the collection of field measurements of soil-gas vapour and computer analyses involving US EPA vapour transport models. Comparison of the results from the computer analysis and the field measurements showed that highly variable field results are to be expected given the highly variable volatile concentrations that have been measured in the shallow groundwater and unsaturated soils at the Former Gasworks site. The low soil gas levels measured in wells MW30-MW34 in March 2005 are consistent with the low groundwater concentrations that were measured in the last monitoring undertaken also in March 2005 and the low soil concentrations that have been measured in the plume area.

However, the computer analysis shows that much higher soil gas vapours may be present at the site than were measured by the investigation. This is because the results of the computer analyses show that much higher soil gas levels may occur if the higher volatile concentrations measured in the earlier groundwater monitoring rounds and/or higher soil concentrations measured in some shallow soil samples are more representative of site conditions. Due to this high degree of variability, there is potential for elevated levels of soil gas vapours to be emitted from the ground surface of the site and the exposure pathway from volatile soil vapours needed to be included in this risk assessment.

The analysis also showed that the primary source of BTEX in the soil vapour at the volatile plume area is likely to be from the shallow groundwater, since no significant BTEX levels have been measured in the shallow soils. On the other hand, the analyses showed that the primary source of the six target PAHs in the soil vapour at the volatile plume area is likely to be from the unsaturated shallow soils, due to the relatively higher PAH concentrations in these soils compared to the shallow groundwater.

Groundwater Contamination

The site-specific risk assessment involved the collection of a third round of groundwater monitoring data, which was combined with the data obtained by previous investigations. The study has found that high levels of light-end petroleum hydrocarbons (TPH C_6-C_9 and BTEX) and light-end PAHs (naphthalene, acenaphthalene, fluorene, pyrene) are present in the groundwater at locations close to the former gasworks, in the vicinity of the former gasholders and location of possible tar tanks. Although high concentrations of low-end hydrocarbon contamination were recorded during previous investigations at the Former Gasworks site, minimal middle to high-end contamination was detected by the additional investigation conducted by SKM. Heavy metal contamination at the Former Gasworks site is widespread with concentrations elevated above ANZECC (2000) trigger values for 95% level of protection for freshwater aquatic ecosystems. The highest concentrations were recorded at locations near to the former gas production process areas.

Site Contamination Model

The main contaminants of concern for a site-specific risk assessment at the Former Gasworks site are PAH compounds (particularly naphthalene and benzo(a)pyrene), benzene, ethylbenzene, xylenes and the heavy metals cadmium, copper, lead, nickel and zinc. The environmental media of concern are the fill layer, the underlying natural soils, groundwater and soil gas.

The conceptual site contamination model identified the potential receptors of ground contamination from the Former Gasworks site to be:

- Future long-term commercial/industrial users of the Former gasworks site (RailCorp workers);
- Future maintenance / construction workers at the Former Gasworks site and surrounding areas;
- The community who live in residential land adjacent to the western boundary of the site, off-site construction workers and users of any groundwater extracted from wells down-gradient of the site; and
- Freshwater aquatic ecosystems in the headwaters of Alexandra Canal.

The main exposure pathways for future long-term site workers at the Former Gasworks site are considered to be:

- Ingestion and dermal contact with contaminated surface soils;
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated soils in the unsaturated zone above the shallow aquifer; and
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated groundwater in the shallow aquifer.

The main exposure pathways for construction workers at the Former Gasworks site are considered to be the same as those for long-term site workers plus the ingestion and dermal contact with contaminated groundwater. This additional exposure pathway has been included because of the potential for excavations to extend deeper than 1.5m and past the shallow aquifer water table. Construction workers at the site may also be subjected to volatile soil gas vapours and inhalation of dusts, particularly when excavating in highly contaminated areas such as near areas that contained tar pits, retorts and gasholders. However, the site-specific risk assessment did not include these exposure pathways since these health risks should be managed as part of an occupational health and safety plan covering any earthworks conducted at the Former Gasworks site.

The main exposure pathways for residents and off-site construction workers at properties surrounding the Former Gasworks site are considered to be:

- Ingestion and dermal contact with contaminated groundwater;
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated soils in the unsaturated zone above the shallow aquifer; and
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated groundwater in the shallow aquifer.

The main exposure pathways for the freshwater ecosystems in the headwaters of Alexandra Canal are considered to be the extraction and discharging of contaminated groundwater to the stormwater system that would be discharged into the headwaters of Alexandra Canal.

Health Risks to On-site Construction Maintenance Workers

The site-specific risk assessment found that there is potential for on-site construction/maintenance workers at the Former Gasworks site to be exposed to a high risk of health impacts from ground contamination if working in an unremediated environment with no personal protective equipment (PPE) or special work procedures. The hazard quotient was calculated to be 6.6, which exceeds the acceptance criteria of 1. The main health risks are posed by workers exposed to PAHs and petroleum hydrocarbon contamination, which occurs both in the shallow soils and groundwater.

In order to mitigate these risks, it will be necessary for work procedures to be adopted by on-site construction/maintenance workers at the Former Gasworks site that will minimise/avoid:

- Dermal contact with contaminated groundwater;
- Physical contact with the surface soils;
- Dust generation; and
- Require high levels of hygiene and decontamination.

A program of environmental monitoring should also be undertaken when any construction work or significant maintenance work is undertaken at the Former Gasworks site. Alternatively, consideration should be given to capping the contaminated soils with a clean-soil cover or pavement.

Health Risks to Long-Term Site Workers

The site-specific risk assessment found that there is potential for long-term site workers at the Former Gasworks to be exposed to an unacceptable health risk from ground contamination if

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working in an unremediated environment with no personal protective equipment (PPE) or special work procedures. The hazard quotient was calculated to be 2.95, which exceeds the acceptance criteria of 1. The main health risks are posed by long-term site workers exposed to high concentration of PAHs and TPH C_{10}-C_{36} that have been detected in fill materials in the tar tank/gasholder area on the Former Gasworks site.

In order to mitigate these risks, it will be necessary for work procedures to be adopted by long-term Site Workers at the Former Gasworks site that will minimise/avoid:

- Physical contact with the surface soils;
- Dust generation; and
- Require high levels of hygiene and decontamination.

Alternatively, consideration should be given to capping the contaminated soils with a clean-soil cover or pavement.

Health Risks to Nearby Residents and Off-site Construction Workers

The site-specific risk assessment found that nearby residents would face a low risk from contamination present at the Former Gasworks site provided:

- Access to the Former Gasworks site is restricted to authorised personnel, who would largely be on-site workers; and
- Licensed groundwater extraction does not occur in the area;

The site-specific risk assessment found that off-site construction workers should face a low risk from working in deep excavations at nearby residential sites and that no restrictions should be required to manage construction works at these properties.

Phytotoxic Impacts to Future Landscaping at the Site

The investigation found there is a risk that some heavy metal contaminants may affect the health of plants that are grown at the Former Gasworks site in the fill soils. To address these risks it is recommended that:

- Landscaping areas be formed in areas where there is a 1-2m thick layer of clean soil that is conditioned to be suitable for plant growth; and/or
- Native plants be used at the site having a tolerance of elevated heavy metal concentrations.

These recommendations should be included in a long-term SMP that will need to be placed on the Former Gasworks site.

Aesthetic Assessment

This study considers there is a low risk of aesthetic issues affecting the future use of the Former Gasworks site provided the site continues to remain commercial/industrial land and any site works are undertaken in a manner that properly manages the aesthetic impacts associated with subsurface materials at the site. A long-term SMP will need to be placed on the Former Gasworks site in order to ensure that any future works are undertaken in a manner that properly manages the aesthetic impacts associated with subsurface materials at the site.

Need for Remedial Works

This site-specific health risk assessment has concluded that contamination at the Former Gasworks site would present an unacceptable health risk to long-term site workers and construction/ maintenance workers undertaking work at the site. The main causes of the elevated health risks are from exposure to contaminated surface soils together with exposure to contaminated groundwater for the case of a construction/maintenance worker working in wet conditions at the site. These risks could be reduced to acceptable levels if a program of remedial works were carried out at the site. Alternatively, access to the Former Gasworks site should continue to be restricted.

Recommendations

It is recommended that access to the Former Gasworks site should continue to be restricted if no redevelopment of the site is proposed in the near future. However, if the site is to be redeveloped and used for ongoing commercial/industrial land use, it is recommended that a program of on-site remedial work be undertaken.

The remedial work should at a minimum involve the capping or removal of contaminants in the upper 0.5m of soil across the site. Consideration should also be given to the removal of ongoing sources of groundwater contamination such as in the suspected area of the former tar tanks and sludge in the gasholder base. A long-term SMP should also be prepared and used to manage activities at the site in order to ensure the risks posed by contamination are properly managed. The issues that the SMP should address include among other things are:

- A prohibition on the extraction and reuse of groundwater at the Former Gasworks site and a prohibition on the construction of drained basements or deep pits that intersected the groundwater table. These restrictions are required to ensure that the risk to long-term site workers from ingestion or dermal contact with contaminated groundwater remains low;
- The requirement for an occupational health and safety plan to be prepared and implemented for any earthworks conducted at the Former Gasworks site. This requirement is needed in order to ensure on-site construction/maintenance workers and long-term site workers are not subjected to volatile soil gas vapours and dust levels that exceed OH&S standards;

- The erection and maintenance of security fencing and controlling site access to ensure that the risk to the surrounding residential community from on-site soil contamination remains low. This requirement may not be required if remedial works are conducted at the Former Gasworks site;
- Any groundwater intercepted by on-site construction works would need to be managed within the Former Gasworks site. This requirement is needed to protect freshwater ecosystems in the headwaters of Alexandra Canal;
- Landscaping areas should only be formed in areas where there is a 1-2m thick layer of clean soil that is conditioned to be suitable for plant growth;
- Native plants should be used at the site having a tolerance of elevated heavy metal concentrations; and
- Any future works at the Former Gasworks site should be undertaken in a manner that properly manages the aesthetic impacts associated with subsurface materials at the site.

2 Introduction

2.1 Purpose

This report presents the results of a human health and ecological risk assessment for the Former Gasworks Area of the property known as the Macdonaldtown Triangle, Erskineville, NSW (hereafter referred to as 'the Site'). The Macdonaldtown Triangle is located in railway land between Macdonaldtown Station to the north, the Illawarra and East Hills rail lines to the south and east, and Burren Road and residential properties to the west, as shown by the regional plan in **Figure 1**. The assessment has been undertaken by Sinclair Knight Merz (SKM) in accordance with our proposal dated 15 October 2003 and authorisation provided by RailCorp (formerly StateRail) dated 13 January 2004.

It is understood that the Former Gasworks site will remain the property of RailCorp and continue to be zoned to allow commercial/industrial land use, although it is not known what site activities will occur or if any structures/ buildings will be established on the site.

The risk assessment has identified the potential issues that should be addressed in respect to contamination on the Site and the future implications for development or landuse on the site. Ground contamination that is present at the neighbouring former cleaning sheds site has been addressed in a separate risk assessment prepared by SKM (Macdonaldtown Triangle, Former Cleaning Shed Site, Human Health & Ecological Risk Assessment, August 2005).

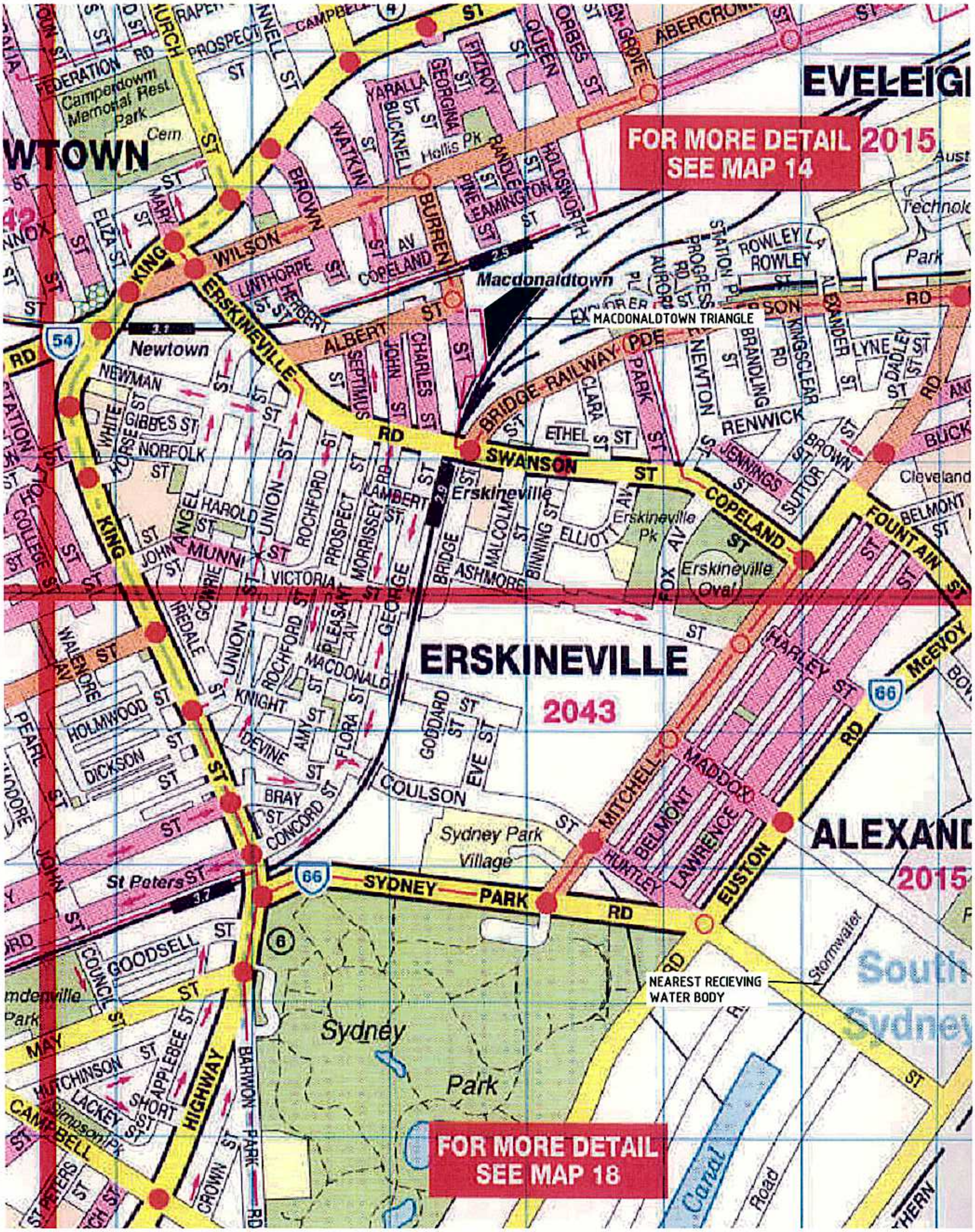
SKM has been engaged by RailCorp to be the Environmental Consultant responsible for the management of additional environmental investigations at the Site and the preparation of a risk assessment. The Sampling and Analysis Plan (SAP) developed by SKM (SKM, August 2004) has been independently reviewed prior to the commencement of the fieldwork program by Dr Bill Ryall, a NSW Department of Environment & Conservation (DEC) Site Auditor appointed by RailCorp.

2.2 Scope of Work

The main tasks that have been undertaken as part of this assessment are as follows:

- An assessment of site conditions, which has involved an evaluation of the main features of the Site (**Section 3**) and its history (**Section 4**);
- A review of previous investigations (**Section 5**);
- Development of a site investigation methodology (**Section 6**) and quality assurance and quality control protocols (**Section 7**);

Figure 1
REGIONAL PLAN
Macdonaldtown Rish Assessment



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- A screening assessment of the risks posed by ground contamination at the Site and identification of environmental investigation levels (**Section 8**) for assessing soil contamination, groundwater contamination, aesthetics, and soil-gas quality;
- A computer analysis of the volatilisation and vapour transport of volatile gases from contaminated soil and groundwater and their impact on indoor air quality (**Sections 9 & 11**);
- A site-specific health and ecological risk assessment, which has involved hazard identification, toxicological assessment, human health exposure assessment and ecological risk characterisation (**Section 13**); and
- Provision of conclusions and recommendations (**Section 14**).

The scope of the additional fieldwork and laboratory testing undertaken by SKM for this assessment comprised the following:

- The drilling of 13 clustered monitoring wells (both shallow and deep) for soil and groundwater sampling purposes (MW30 – MW42S);
- Soil gas sampling from 5 permanent monitoring wells located in areas of elevated volatile contamination (MW30-MW34);
- Sampling and laboratory testing of soil (8 locations) and groundwater samples (30 locations);
- Field screening of volatile soil-gas concentrations in sampled soils using a photo-ionisation detector (PID); and,
- In-situ falling head permeability tests at three wells.

2.3 Standards and Guidelines

2.3.1 Investigations

The site works conducted as part of the additional investigation have been undertaken in accordance with the appropriate legislative, health and safety (human and environmental) requirements.

The investigation has also been undertaken in accordance with the methodologies and technical requirements of:

- The NSW DEC (formerly NSW EPA) as specified in the DEC-endorsed documents listed on the NSW DEC webSite at www.epa.nsw.gov.au/clm/guidelines.htm;
- The Voluntary Investigation Agreement entered into by StateRail and the DEC; and
- State Environmental Planning Policy (SEPP) 55 for the remediation of contaminated land.

2.3.2 Risk Assessment

The methodologies used by this study follow the latest protocols endorsed by the DEC for assessing the human health and ecological risks posed by ground contamination. These protocols are specified in the following guidelines issued by Australian health and environmental agencies:

- National Environment Protection Measures (1999) produced for the assessment of Site contamination by the National Environment Protection Council (NEPC)
- NSW EPA Guidelines on contaminated land
- National Environmental Health Forum Monographs
- South Australian Health Commission National Workshops on the health and ecological risk assessment and management of contaminated Sites
- Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines

The assessment has given precedence to the use of the most up-to-date criteria and guideline levels that have been developed by Australia and New Zealand regulatory agencies where available.

2.4 Risk Assessment Methodology

2.4.1 Use of Investigation Levels

The ANZECC/NHMRC (1992) and NEPC (1999d) guidelines define an *Investigation Level* as a *"concentration of a contaminant above which further appropriate investigation and evaluation will be required"*. This means that environmental media that have contaminant levels less than a set of appropriate Investigation Levels are considered no to pose a risk to human health or the environment for a specified land use and require no further investigation or evaluation. The first step in a risk assessment is therefore to determine whether environmental media at a site exceed *Investigation Levels* that are appropriate for the current or intended land use.

This first step in the risk assessment process has been undertaken in this study by:

- Reviewing and assessing the information and contamination data provided by previous investigations **(Section 5)**;
- Identifying the areas of environmental concern, the potential pathways of exposure, potential receptors of concern and contaminants of concern and then by assessing the data gaps in the previous investigations and designing an investigation that addresses these data gaps (**Section 6**);
- Establishing *Investigation Levels* for the potential contaminants of concern at the Site for the land uses that are relevant to the future management of the Site (**Section 8**); and

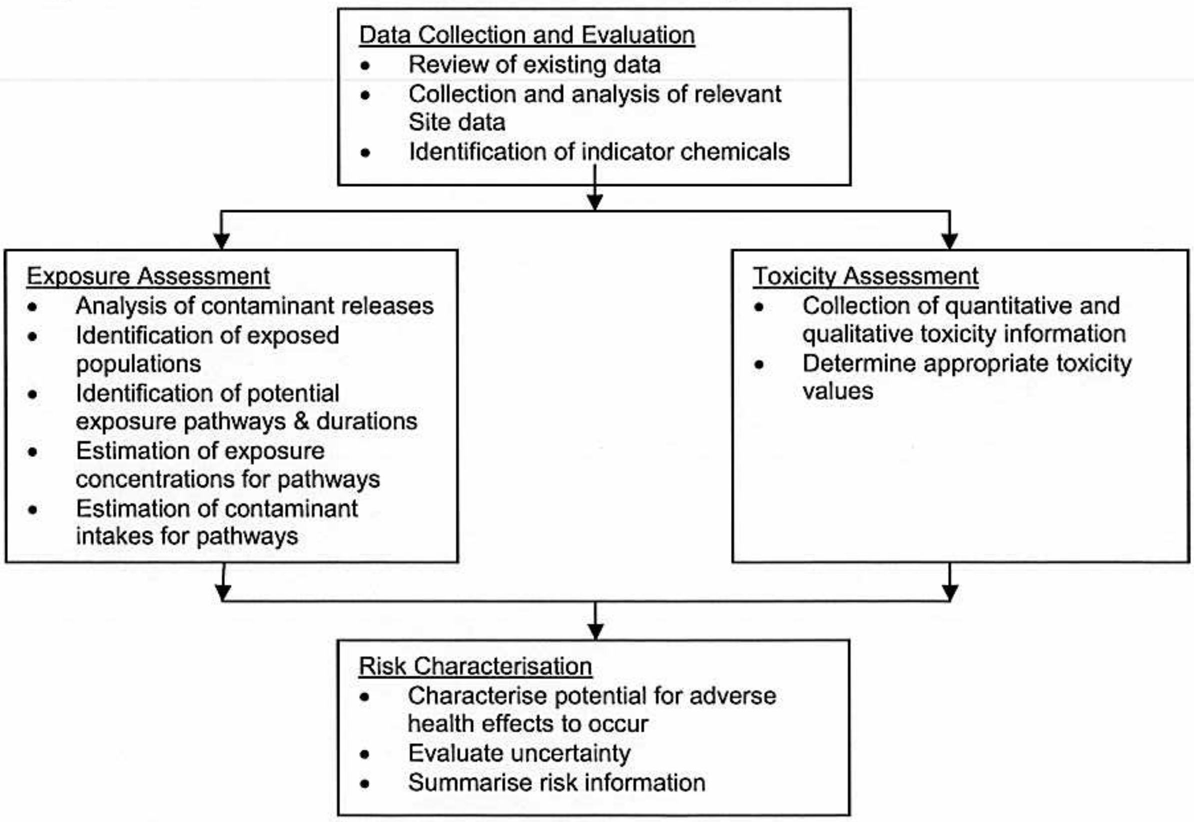
- Assessing the additional contamination data in terms of soil and soil vapour (**Section 9**) and groundwater and identifying areas of the site (if any) that exceed the *Investigation Levels* (**Section 10**).

For those portions of the Site found to exceed Investigation Levels, a site specific risk assessment has been undertaken. The methodology used in this study for undertaking a site-specific risk assessment for human health is described in **Section 2.4.2**, with the results provided in Section 12. The methodology for the site-specific ecological assessment is described in **Section 2.4.3**, with the results provided in **Section 13.5.**

2.4.2 Site Specific Risk Assessment for Human Health

The methodology used in this study for assessing risks to human health from ground contamination is based on the methodology given in the NEPC (1999a) Schedule B(4) guidelines, which have been endorsed by the DEC. The approach is consistent with international risk assessment methodologies. A diagrammatic representation of the health risk assessment methodology is shown in **Figure 2**.

- **Figure 2 Human Health Risk Assessment Methodology**



Reference: ANZECC & NHMRC (1992) & Langley (1993)

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This methodology is intended to achieve the following four objectives:

- To establish baseline risks and whether site remediation or other action is necessary;
- To determine a tolerable level of contaminants that can remain in place with adequate protection of public health;
- To enable comparison of potential health impacts of various remediation techniques; and
- To provide a consistent method of appraising and recording public health risks at Sites.

The health risk assessment has been undertaken in four stages, with the following steps undertaken:

- Review of existing data, site inspection and collection and assessment of chemical data;
- Assessment of hazards posed by soil and groundwater contamination at the Site and the toxicity of contaminants of concern resulting in the derivation of a tolerable daily intake that is protective of human health;
- A human health exposure assessment examining the various ways that exposure to the contaminants may occur, background concentrations, identifying the affected population groups, and estimating the contaminant uptake levels for these groups; and,
- Risk characterisation involving the establishment of the remedial objectives and development of remediation strategies.

2.4.3 Site Specific Risk Assessment for Ecological Receptors

The methodology used in this study for assessing ecological risks from soil and groundwater contamination is based on the methodology given in the NEPC (1999c) Schedule B(5) guidelines, which have been endorsed by the DEC. This approach is consistent with international risk assessment methodologies. The methodology of Ecological Risk Assessment (ERA) consists of five basic components, these being problem identification, receptor identification, exposure assessment, toxicity assessment and risk characterisation. These components and the relationships between them are demonstrated in **Figure 3**.

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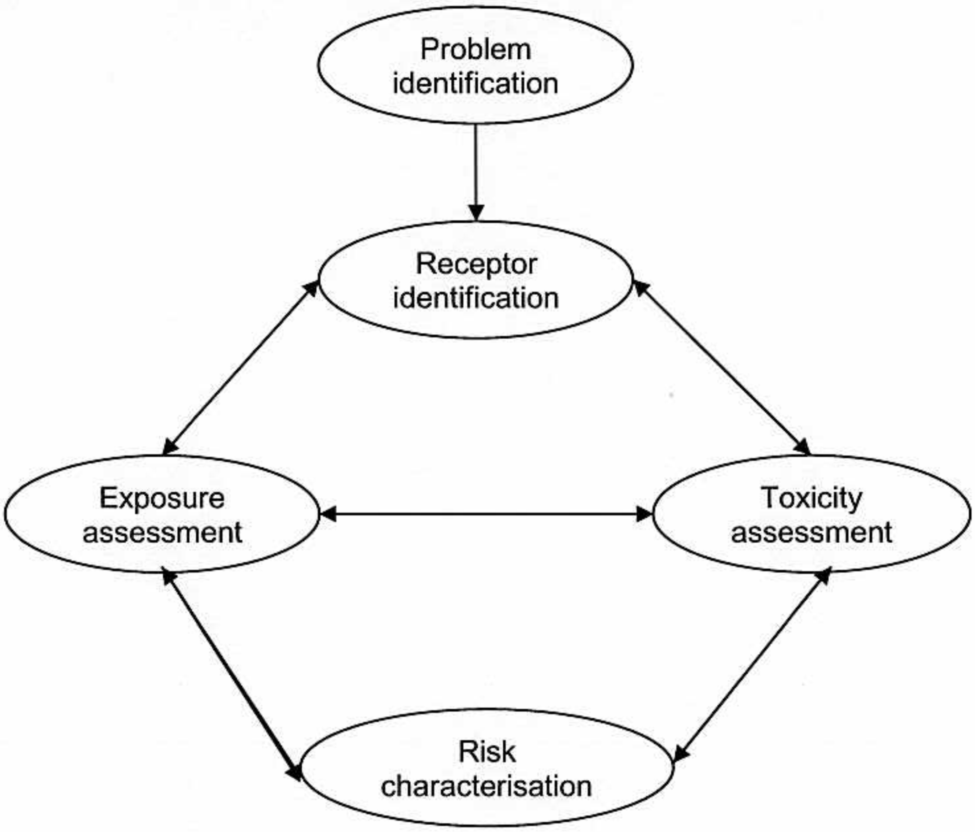
- **Figure 3 Ecological Risk Assessment Methodology**



Reference: NEPC (1999c)

The Problem Identification component is a scoping phase that establishes the objectives of the ERA and identifies the data that is required to achieve those objectives. The Receptor Identification component focuses on 'what species may be at risk' and 'what do we want to protect?' The NEPC (1999c) guidelines advise that this concept propose that not every organism may be at risk and not every organism can be protected. The assessment needs to focus on identifying the ecological values of a Site that need to be protected, taking into consideration societal relevance, ecological and economic significance. The Toxicity Assessment component involves determining the toxicity effects of the contaminants of concern to the potential receptors of concern. The Exposure Assessment component characterises the physical setting identifies potential exposure pathways and estimates exposure duration, concentrations and intakes. Risk Characterisation combines the exposure and toxicity information to determine the level of individual contaminants that may impact upon the receptors.

The NEPC guidelines describe how the ERA process can be undertaken at three different levels of detail. Each level consists of the same basic components but incorporates an increasing degree of data collection and complexity and decreasing uncertainty as an assessment proceeds from Level 1 to Level 3. Level 1 is a simple screening method designed to suit generic situations and protect all biota likely to inhabit a Site. Level 2 involves a desktop study with limited field studies that provide an increased level of detail to components of the ERA process. Level 3 is a detailed risk assessment that involves field studies and detailed assessment techniques. Higher risk assessment levels are generally only applied to those contaminants and organisms that fail environmental criteria when assessed during a lower level risk assessment.

2.5 Definitions and Acronyms

A number of abbreviations have been adopted throughout this report and are detailed below:

- ANZECC – Australia New Zealand Environment and Conservation Council
- ANZFA – Australia New Zealand Food Authority
- ARMCANZ – Agriculture and Resource Management Council of Australia and New Zealand
- ATSDR – Agency for Toxic Substances and Disease Registry, US Department of Health and Human Services
- BTEX – Benzene, Toluene, Ethyl benzene and Xylene
- CLM Act – Contaminated Land Management Act
- CoC – Chain of Custody
- DEC – Department of Environment and Conservation
- DIPNR – Department of Infrastructure, Planning and Natural Resources
- DO – Dissolved Oxygen
- DP – deposited Plan
- EIL – Ecological Investigation Levels
- EMP – Environmental Management Plan
- EPA – Environment Protection Authority
- ERA – Ecological risk assessment
- FDA – US Food and Drug Administration
- HIL – Health Investigation Levels
- IARC – International Agency for Research on Cancer
- IPCS – International Programme on Chemical Safety
- IRIS – US EPA Integrated Risk Information System
- mg – milligrams (10^{-3} grams)
- MRLs – Maximum residue limits
- MS – Matrix Spike
- MSD – Matrix Spike Duplicate
- NATA – National Association of Testing Authorities, Australia
- NEHF – National Environment and Health Forum
- NEPC – National Environment Protection Council
- NEPM – National Environment Protection Measure
- ng – nanograms (10^{-9} grams)

- NHMRC – National Health and Medical Research Council
- NSW – New South Wales
- OCPs – Organochlorine Pesticides
- OH&S – Occupational Health and Safety
- OPPs – Organophosphate Pesticides
- OSHA – Occupational Safety & Health Administration (US Department of Labor)
- PAHs – Polycyclic Aromatic Hydrocarbons
- PCBs – Polychlorinated biphenyls
- PID – Photo-ionisation Detector
- pg – picograms (10^{-12} grams)
- ppb – parts per billion (ie. µg/kg)
- ppt – parts per trillion (ie. ng/kg)
- PTDI – Provisional Tolerable Daily Intake
- QA/QC – Quality Assurance/Quality Control
- RAP – Remediation Action Plan
- RPD – Relative Percent Difference
- SEPP – State Environment Planning Policy
- SKM – Sinclair Knight Merz
- SLRA – Screening level health and ecological risk assessment
- SPCC – State Pollution Control Commission
- TSS – Total suspended solid
- TDS – Total Dissolved Solids
- TPH – Total Petroleum Hydrocarbons
- UCL – Upper confidence limit
- µg – micrograms (10^{-6} grams)
- US EPA – United States Environment Protection Agency
- WHO – World Health Organisation

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3 Site Description

This section of the report provides an overview of the physical conditions at the Site and surrounding areas. The physical features that are assessed include Site location, surrounding land uses, topography, surface hydrology, geology, hydrogeology, surface conditions, underground structures and buried services, and sensitive environments. The information is used as a basis for the contamination assessments provided in later sections of this report.

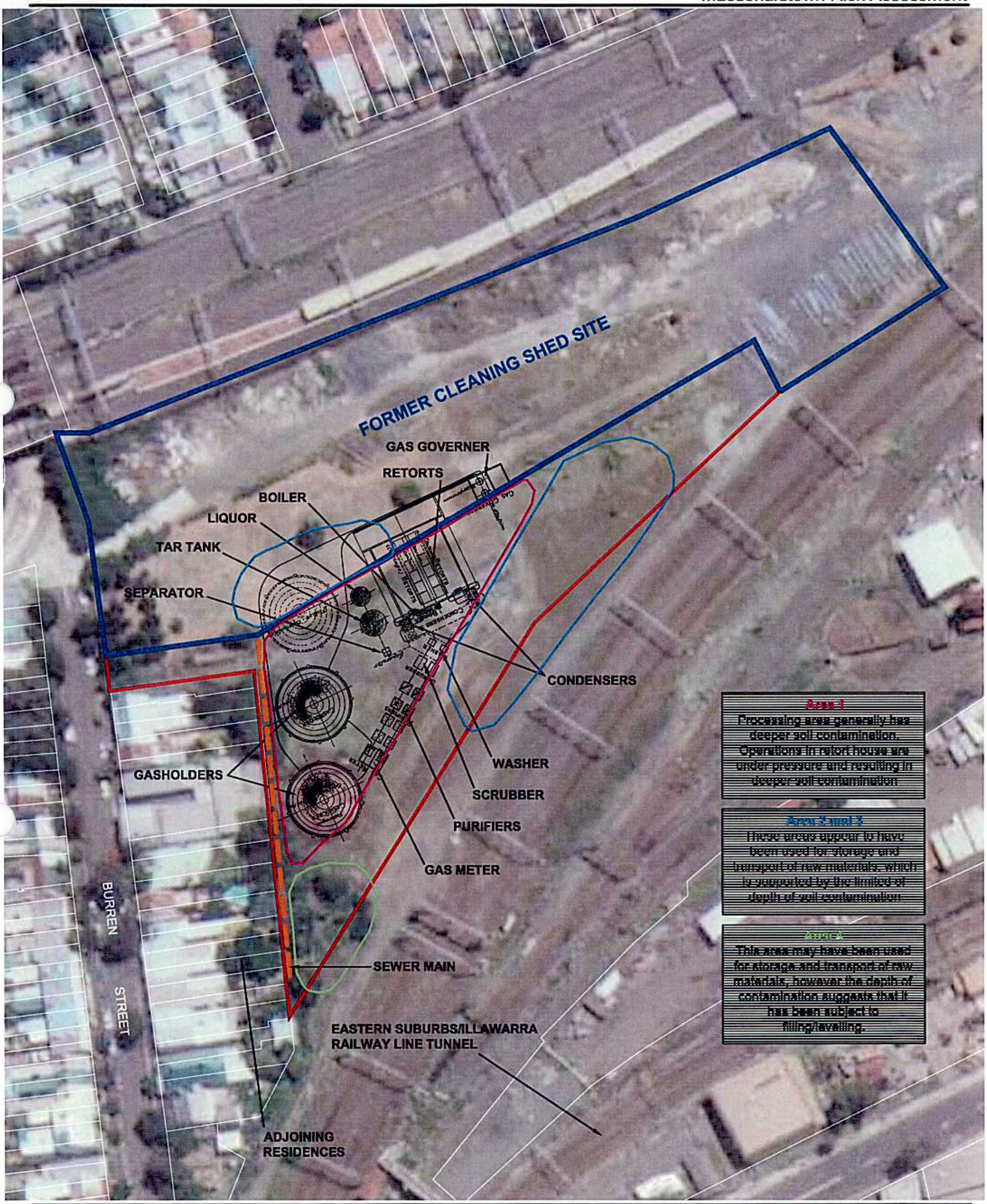
3.1 Site Location and Surrounding Land Uses

The Former Gasworks site along with the adjacent Former Cleaning Shed site is referred to as "The Macdonaldtown Triangle" and is identified as Lot 50 in Deposited Plan 1001467 in the Local Government Area of South Sydney, Parish of Petersham and County of Cumberland. The site comprises the former gasworks area and the former cleaning sheds (**Figure 4**). Two additional areas, referenced as the "Neck" and the "Adjoining properties" also make up part of the site, however these are not to be considered under the current scope of works. Groundwater wells that have been installed in these areas may however be included in the sampling regime and groundwater modelling exercise.

A gasworks operated by the predecessors of StateRail formerly occupied approximately 8,000 m^2 of "The Macdonaldtown Triangle" site, with the remaining 15,000 m^2 being used for a range of railway related activities that included cleaning, sheds and rail sidings. The site is generally bounded by railway and rail related activities to the north, the south and east. The Former Cleaning Shed site to the north is to be redeveloped by RailCorp for use as a train stabling facility that is to consist of six siding tracks, staff amenities buildings, drainage infrastructure and landscaping. Residential properties are located to the west.

The site is generally unsealed, triangular in shape, with all buildings and structures removed except for two disused gas holders in the south west of the site and associated structures such as tar pits and building foundations. Surrounding land uses include Macdonaldtown Railway Station and the main Western railway line to the north, railway lines to the east, the Illawarra railway line to the south and residential properties to the west.

Figure 4
SITE LAYOUT
Macdonaldtown Risk Assessment



LEGEND
- GASWORKS SITE
- CLEANING SHED SITE

0 10 20 30 40 50 60 m

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3.2 Topography and Surface Hydrology

The Former Gasworks site slopes gently towards the south west, with the northern boundary being approximately 20.3 m AHD and the northwest corner, close to Burren Street and the residential properties being approximately 19.9 m AHD. A 2 metre high retaining wall and grassed embankment separates the Site from the former gasworks area.

Surface water at the Site is likely to run towards the Illawarra railway line located beyond the southern boundary of the Site. A concrete lined surface water drain is installed along the western boundary of the site and this is considered likely to receive surface water runoff after migrating across the southern boundary of the Site.

3.3 Geology

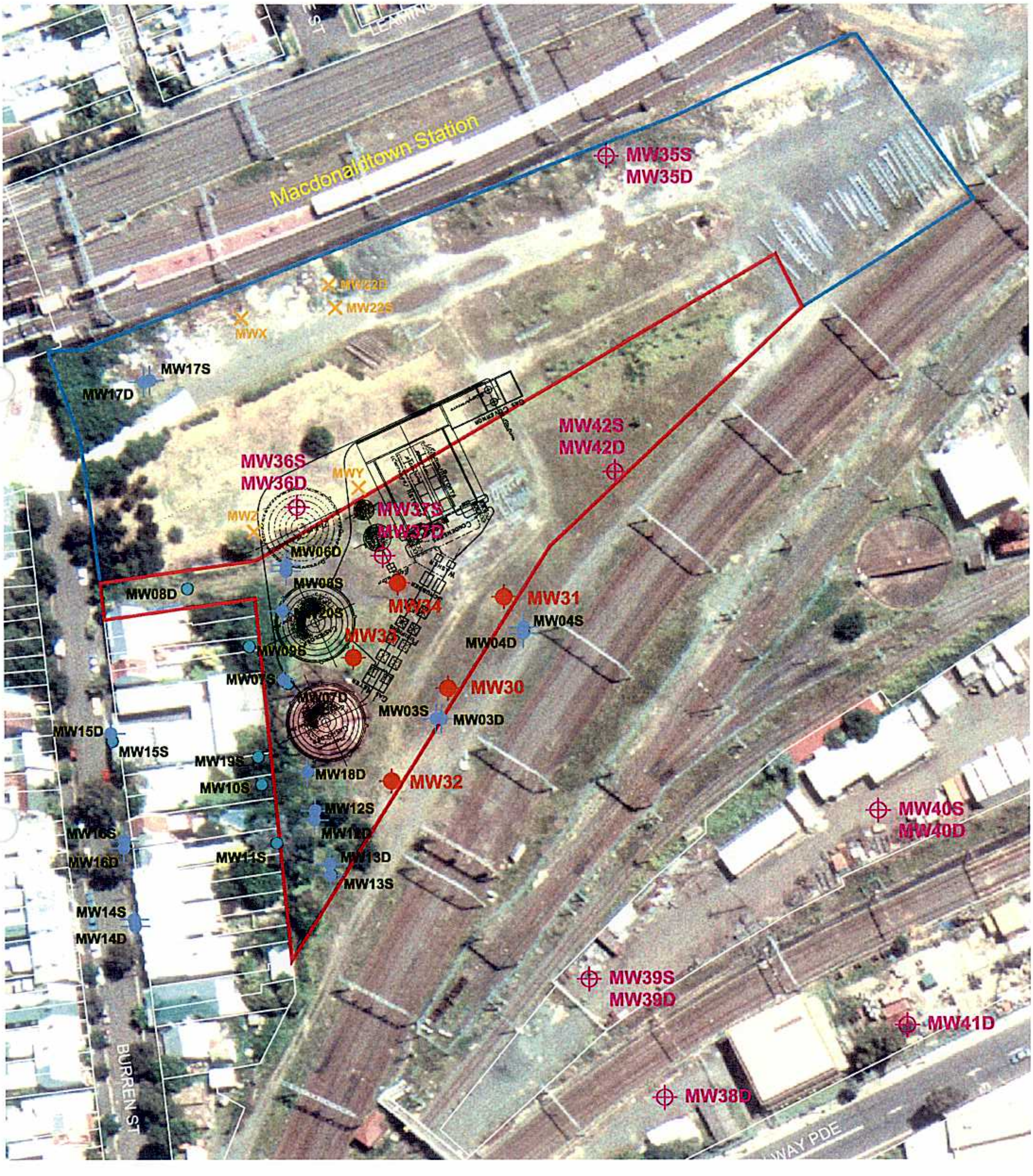
The Geology of the Sydney 1:100,000 Sheet (Ed. 1, Sheet 9130, 1983) indicates that the Macdonaldtown Triangle area is underlain by Ashfield Shale comprising black to dark-grey shale, siltstone, laminite, calcareous claystone and coal. Ashfield Shale belongs to the Middle Triassic Epoch and is part of the Wianamatta Group.

Residual soils in the vicinity of the Site are classified in the Soil Landscapes of Sydney 1:100,000 (Sheet 9130, 1983) as part of the Blacktown group. The group are described as shallow to moderately deep red and brown Podzolic soils on crests, upper slopes and well drained areas. Deep yellow Podzolic soils and Soloths on lower slopes and in areas of poor drainage. Limitations for the Blacktown groups are moderately reactive highly plastic subsoil, low fertility and poor soil drainage.

The boreholes undertaken as part of this risk assessment encountered a fill layer to a depth of 0.4 – 2.5 m close to the northern boundary at MW35D and MW35S, respectively, as shown in **Figure 5**. Weathered shale was found below this depth to a maximum depth of 12.2 m at MW35D, at which depth the borehole was terminated. Fill was encountered to a depth of 0.6 m at MW33 in the central portion of the site underlain by residual, silty clay with ironstone nodules. At MW34 fill was encountered to a depth of 0.4 m with silty clay below this. Along the eastern boundary of the site at 42D, fill was encountered to a depth of 2.3 m with predominantly residual clay found below this at a depth of at least 12 m.

Copies of all borehole logs provided in previous investigation and prepared as part of this study are provided in **Appendix A**.

Figure 5
SAMPLE LOCATIONS
Macdonaldtown Risk Assessment



LEGEND

- GASWORKS SITE
- CLEANING SHED SITE
- CH2MHILL MONITORING WELL LOCATIONS
- CH2MHILL MONITORING WELL LOCATIONS NOT PREVIOUS IDENTIFIED
- SKM GROUNDWATER MONITORING WELL LOCATIONS (1 DEEP AND 1 SHALLOW)
- SOIL VAPOUR MONITORING WELLS

0 10 20 30 40 50 60 m

N

AUSIMAGE

SKM

3.4 Hydrogeology

Groundwater beneath the Site flows in a south and southeast direction towards the Illawarra railway and the concrete drain. Standing groundwater levels ranged from 1.0m below ground to 9.5mbgl (metres below ground level). The main water bearing stratum at the Site is likely to be the shale bedrock. Due to a clay layer overlying the aquifer, it is likely that the aquifer is semi-confined and this was supported by the site inspection, where artesian waters were observed to flow from MW14D and MW15D. In this area the groundwater aquifer is sufficiently contained for groundwater to be forced towards the ground surface.

A more detailed assessment of the hydrogeological conditions at the Site is provided in **Section 10**.

3.5 Surface Conditions

The Site is grassed in areas with a large portion of the north-east corner of the Site being covered with a gravel layer. A gravel roadway is located along the northern boundary of the Site, adjacent to the retaining wall found along the boundary with the former cleaning shed site. Trees are located along the western boundary of the Site.

3.6 Underground Structures and Buried Services

A number of elements of the former gasworks plant (retorts and gas governor) were once situated along the northern boundary of the Site, as shown in **Figure 6**. The retort house was an elaborate and substantial structure adjacent to the retaining wall and consisted of a variety of components including coal/ shale stores, boiler rooms and offices. Below ground structures associated with these components of the former gasworks are likely to remain as sub-surfaces features on the southern boundary of the Site.

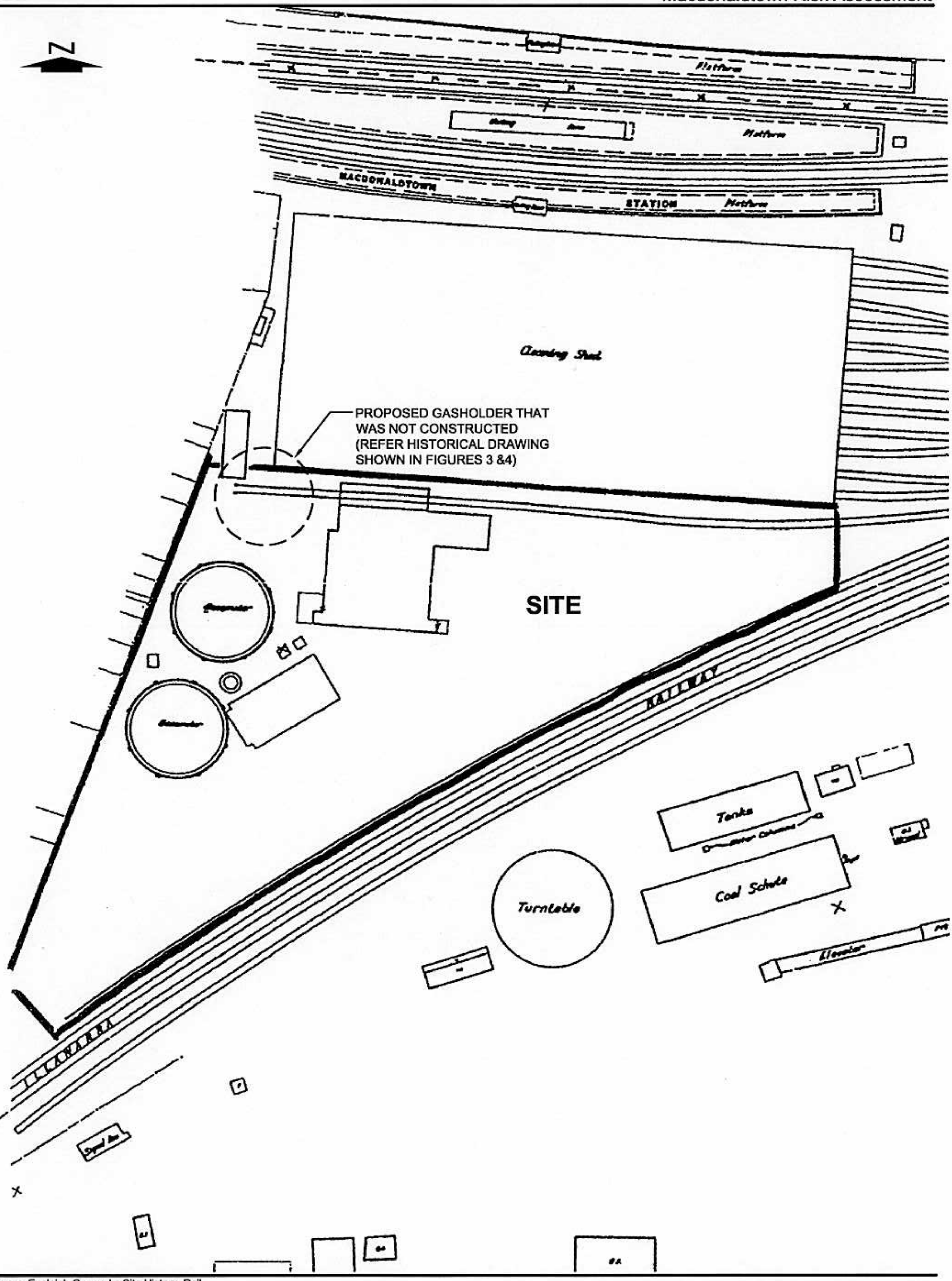
The tar and liquor tanks were located close to the retort house, with below ground structures located close to the northern boundary of the former gasworks site.

A retaining wall with an approximate height of 1.5m runs across the northern perimeter of the Site and is in a poor condition consisting of cemented brick with integral vertical rail supports that in several locations has collapsed.

Adjacent to the retaining wall and the residential area in the north western portion of the site, a concrete slab is raised about 0.8 m above the ground level, with separate vertical buffs to prevent vehicle damage. The top of the concrete slab (12.1 x 2.9 m) is believed to have been prepared to support a timber frame superstructure. It was believed that it was likely to be an office or store area.

SKM

Figure 6
HISTORICAL LAYOUT OF THE MACDONALDTOWN TRIANGLE AREA
Macdonaldtown Risk Assessment



Source: Eveleigh Gasworks Site History, Rail Services Australia Environmental Services, November 1999

RailCorp and Dial before you Dig records indicate a number of underground services are located within the Site boundary. Services located at the Site include:

- A telephone cable in the north-west corner of the Site;
- Energy Australia 240V Station Supply located along the western boundary; and,
- Low Voltage (LV) supply to Erskineville Signals Depot via steel cable inspection pits positioned along the length of the surface drain.

3.7 Sensitive Environments

The surrounding land use is a mix of industrial and residential. Industrial land is associated with the vacant railway land and the Macdonaldtown railway station and main western line to the north of the site and active rail track to the east and south of the Site. The presently vacant area immediately to the north of the site, referred to as the Cleaning Shed area, is to be turned into a train stabling facility for CityRail.

Residential land is associated with the 'Standard' residential properties located to the west of the site along Burren Street. Many of these properties are old terrace housing, while some of the blocks becoming redeveloped as modern town houses and apartments. The residential properties along Burren Street represent the most sensitive adjacent land use in the area.

4 Site History

This section of the report provides an assessment of the past land uses that have occurred at the Site and in the surrounding areas that are likely to be the main causes of ground contamination in the area. The information provided by this assessment, together with the results obtained by previous investigations, was used as the basis for developing the investigation strategy for the additional investigation work undertaken as part of this assessment.

4.1 Sources of Historical Information

RailCorp provided SKM with the following reports on investigations and assessments that have been undertaken at the Site, these being:

- CH2MHill (13 June 2000) "Macdonaldtown Triangle Phase I and Phase II Environmental Site Assessments."
- CH2MHill (November 2001) "Soil and Groundwater Investigations of the Former Gasworks Area and Off Site, Macdonaldtown Triangle, Erskineville."
- GHD (1995). *Macdonaldtown Rail Yard: Development of Environmental Buffer Zone for the Local Residents*. October 1995.
- Banksia Heritage and Archaeology (2004). *Macdonaldtown Station Works – Archaeological Assessment*. April 2004.
- Rail Services Australia (1999). *Eveleigh Gasworks Site History*. October 1999.

Other sources of historical information include RailCorp records and aerial photographs.

4.2 Previous Layout and Activities

The Macdonaldtown Site was acquired by the 'Railways' in 1888. Although previous land titles dating back to 1794 are available, they do not include details of the Site usage.

Construction of a small gasworks at the Site started prior to 1891 (GHD, 1995), with construction completed in 1892. It is understood that the gasworks was constructed to provide lighting for carriages, stations, signals and railyards. The gasworks comprised a retort house and two gasholders.

Records indicate that the gasworks included two tar pits (located west of retort house). Gas production ceased during the 1950's due to poor quality feed stock being used in the gas production process. Although plant and machinery associated with the gas production were demolished and removed in 1958, the gasworks continued to be used for gas storage until the mid 1970's.

Information provided by RailCorp indicates that the Site located to the north of the gasworks was used for cleaning sheds and railway sidings. Operations continued until the mid 1980's, after which the buildings and railway tracks were removed. Since the 1980's the Site has been used as a staging depot for the storage and fabrication of materials for track upgrading and renewal projects (CH2M Hill, 2000).

The general layout of the former gasworks and location of structures in relation to the Site boundary is shown in **Figure 4,** which is based on information provided by Rail Services Australia (1999).

4.3 Historical Aerial Photographs

A review of aerial photographs is included in the CH2MHill Phase 1 and 2 Environmental Site Assessment Report (CH2M Hill, 2000). Summary information on the historical aerial photographs is provided below.

1961 Photograph – The 1961 photograph shows the presence of a large rectangular building located along the northern boundary of the Cleaning Sheds area. This is assumed that this is the building used for the cleaning of railway carriages and as railway sidings. The two gasholders are visible on the former gasworks site along with two smaller rectangular buildings. The first of these buildings is located along the southern side of the large railway shed, in the approximate position of the retort house. The second building lies in a southwest – northeast direction, located to the east of Gasholder No.1. The building seems to include chimneys and is possibly the gas purifying process buildings.

The surrounding land use is appears to be the same as it is today with the residential properties to the west and the surrounding railway infrastructure.

1970 Photograph – The building located along the southern edge of the large railway building (possible retort house) has been removed. Gasholder No.2 and possibly the gas purifying building have also been removed from the site (CH2M Hill, 2000).

1986 Photograph – The large railway building has been removed, with only the concrete floor slab and railway tracks remaining. The remainder of the Site is unchanged (CH2M Hill, 2000).

1999 Photograph – The Site appears as present (CH2M Hill, 2000)

4.4 History of Surrounding Properties

The earliest photographs show the surrounding land use to be consistent with present usage, as described previously in **Section 3.1**.

4.5 Heritage Aspects

The archaeological assessment undertaken by Banksia Heritage and Archaeology (Banksia Heritage and Archaeology, 2004) indicates that all structural remains of the retort house and gas governor are likely to have been removed, with these features now providing negligible significance in regards to heritage aspects.

The retaining wall is also considered to be of low significance and is a common modern type - rail infrastructure item.

SKM

5 Review of Previous Investigations

This section of the report provides an assessment of the site contamination data provided in previous investigations conducted at the Former Gasworks site and the overall Macdonaldtown Triangle area. The available information is initially identified (Section 5.1) followed by an assessment of the main investigation reports (Sections 5.2 to 5.4). Information obtained from an early site inspection conducted by SKM is then presented (Section 5.5). Assessments of the available data are then provided (Section 5.6), which include an analysis of soil data from the Former Gasworks site, a groundwater analysis and the identification of data uncertainties. The data provided by the previous investigations is then used to define a conceptual contamination model for the site (Section 5.7). This model is then used to determine the data gaps that existed in the information provided by the previous investigations (Section 5.8), which forms the basis for the design of the investigation program undertaken for this study.

5.1 Available Information

Stage 1 and 2 Environmental Assessments were undertaken at the Former Gasworks site by CH2MHill in June 2000 and additional investigations were undertaken at the Site and in the surrounding area in November 2001.

SKM has reviewed all available site contamination reports previously undertaken at the Macdonaldtown Triangle area, which comprise in chronological order:

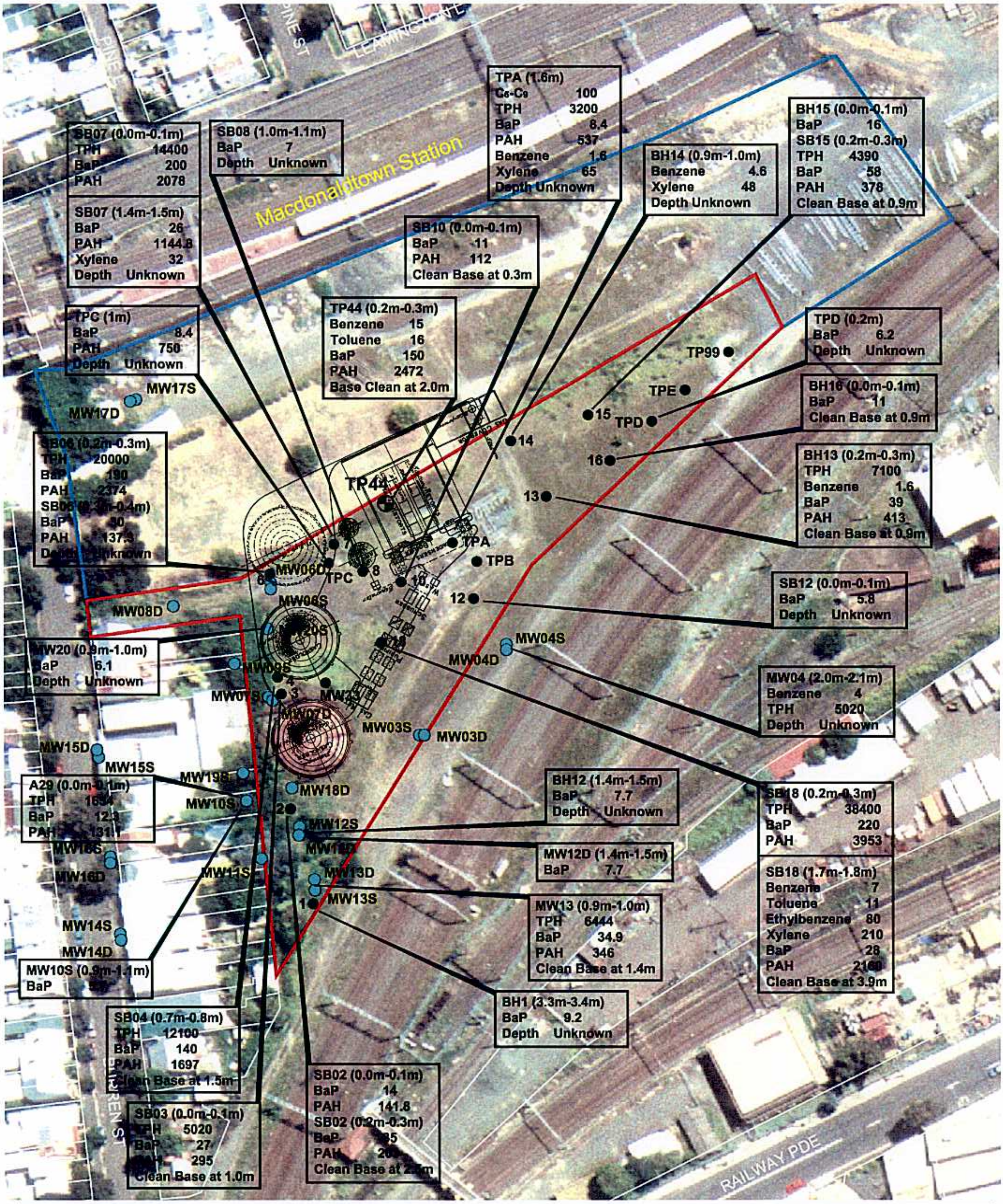
- IT Environmental (April 1999). *"Environmental Condition Audit, 4GT Maintenance Facility – Eveleigh Rail Yards"*;
- CH2MHill (13 June 2000*) "Macdonaldtown Triangle Phase 1 and 2 Environmental Site Assessments"*;
- CH2MHill (November 2000) *"Vegetable, soil and sediment sampling from the Former Gasworks Area of the Macdonaldtown Triangle, Erskineville, New South Wales"*; and
- CH2MHill (November 2001) *"Soil and Groundwater Investigations of the Former Gasworks Area and Off Site, Macdonaldtown Triangle, Erskineville"*;

The information obtained by the IT (April 1999) report was included as part of the CH2MHill (June 2000) report, with the main findings summarised in **Section 5.2**. The main findings of the two later CH2MHill reports are summarised in **Sections 5.3** and **5.4**, followed by a review of the groundwater data in **Section 5.5**.

The locations where contamination was found by previous investigations to exceed Investigation Levels are shown in **Figures 7** and **8**, with copies of figures from earlier reports showing all sampling locations provided in **Appendix G**.

SKM

Figure 7
FILL MATERIAL HOT SPOT IDENTIFICATION
Macdonaldtown Risk Assessment



LEGEND

GASWORKS SITE

CLEANING SHED SITE

NOTE

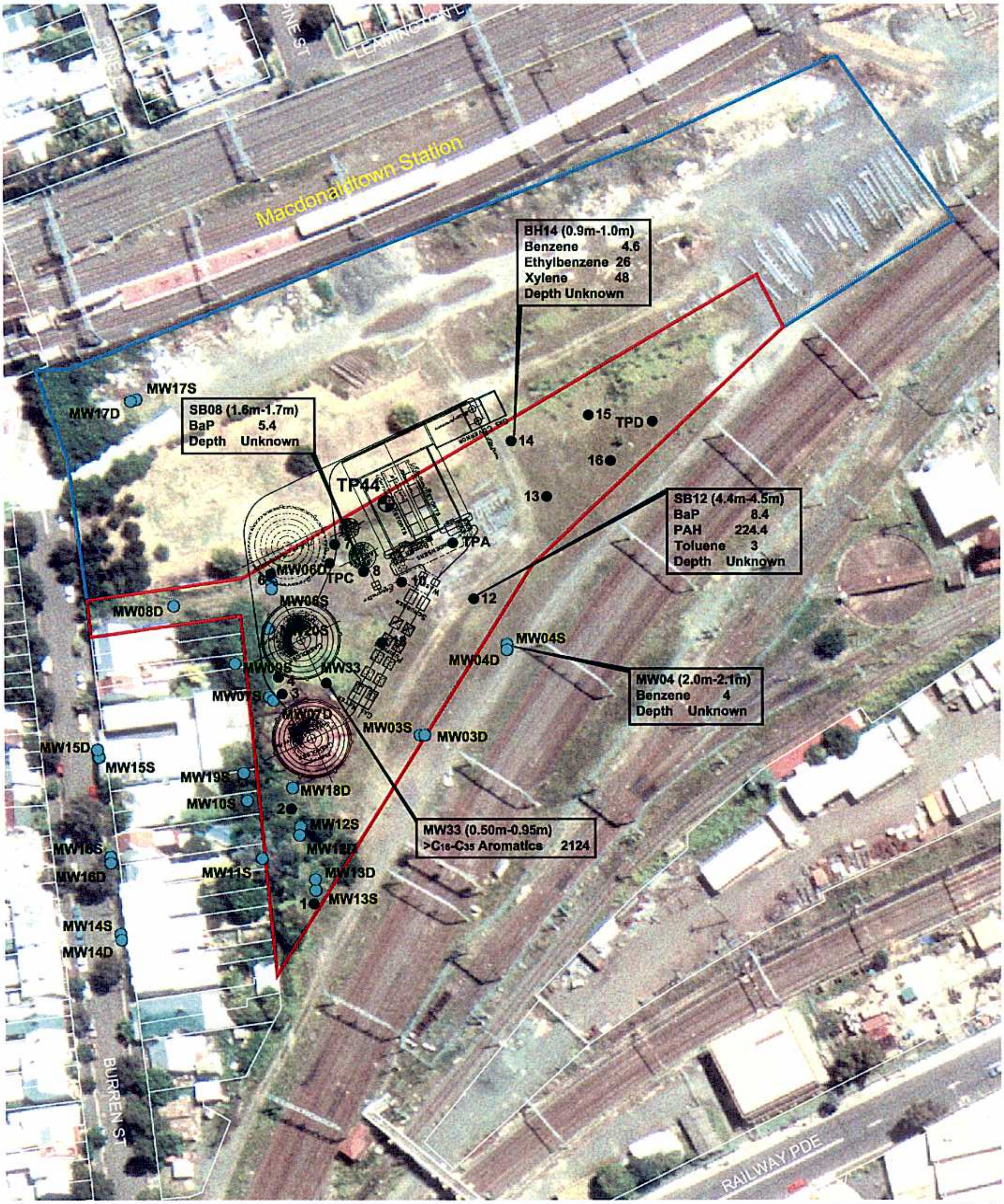
ALL CONTAMINANT CONCENTRATIONS IN mg/kg

0 10 20 30 40 50 60 m

N

AUSIMAGE

Figure 8
NATURAL MATERIAL HOT SPOT IDENTIFICATION
Macdonaldtown Risk Assessment



LEGEND
- GASWORKS SITE
- CLEANING SHED SITE

NOTE
ALL CONTAMINANT CONCENTRATIONS IN mg/kg

0 10 20 30 40 50 60 m

N

AUSIMAGE

SKM

5.2 CH2MHill 13 June 2000

This Phase 1 and 2 Environmental Site Assessment involved an investigation across the Macdonaldtown Triangle area that included sampling soils at 50 locations and the investigation of groundwater at 3 shallow (up to 2m) and 3 deep (up to 10m) monitoring wells designated MW 03S, MW 03D, MW 04S, MW 04D, MW 06S and MW 06D. The main findings made by the investigation are as follows.

Former Cleaning Shed Area

- Fill consisting of sand, gravel, ballast, ash and coke is widespread across the area at varying depths of between 0.2 to 2.5m.
- 25 sampling locations were investigated across the Former Cleaning Shed Site with 40 samples analysed for heavy metals, 39 samples analysed for PAHs; 5 samples analysed for VOCs; 29 samples analysed for BTEX, and 3 samples analysed for TPH, phenols, OCPs and PCBs.
- Soil samples analysed were generally below the *Investigation Levels*, however isolated hot spots of contamination were identified including PAHs, benzene and toluene.

Former Gasworks Area

- Fill material was found to be widespread across the Former Gasworks area, varying between 0.1 to 3.2m in depth.
- Contamination including TPH, PAH and BTEX is widespread throughout the fill material but not in the underlying natural soils, as shown in **Figures 7** and **8.**

Groundwater Assessment

- Groundwater investigations of both the surficial and Ashfield Shale aquifer were only undertaken in the former gasworks area due to the thin layer of fill and the extensive nature of a concrete slab identified below the surface of the former cleaning shed area.
- For the surficial aquifer, PAH, TPH, metals, phenols and BTEX contamination was identified exceeding the ANZECC 1992 criteria by up to three orders of magnitude. The groundwater is expected to flow towards the south south-east but may be affected by underground structures. There is also the potential for surficial groundwater to seep out along fill material into an open drain adjacent the southwestern boundary and/or onto residential properties.
- Concentrations of PAHs, benzene, heavy metals and phenols in the fractured Ashfield Shale Aquifer exceeded the ANZECC 1992 Guidelines. The groundwater in this aquifer is expected to flow in a south south-east direction but may be affected if any of the remaining structures extend to its depth.

Recommendations

The recommendations made by the Phase 1 and 2 Environmental Site Assessment were:

- Notification to the EPA with respect to the potential for the Site to pose a "significant risk of harm".
- Cessation of all works in the former gasworks area.
- Minimise activities in the Former Cleaning Shed area for access purpose only.
- Cessation of public access and usage of the Site by local residents.
- Development of an EMP, OH&S, and RAP for the Macdonaldtown Triangle area.
- Development of a community information strategy to inform all relevant stakeholders.
- Undertake a soil gas survey, surface soil sampling and surficial groundwater sampling program within the residential properties bounding the south-western portion of the Site.
- Collection of soil samples from vegetable gardens currently being used by local residents on Site.
- More detailed assessment of the groundwater quality of both the shallow aquifer and deeper fractured Ashfield Shale aquifer.
- Prior to future development to the north east of the area, soil sampling should be undertaken in this area to assess whether the soil contamination identified in the Former Cleaning Shed area extends across the investigation boundary.

5.3 CH2MHill November 2000

The CH2MHill report identified a surface drain located along the western boundary of the former gasworks site that was considered likely to receive surface water from the Former Cleaning Shed and Former Gasworks areas. Investigations conducted as part of the November 2000 report involved the collection of sediment samples at three sampling locations along the drain to assess the potential for contamination to migrate from the Macdonaldtown Triangle area.

The results indicated that concentrations of lead, TPH C_{10}-C_{36}, benzo(a)pyrene and total PAHs were greater than the adopted *Investigation Levels* for commercial/industrial land use. The report concluded that the drain was impacted by contamination from the former gasworks operation, although the migration was considered to be limited, with decreasing contaminant levels away from the investigation area.

5.4 CH2MHill November 2001

The aim of the assessment was to further delineate the status of groundwater quality and soil contamination within the western portion of the former gasworks area together with selected properties to the west along the eastern side of Burren Street.

Twenty-one groundwater wells were constructed that included 12 shallow and 9 deep monitoring wells. The majority of locations comprised a nested pair of shallow and deep wells.

East Burren Street Residential Area

- Soils consisted of fill up to 0.8m deep over natural clays.
- Soil samples collected and analysed from all four residential backyards tested indicated that some potential contaminants of primary concern (CoPC) have been identified that exceed the *Investigation Levels*.
- The CoPC include lead, TPH and PAH.
- The CoPC were identified in both soils at the surface and below the surface.
- Groundwater was recorded at approximately 1m below ground surface.
- Groundwater flows towards the south and south-east.
- Groundwater does not appear to flow from the former gasworks towards the residences along Burren Street.
- Analytical results for samples from both the deep and surficial aquifers in the residential area were either below the Limit of Reading (LOR) or the *Investigation Level.*

Former Gasworks Area

- Fill was encountered between 0.3 and 4.4m deep.
- TPH and PAH levels exceeded commercial/industrial *Investigation Levels* in soil collected from three shallow samples in the fill horizon.
- The hydraulic gradient appears slightly "flatter" within the shallow horizon.
- Shallow groundwater flow appears locally disturbed as a result of the presence of the former gasometers.
- The surface water drain along the north-south boundary between the Burren Street Residential Area and the former gasworks area may be preferentially capturing or redirecting flow from the shallow horizon.
- The volume of groundwater discharging beneath and off the former gasworks area has been estimated at approximately 1,000m^3/year and 200m^3/year for shallow and deep horizons respectively.
- In general, the CoPC were present at lower concentrations than recorded in the June 2000 investigation.
- CoPC were detected at levels that exceed the nominated criteria.

Recommendations

- Prepare a site-specific Environmental Management and Occupational Health and Safety Management Plan and a Remedial Action Plan;
- Conduct supplementary assessments to clarify uncertainties relating to the degree and extent of environmental issues, these being:
  - Shallow soil investigations at selected and as yet untested yards located adjacent to the western boundary of the FGW and the EBS to better define the degree and extent of impacted soil in this area;
  - Evaluate water condition, flow and potential receptors associated with the "dish drain" adjacent the western edge of the former gasworks area;
  - Evaluate groundwater conditions off-site and down gradient of the southern boundary of the former gasworks area, identify potential receptors and pathways and better define the potential down gradient off-site environmental risks; and
  - Undertake ongoing monitoring of the groundwater wells to better establish trends for groundwater condition and help to validate the assumptions discussed regarding the local hydrogeological flow regime and allow a more complete and therefore reliable quantitative risk assessment, if appropriate.

5.5 SKM Site Inspection

SKM personnel undertook a site inspection on Thursday 1st April 2004 to check the status of the existing wells to determine whether they were suitable for additional use during additional monitoring events. The inspection found that the majority of the wells installed during the previous investigations were still useable with the exception of two of the wells.

Five monitoring wells were identified at the Macdonaldtown Triangle area that are not located or mentioned in any of the previous reports by CH2MHill. The construction and locks on the monitoring wells suggested that they were installed by CH2MHill. One pair of unknown wells were labelled MW 22S and MW 22D, and the remaining three wells have been labelled MW X, MW Y and MW Z. Four out of the five additional monitoring wells were found to be operational and contained water.

During the inspection of the monitoring wells, water levels were taken to assist in calculating groundwater contours and monitoring wells were purged in order to allow for groundwater recharge. Groundwater was observed to rise and flow from the top of MW14D when it was opened. This well is located on the footpath at Burren Street. Groundwater was also observed to be flowing from MW15D with water flowing out of the top of the well into the street gutter. The workers at the residential property informed SKM that the water had been flowing from the well for the duration of time that they had been working on the premises (since November 2003). The gatic cover was lifted and the cap was found to be missing.

MW15S is a shallow monitoring well that records show to have been located on the footpath in Burren adjacent to a residential property (DP79745) but which could not be found by SKM at the time of the site inspection. In the past 2 years this property has been redeveloped and a set of new apartments constructed. It is possible that this well could have been destroyed or covered over during that period.

Table 1 lists the monitoring wells identified during the site inspection, the groundwater levels that were measured in the monitoring wells and the status of the wells.

- **Table 1 Status of Monitoring Wells from Previous Investigations**

Monitoring Wells	Groundwater Level (mbgl)	Functional	Comments
MW 03S	1.95	Yes	No odour, silty
MW 03D	3.62	Yes	Very strong hydrocarbon odour, very clear water
MW 04S	1.25	Yes	Odour, silty
MW 04D	3.15	Yes	Odour, clear
MW 06S	5.42	Yes	Strong hydrocarbon odour
MW 06D	1.65	Yes	
MW 07S	3.1	-	Well was dry
MW 07D	2.47	Yes	Extreme hydrocarbon odour, clear
MW 08D		No	Bailer or dipper would not go down past 1.5m from top of monument box. May be able to be fixed.
MW 09S		-	Not checked as well located in residential property
MW 10S		-	Not checked as well located in residential property
MW 11S		-	Not checked as well located in residential property
MW 12S	4.5	Yes	Very little water, no odour, bailer stained orange
MW 12D	3.88	Yes	No odour, water relatively clear
MW 13S	3.96	Yes	No odour, water is orange
MW 13D	3.78	Yes	No odour, water relatively clear
MW 14S	2.0	Yes	No odour, water relatively clear
MW 14D	0	Yes	Groundwater relatively clear and flowing out of top of well
MW 15S		No	Could not be located
MW 15D	0	Yes	Groundwater flowing out of top of well, slight hydrocarbon odour. Cap was not on well.
MW 16S	2.04	Yes	Strong sulfur odour, bailer and water very black at bottom of well
MW 16D	0	Yes	Strong sulfur smell, groundwater slowly rising above top of well.

Monitoring Wells	Groundwater Level (mbgl)	Functional	Comments
MW 17S	2.75	Yes	Very silty, orange staining
MW 17D	1.9	Yes	No odour, relatively clear water
MW 18D	3.25	Yes	Orange staining, No odour
MW19S		No	Could not be found
MW 20S	0.7	Yes	Well appears blocked approx. 0.5m below the bottom of the well. Monument stand is loose. Bailer and string stained black. Groundwater black. Slight HC odour.
MW 22S		-	Unable to get dipper or bailer down well. May be able to be fixed
MW 22D	2.08	Yes	No odour, very silty, dark brown
MW X	1.3	Yes	No odour, relatively clear water
MW Y	2.7	Yes	Well depth approx. 3.8m, sulfur odour, orange staining
MW Z	3.36	Yes	Well depth approx. 3.75

5.6 Conceptual Site Contamination Model

5.6.1 Potential Sources of Contamination

The historical, site and contamination data provided by previous investigations at the Macdonaldtown Triangle Area indicate that the potential sources of ground contamination at the Former Gasworks area related to the former use of these areas as a gasworks and railway-related activities. The available data is considered to support the adoption of the following sources and laydown mechanisms for contamination at the Macdonaldtown Triangle Area:

- Dumping of waste materials from the former gasworks operation (eg. ash, spent oxide, coke, tar, ammoniacal liquors);
- Dumping of waste materials from former railway uses (eg. ash);
- Leakage of liquid wastes from pits, tanks and gas holders (eg. tars, phenolic wastes, ammoniacal liquors);
- Spillage of lead-based paint from former structures and train maintenance;
- Spillage of chemicals used for train cleaning (eg. solvents);
- Spillage of oils and greases from former train usage and maintenance;
- Atmospheric deposition of contaminants from the heavy industrial use of the general Erskineville/Macdonaldtown/Redfern area;
- Importation of contaminated fill; and

- Migration of contaminated groundwater from railway operations up-gradient of the site such as at the former Eveleigh railyards.

5.6.2 Potential Contaminants of Concern

Potential contaminants of concern that may be present at the Site, based on the potential contaminant sources listed in the previous section, are summarised in **Table 2**.

- Table 2 Potential Contaminants of Concern

Contaminant	Areas of Environmental Concern
Fuels, oils, tar and greases	Gasworks waste disposal areas, tanks, former tank locations, pits, pipelines, drums and containers and possibly buried disposal areas, rail activities
Heavy metals	Gasworks waste disposal areas, coal stockpiles, treatment processes, pipes, roof and window flashing (borders / waterproofing), batteries, general refuse
Semi volatile and Volatile organic compounds	Gasworks waste disposal areas, tanks, former tank locations, pits, pipelines, drums and containers and possibly buried disposal areas
PAHs	Gasworks waste disposal areas, coal stockpiles, tanks, former tank locations, waste drums and containers

These analytes correspond to recommendations given in the Contaminated Sites Monograph Series No. 3 (1994) *'Identification and Assessment of Contaminated Land, Improving Site History Appraisal'* and relevant NSW DEC guidelines (eg. service stations and gasworks).

5.6.3 Environmental Media of Concern

Information provided by previous investigations on the Site indicate that the environmental media that need to be targeted are as follows:

- Shallow soils and fill layer (depth generally 0-1.5m);
- Deeper soils comprising predominantly undisturbed, natural soils (depth generally >1.5m);
- Groundwater; and
- Soil-gas.

Ambient air quality was also identified as a potential issue since the previous investigations found some hot-spots and groundwater contaminated with volatile organic hydrocarbons such as benzene and naphthalene.

SKM

5.6.4 Potential Receptors

As previously mentioned in **Section 2.1**, it is understood that the site will remain the property of RailCorp and continue to be zoned to allow commercial/industrial land, although it is not known what site activities will occur or if any structures/ buildings will be established on the site.

The potential receptors of ground contamination from the Macdonaldtown Triangle area are expected to be:

- Future commercial/industrial users of the site;
- Future maintenance / construction workers at the Site and surrounding areas;
- The community who live in residential land adjacent to the western boundary of the site (**Figure 4**) and users of any groundwater extracted from wells down-gradient of the site; and
- Freshwater aquatic ecosystems.

Freshwater aquatic ecosystems have been included as a potential receptor even though the nearest water body is the headwaters of Alexandra Canal (Sheas Creek) located some 1.3km to the south of the Site (**Figure 1**). At this location the creek flows would consist of surface water drainage from the Redfern/Alexandria area that would be largely unaffected by tidalal influences from the receiving waters in Botany Bay. The subsurface conditions for much of the distance between the Site and the Canal consist of residual clays and shale, and the hydraulic heads are low given the relatively flat, uniform topography. Aquatic ecosystems have been included since there is a risk that extracted/intercepted groundwater could be discharged into the stormwater system that would discharge into Alexandra Canal. An example of such an exposure pathway is the possible interception of contaminated groundwater by drainage systems inside the Eastern Suburbs/Illawarra railway line tunnel that is located approximately 100m from the southern boundary of the Macdonaldtown Triangle area, as shown in **Figure 4**.

5.7 Assessment of Data from Previous Investigations

5.7.1 Assessment of Soil Data

The soils at the Former Gasworks site were extensively investigated by other environmental consultants between 2000 and 2001, with the results of these investigations presented in two reports (CH2MHill, 2000 & 2001). Copies of figures from earlier reports showing all sampling locations at the Gasworks areas are provided in **Appendix G,** together with summary tables of the laboratory data. These figures show that the soil sampling locations are reasonably well spread out across the Former Gasworks site and that the data provided by the previous investigations should be representative of site conditions. The soil sampling locations where contamination was found by previous investigations to exceed the *Investigation Levels* in the fill material and natural soils are shown in **Figure 6** and **Figure 7**, respectively.

On account of the available data from previous investigations, the SKM investigation conducted as part of this risk assessment has only focused on the collection of a few soil samples required as part of assessments for soil-vapour, as discussed in **Section 5.8.** These few additional data points have been included in the assessment of soil data presented below.

A summary of all laboratory results obtained for soil samples in the Former Gasworks area is provided in **Table B** in **Appendix B**. This table identifies each soil sample that has been tested, the time the sample was collected, its sampling depth, material type and the concentrations for all analytes tested. The soils have been divided into two material types, these being fill and natural undisturbed soils. The total number of soil samples tested for contaminants of concern for each material type are summarised in **Table 2b**. The potential contaminants of concern are as listed in **Section 5.6.2** with the Soil Acceptance Criteria (SAC) for these contaminants discussed in **Section 8.1**.

- **Table 2b Sampling Frequency for Soils at the Former Gasworks Area**

Potential Contaminant of Concern	Number of Samples Tested		Total
	Fill	Natural Soil	
Heavy metals (arsenic, cadmium, chromium, copper, nickel, lead & zinc)	45	17	62
Heavy metals (mercury)	41	17	58
Total cyanide	12	4	16
BTEX	38	21	59
TPH	24	11	35
PAHs	46	19	65
Total phenols	21	4	25
OCPs	4	0	4
PCBs	3	1	4
VOCs	8	1	9
Asbestos	15	0	15

The NSW EPA (1995) sampling guidelines and the NEPC (1999) guidelines recommend a minimum sampling frequency of 19 samples for a 0.8 ha area. The results indicate that the available data provided by the investigations for the Former Gasworks site meet the NSW DEC minimum sampling requirements as follows:

- Fill layer - heavy metals, BTEX, TPH, PAHs, total phenols.
- Natural soils – BTEX and PAHs

SKM considers the sampling frequencies achieved for the other potential contaminants of concern are acceptable for the purposes of this risk assessment because the concentrations measured for these other analytes were low and well below the soil acceptance criteria. Furthermore, the lower sampling frequencies achieved for the natural soils are considered acceptable since the risk of contamination from these other contaminants is generally lower in these deeper, clayey soils.

All the laboratory soil data for the Former Gasworks Area have been statistically analysed. For each contaminant, the analysis involved the calculation of the average concentration, standard deviation, coefficient of variation (CV) and the estimate of the true average concentration for a 95% Upper Confidence Limit (UCL). The results of the statistical analysis made by the previous investigations are presented in **Tables C** and **D (Appendix B)** for the fill materials and natural soils, respectively.

The data indicate that the fill layer is mainly contaminated with high levels of PAHs and TPH C10-C36 distributed over much of the site. This is indicated by the 95% UCL estimates of the true mean, which are:

- Total PAHs = 586 mg/kg (SAC = 100 mg/kg)
- Benzo(a)pyrene = 38.7 mg/kg (SAC = 5 mg/kg)
- TPH C10-C36 = 8,010 mg/kg (SAC = 1,000 mg/kg)

Hot-spots are considered to be present at individual sampling locations where the contaminant concentration exceeds 250% of the Investigation Level, as recommended in the NEHF (1998) guidelines. In the fill layer, hot-spots were found to be contaminated by benzene and xylenes in addition to PAHs and TPH C10-C36.

Contamination in the fill layer was found to be highest in samples located near to the former tar tanks and gasholders (SB03, SB04, SB06, SB07), retorts and gas converter (TP44, TPA, BH13, BH15) and the gas scrubbers (SB18), as shown in **Figure 7**.

The data indicate that the natural soils generally have lower levels of contamination compared to the fill layer, with the 95% UCL estimates of the true mean for total PAHs being 329mg/kg, while the 95% UCL values for benzo(a)pyrene and TPH C10-C36 are less than or equal to the SAC. In the natural soils, fewer hot-spots were found compared to the fill layer.

Contamination in the natural soils was found to be highest in samples located near to the former tar tanks and gasholders (SB08, MW33), retorts and gas convertor (TP14) and the gas scrubbers (SB12, MW04), as shown in **Figure 8**.

5.7.2 Assessment of Groundwater Data

The groundwater wells that were installed and monitored by previous investigations at the Former Gasworks site comprised wells MW03S, MW04S, MW06S, MW07S, MW12S, MW13S, MW17S, MW20S, (shallow) and MW03D, MW04D, MW06D, MW07D, MW08D, MW12D, MW13D, MW17D, MW18D (deep), as shown in **Figure 5**. As previously mentioned in **Section 5.5**, five monitoring wells were identified at the Former Cleaning Shed Area up-gradient of the site that are not located or mentioned in any of the previous reports. These unknown wells are labelled MWX, MWY, MWZ, MW22S and MW22D in **Figure 5**.

A summary of the groundwater investigations that have been conducted by previous investigations across the Macdonaldtown Triangle area is provided in **Table 3**. The table indicates the groundwater parameters that were tested and the contaminants that were detected above the adopted groundwater *Investigation Levels*. The table indicates that:

- The majority of the groundwater wells have been installed down-gradient of the Former Gasworks Area and in the residential area along the eastern side of Burren Street;
- Exceedances of the groundwater *Investigation Levels* have been detected for dissolved metals, PAHs, phenols, BTEX, particularly around the former retort house, tar well and gasholder area;
- The quality of the groundwater measured at the two wells located up-gradient of the former gasworks site (MW17S & MW17D) complied with the *Investigation Levels* and were considered by the previous investigations to represent background conditions.

A summary of the groundwater data provided by previous investigations conducted at the Macdonaldtown Triangle area is provided in **Tables E** and **F** for the shallow and deep aquifer wells, respectively. Copies of the tables and figures from previous investigation reports are provided in **Appendix G**.

- Table 3 Summary of Groundwater Investigations Conducted by Previous Investigations at the Macdonaldtown Triangle Area

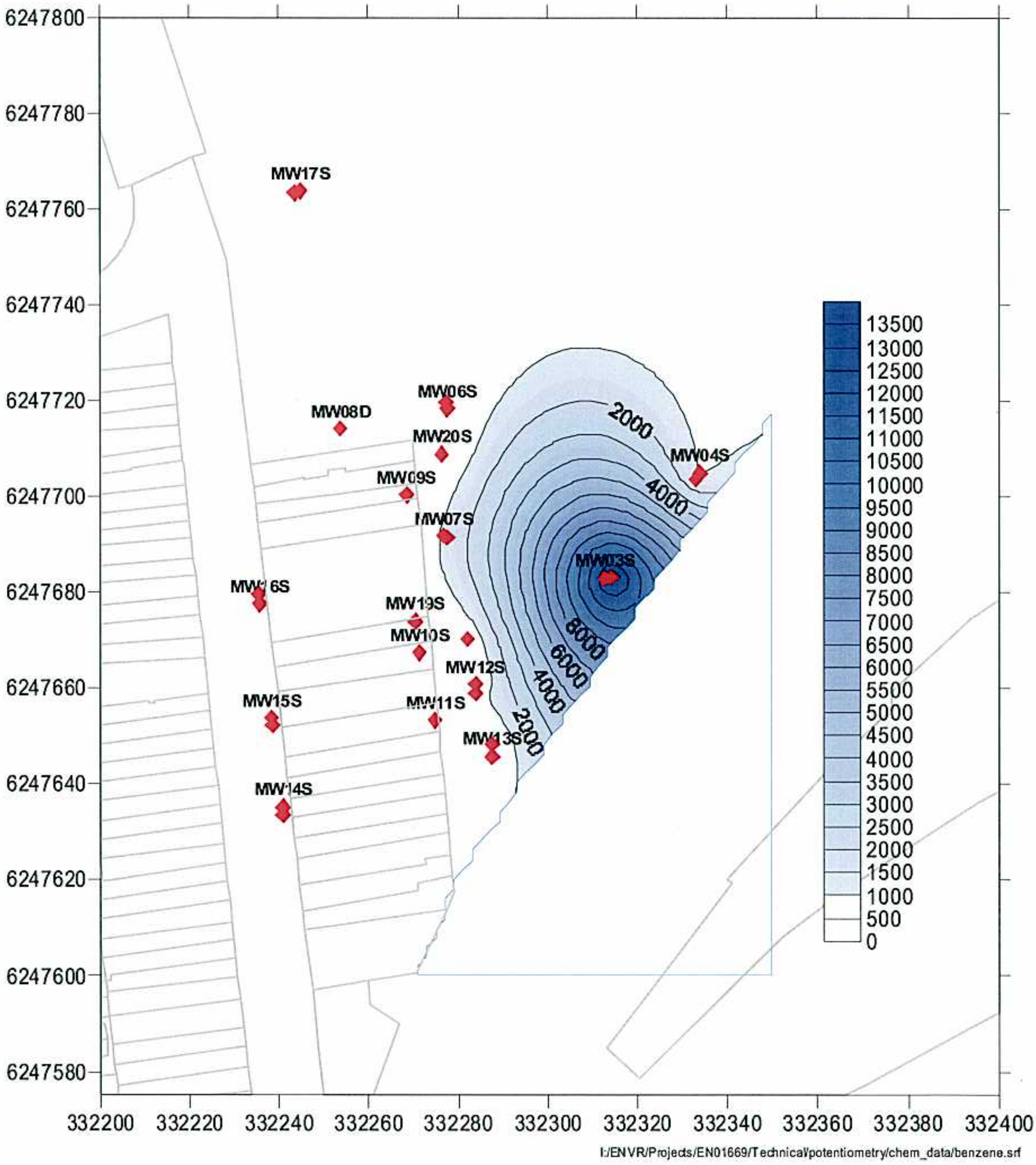
Sample	Date	Location	Purpose/ Target	Analysis undertaken	Exceedances observed
MW03S	June 2000	Downgradient of Former Gasworks Site – shallow aquifer	Contaminant concentrations along southern boundary	Phenols, TPH/BTEX, PAH, Heavy Metals, Ferrous Iron, SO_4, Nitrate as N, Dissolved Methane, pH, Conductivity	Copper, zinc, Iron (II), PAH
MW03D	June 2000	Downgradient of Former Gasworks Site – deep aquifer	Contaminant concentrations along southern boundary	Phenols, TPH/BTEX, PAH, Heavy Metals, Ferrous Iron, SO_4, Nitrate as N, Dissolved Methane, pH, Conductivity	Copper, Zinc, Iron (II), nickel, Phenols, PAH, Benzene
MW04S	June 2000	Downgradient of Former Gasworks Site – shallow aquifer	Contaminant concentrations along southern boundary	Phenols, TPH/BTEX, PAH, Heavy Metals, Ferrous Iron, SO_4, Nitrate as N, Dissolved Methane, pH, Conductivity	Chromium, zinc, Iron (II), PAH
MW04D	June 2000	Downgradient of Former Gasworks Site – deep aquifer	Contaminant concentrations along southern boundary	Phenols, TPH/BTEX, PAH, Heavy Metals, Ferrous Iron, SO_4, Nitrate as N, Dissolved Methane, pH, Conductivity	Copper, Zinc, Iron (II), PAH
MW06S	June 2000	Up gradient of the former gasometer close to the boundary of the former cleaning shed area and coal stacks – shallow aquifer	Contaminant concentrations beneath former coal stacks and Coal Road	Phenols, TPH/BTEX, PAH, Heavy Metals, Ferrous Iron, SO_4, Nitrate as N, Dissolved Methane, pH, Conductivity	Cadmium, Copper, zinc, Iron (II), Phenols, PAH, Xylene, TPH
MW06D	June 2000	Up gradient of the former gasometer close to the boundary of the former cleaning shed area and coal stacks – deep aquifer	Contaminant concentrations beneath former coal stacks and Coal Road	Phenols, TPH/BTEX, PAH, Heavy Metals, Ferrous Iron, SO_4, Nitrate as N, Dissolved Methane, pH, Conductivity	Copper, Zinc, Iron (II), nickel, lead
MW 03S	November 2001	Downgradient of Former Gasworks Site close to former gas purifier – shallow aquifer	Contamination concentrations along southern boundary	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 03D	November 2001	Downgradient of Former Gasworks Site – deep aquifer	Contamination concentrations along southern boundary	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	Cyanide, TPH, Benzene, Toluene, ethyl benzene, Total phenols, PAH
MW 04S	November 2001	Downgradient of Former Gasworks Site –	Contamination concentrations	Heavy Metals, Cyanide, TPH,	

Sample	Date	Location	Purpose/ Target	Analysis undertaken	Exceedances observed
		shallow aquifer	along southern boundary	BTEX, VOCs, PAHs, Phenols	
MW 04D	November 2001	Downgradient of Former Gasworks Site – deep aquifer	Contamination concentrations along southern boundary	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	Benzene, Total phenols, PAH
MW 06S	November 2001	Up gradient of the former gasometer close to the boundary of the former cleaning shed area and coal stacks – shallow aquifer	Contaminant concentrations beneath former coal stacks and Coal Road	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 06D	November 2001	Up gradient of the former gasometer close to the boundary of the former cleaning shed area and coal stacks – deep aquifer	Contaminant concentrations beneath former coal stacks and Coal Road	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 07S	November 2001	Close to the former/ present gasometer	Western extent of contamination	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	Benzene, ethyl benzene, total xylene, phenols, PAH,
MW 07D	November 2001	Close to the former/ present gasometer	Western extent of contamination	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	Benzene,
MW 08D	November 2001	Beneath former Coal Road	Contamination to the north of the residential properties	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 09S	November 2001	West of Former Gasworks boundary in residential area and close to the former gasometer	Western extent of contamination beneath residential properties	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 10S	November 2001	West of Former Gasworks boundary in residential area and close to the former gasometer	Western extent of contamination beneath residential properties	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 11S	November 2001	West of Former Gasworks boundary in residential area and close to the former gasometer	Western extent of contamination beneath residential properties	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 12S	November 2001	Downgradient of Gasometer – shallow aquifer	Contaminant concentrations in the vicinity of the gas holders	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	PAH,
MW 12D	November 2001	Downgradient of Gasometer – deep aquifer	Contaminant concentrations downgradient of the gas holders	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	Benzene, PAH,
MW 13S	November 2001	Downgradient of Gasometer and in vicinity of	Contaminant concentrations	Heavy Metals, Cyanide, TPH,	PAH,

Sample	Date	Location	Purpose/ Target	Analysis undertaken	Exceedances observed
		drainage line- shallow aquifer	downgradient of the gas holders	BTEX, VOCs, PAHs, Phenols	
MW 13D	November 2001	Downgradient of Gasometer and in vicinity of drainage line – deep aquifer	Contaminant concentrations downgradient of the gas holders	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	PAH
MW 14S	November 2001	West of Former Gasworks boundary and residential area beneath pavement on east side of Burren Street	Western extent of contamination	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 14D	November 2001	West of Former Gasworks boundary and residential area beneath pavement on east side of Burren Street	Western extent of contamination	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 15S	November 2001	West of Former Gasworks boundary and residential area beneath pavement on east side of Burren Street	Western extent of contamination	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 15D	November 2001	West of Former Gasworks boundary and residential area beneath pavement on east side of Burren Street	Western extent of contamination	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 16S	November 2001	West of Former Gasworks boundary and residential area beneath pavement on east side of Burren Street	Western extent of contamination	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 16D	November 2001	West of Former Gasworks boundary and residential area beneath pavement on east side of Burren Street	Western extent of contamination	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 17S	November 2001	Upgradient of Former Gasworks and concrete slab – shallow aquifer	Background concentrations of contaminants	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW 17D	November 2001	Upgradient of Former Gasworks and concrete slab – deep aquifer	Background concentrations of contaminants	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	
MW18D	November 2001	Close to western boundary of Former Gasworks– deep aquifer	Contaminant concentrations in the vicinity of the gas holders	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	PAH
MW20s	November 2001	Close to western boundary of Former Gasworks– shallow aquifer	Contaminant concentrations in the vicinity of the gas holders	Heavy Metals, Cyanide, TPH, BTEX, VOCs, PAHs, Phenols	PAH

SKM has prepared concentration plots using the previous investigation data for the various groundwater contaminants in the deep groundwater identified during the previous investigations. These plots are shown in **Figures 9 to 13** on the following pages for benzene, C_6-C_9, C_{10}-C_{36}, naphthalene and phenols, respectively.

- ***Figure 9 Historic Benzene Levels in Deep Groundwater (μg/L)***



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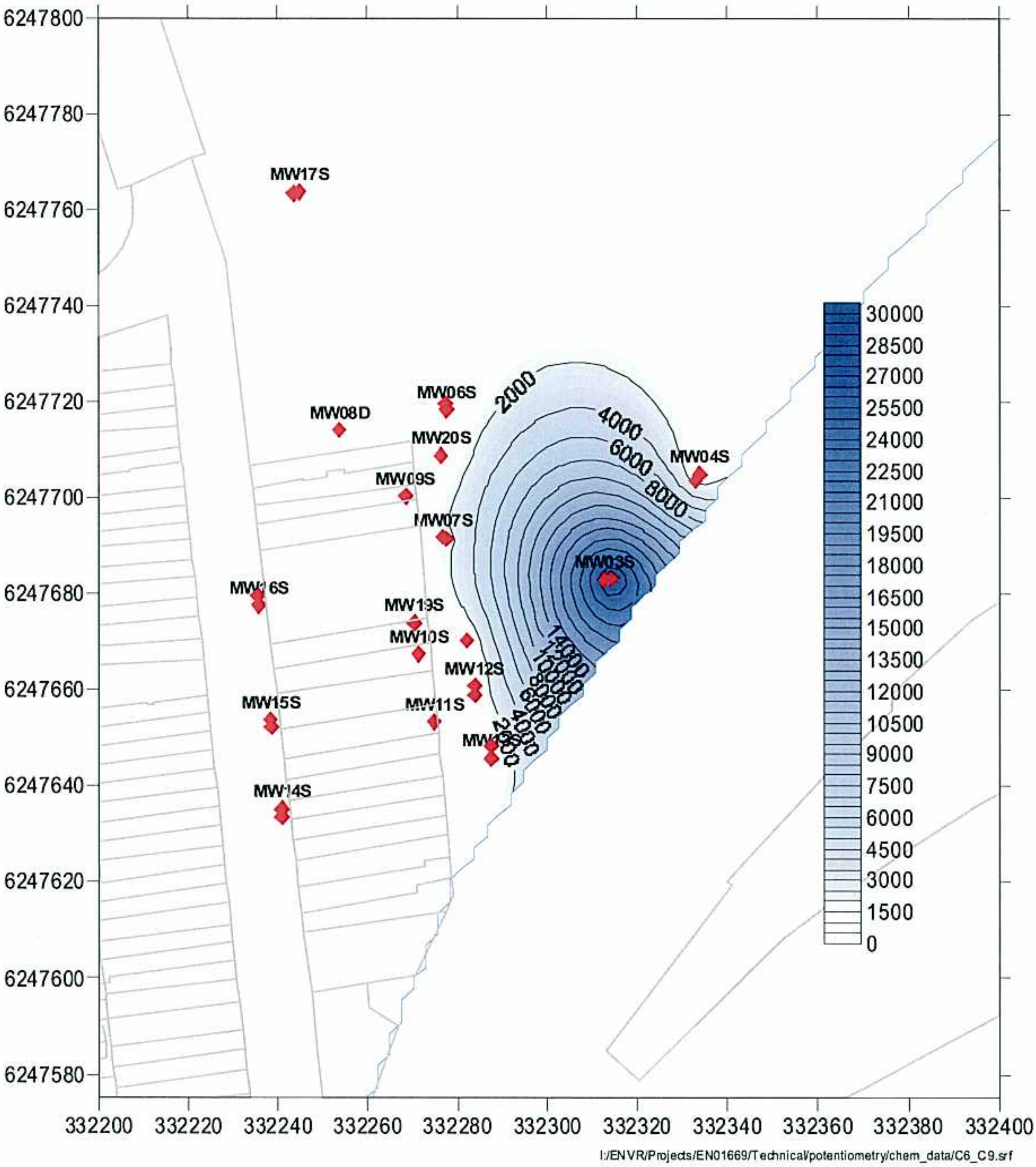
- *Figure 10 Historic C6-C9 Levels in Deep Groundwater (μg/L)*



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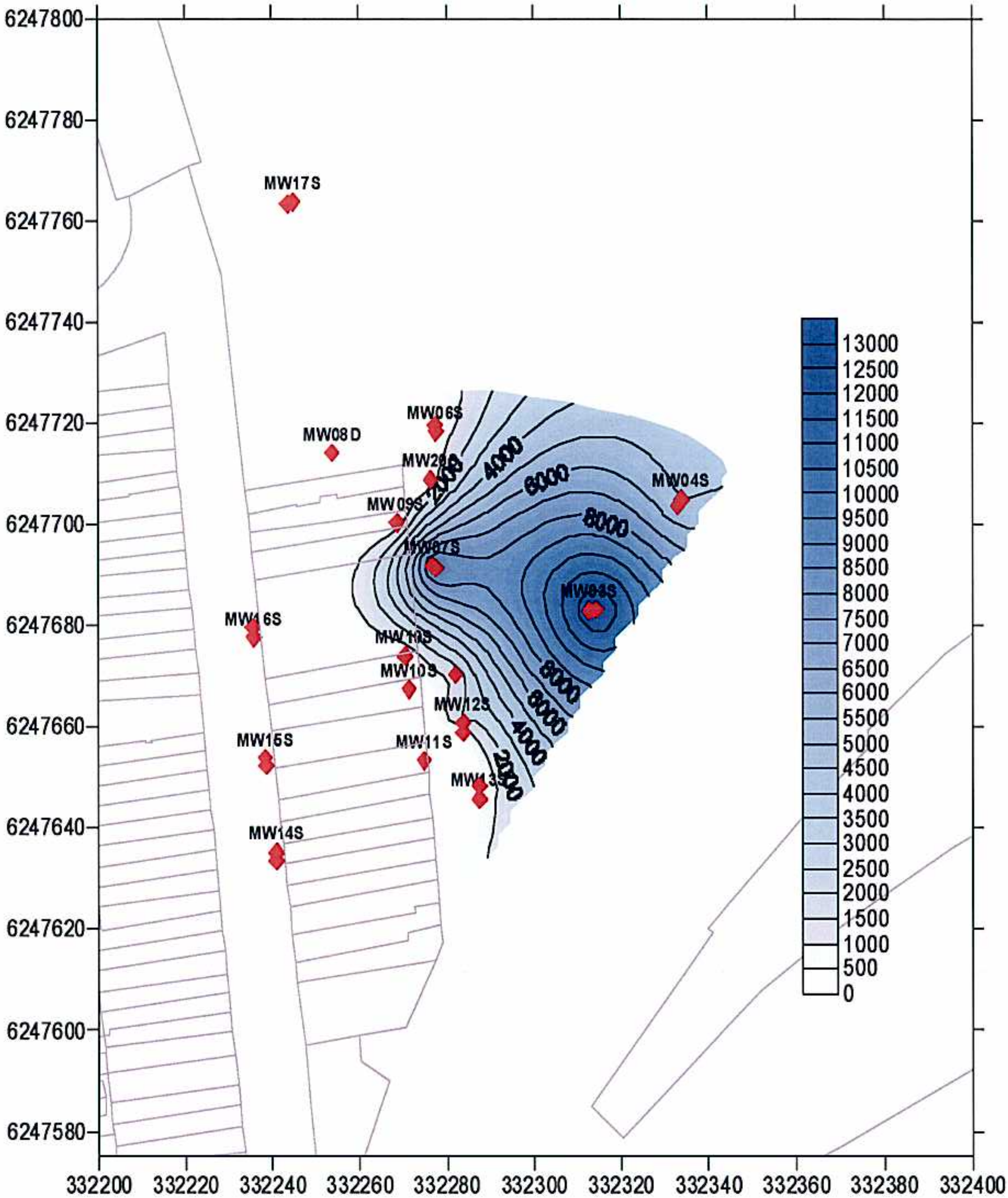
- *Figure 11 Historic C10-C36 Levels in Deep Groundwater (µg/L)*



I:/ENVR/Projects/EN01669/Technical/potentiometry/chem_data/C10_C36.srf

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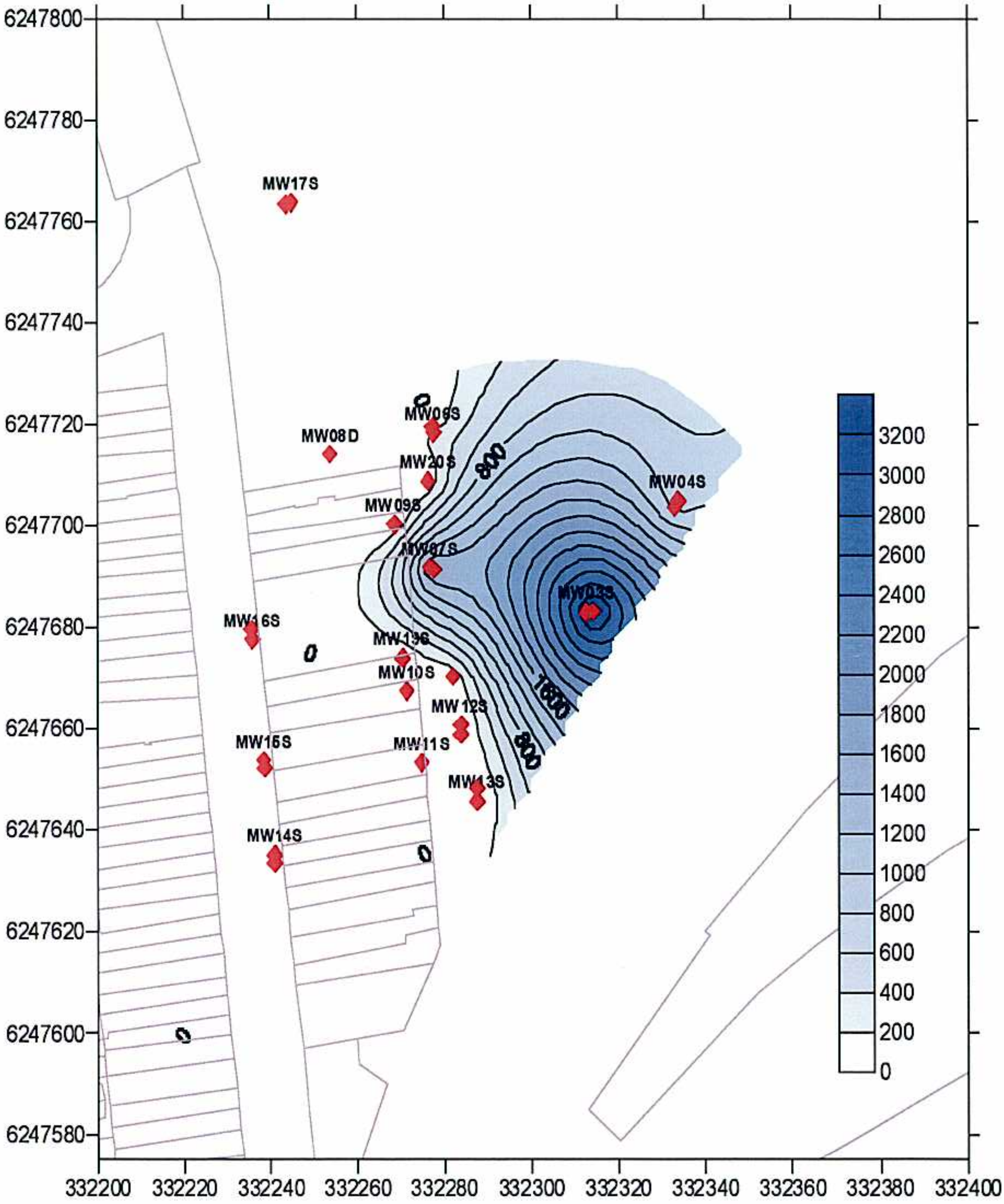
Figure 12 Historic Naphthalene Levels in Deep Groundwater ($\mu g/L$)



I:/ENVR/Projects/EN01669/Technical/potentiometry/chem_data/naphth.srf

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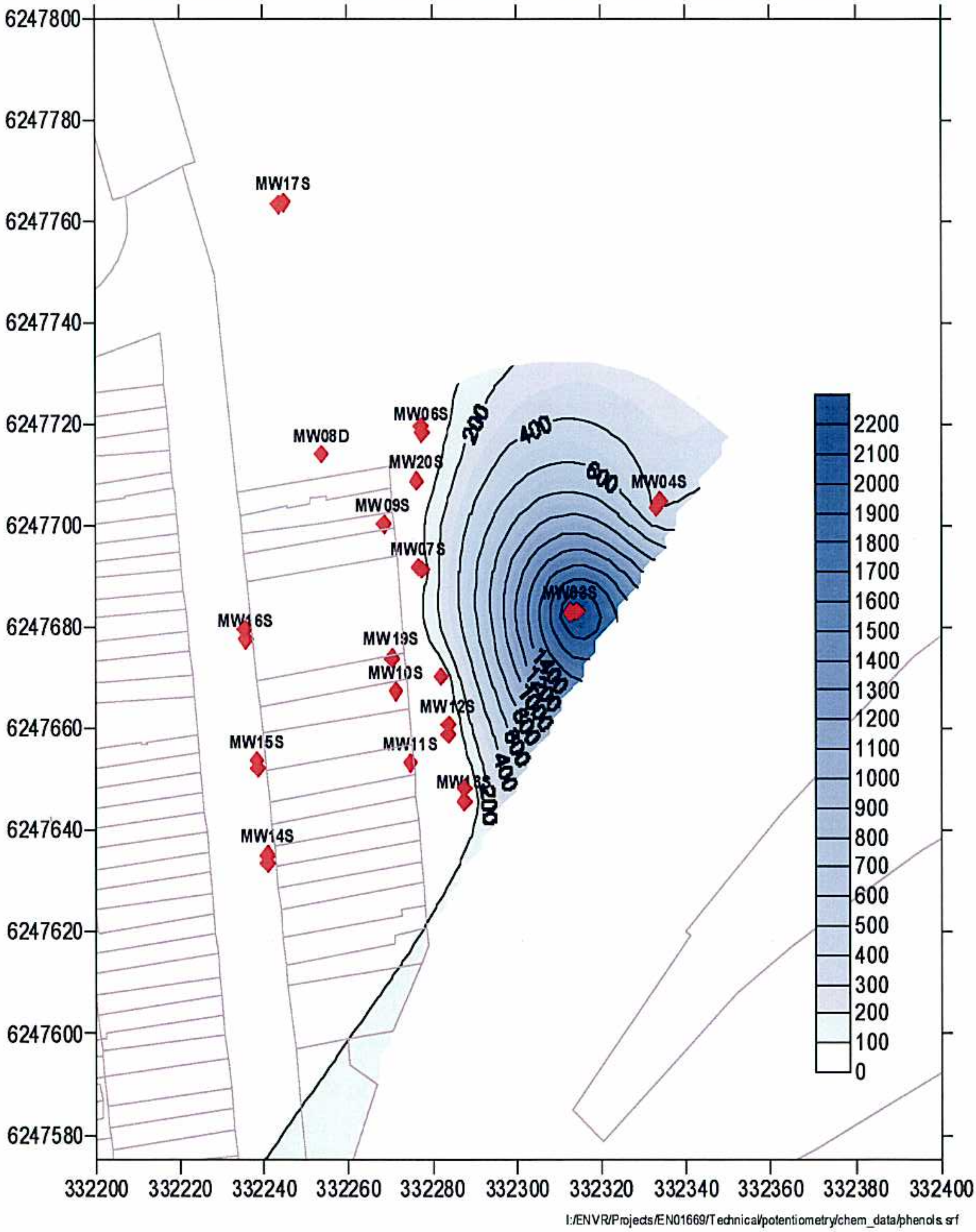
Figure 13 Historic Phenols Levels in Deep Groundwater (µg/L)



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The plots indicate that the northern extent of the contamination plume had not been delineated by the previous investigations, particularly for C_{10}-C_{36} and naphthalene, as monitoring had generally not been conducted across the Former Cleaning Shed Site, with the exception of monitoring wells along the northern boundary of the Site.

5.7.3 Data Uncertainties

Data uncertainties that were identified by SKM with the previous investigations include:

- The site inspection undertaken by SKM in April 2004 identified five wells located in the Macdonaldtown Triangle area that were not mentioned in the previous CH2MHill reports. Two of the wells were marked MW22S and MW22D, while the other three were unmarked.
- The GPS data for a number of the boreholes, particularly MW03 and MW04, appears to be inconsistent with their actual position on the Site. When loading into a geo-referenced computer package, the sample locations lie outside the boundaries of the Macdonaldtown Triangle area.

5.8 Identification of Data Gaps

The assessment of the available data that is presented in this section has identified the main contamination issues affecting the Macdonaldtown Triangle area. A summary of the main contamination issues is provided in **Table 4**.

- Table 4 Summary of Contamination Issues

Area	Soil	Groundwater
Former Cleaning Sheds (1.53Ha)	▪ 25 sample locations across Site; - ***complies with NSW EPA sampling design guidelines.*** ▪ Fill material consisting of sand, gravel, ballast, ash and coke breeze is widespread across the area and varies in depth between 0.20 to 2.50 m. ▪ The CH2MHill June 2000 lab results are generally below the Site criteria. Isolated contaminant concentrations exceeding the adopted soil criteria were identified (PAHs, benzene, benzo(a)pyrene, and toluene). ▪ Speciated TPH data not available.	▪ Groundwater investigations of both the surficial and Ashfield Shale aquifer have only been undertaken in the area of the Former Gasworks. ▪ Groundwater wells were installed through November 2001 to determine background water quality at the Site.
Former Gasworks (0.791 Ha)	▪ 20 sample locations across Site; complies with NSW EPA sampling design guidelines. ▪ Fill material is widespread across the area and varies between 0.10 to 3.20 m in depth.	***<u>Surficial Aquifer</u>*** ▪ Concentrations of total PAHs, TPH C_{10}-C_{36}, heavy metals, phenols and BTEX exceed by up to three orders of magnitude the adopted ANZECC (1992) guidelines. Groundwater quality in the surficial aquifer adversely

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Area	Soil	Groundwater
	▪ Contamination is widespread throughout the fill material but not underlying soils and include TPH, PAH, and BTEX. ▪ Speciated TPH data is not available for the Site.	impacted by the above compounds. ▪ General groundwater is estimated to be south south-east. Localised subterranean structures may influence groundwater flow ▪ Potential for surficial groundwater to seep out along the fill material and impact adjacent properties ***Ashfield Shale Aquifer*** ▪ Concentrations of total PAHs, benzene, heavy metals and phenols identified in groundwater samples collected from the Ashfield Shale aquifer exceed the adopted ANZECC (1992) guidelines. A range of the above compounds has impacted the groundwater quality in the Ashfield Shale aquifer. ▪ The Ashfield Shale groundwater flow direction is estimated to be in a south south east direction. Localised subterranean structures may influence groundwater flow
Off Site locations	▪ Soil sampling undertaken in the residential properties in Burren Street ▪ Remediation of these areas is being undertaken under a separate contract	▪ Groundwater wells were installed in Burren Street to the west of the gasworks Site and residential properties in Burren Street

This study considers that the Site has been sufficiently characterised in regards to soil contamination. Fill material is expected to be heterogeneous and additional soil sampling will not provide significant value to the existing data set.

However, the concentrations of volatile compounds within the soil gas phase have not been adequately assessed. The previous investigations identified elevated concentrations of volatile compounds in the soils and groundwater that could form an exposure pathway for contaminants, which need to be considered in a risk assessment. This study considers that an evaluation of soil gas is required in order to evaluate the potential risks associated with volatile gas emissions from soils at the Site. Such an evaluation will:

- Minimise uncertainly in relation to the presence of soil gas and soil gas composition; and
- Provide additional data to evaluate and manage the risk of soil gas impacting Site receptors such as construction/maintenance workers and RailCorp employees.

The previous investigations collected data on total petroleum hydrocarbon (TPH) fractions in soils and groundwater. The fractions analysed were unspeciated, meaning that the TPH compounds in a given hydrocarbon range were not differentiated in terms of aliphatic and aromatic compounds. The toxicological risks posed by TPH compounds vary according to both the hydrocarbon fractions and the speciated fractions. Different reference doses have been developed for aliphatic and aromatic (and alkene) compounds to reflect their significant differences in chemical, physical and environmental fate properties. Consequently, a more accurate assessment of health risks from TPH contamination in soils could be obtained by conducting speciated TPH analysis on areas of the site suspected of having elevated TPH concentrations.

In summary, the main information gaps in the contamination data provided by the previous investigations for the Former Gasworks area are considered to be:

- Concentrations of volatile gases in the soil-vapour phase within shallow soils at the Site;
- The testing of speciated TPH for areas of the site suspected of containing elevated TPH concentrations;
- Groundwater data that defines background conditions along the up-gradient side of the Site;
- Additional groundwater data that defines water quality in the north-eastern area of the site and in the southern portion of the Site where parts of the former gasworks operation existed;
- Additional groundwater data that provides information on flow directions and hydraulic heads at the Site; and
- In-situ permeability data for the shallow and deep aquifers.

Based on the potential contaminants of concern at the Macdonaldtown Triangle area, the soil and groundwater samples should be analysed for:

- pH
- Heavy metals (arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc and manganese)
- Total petroleum hydrocarbons (TPH)
- Speciated TPH
- Benzene, Toluene, Ethyl Benzene and Xylene (BTEX)
- Polycyclic aromatic hydrocarbons (PAHs)
- Semi/Volatile Organic Compounds (SVOC/VOC)
- Phenols

Gasworks waste and contaminants that need not have been targeted by this investigation include cyanide (total and free), sulfate, OCPs, OPPs and asbestos. This is because the results of the previous investigations performed at the Site by others have not identified these contaminants to be of concern.

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6 Site Investigation and Methodology

This section of the report describes the additional fieldwork and laboratory testing conducted for this risk assessment based on an assessment of the data gaps in the previous investigations, as discussed in the previous section. The section initially describes the design of the investigation (Section 6.1) and fieldwork procedures (Section 6.2) and field tests (Section 6.3). Information on the laboratory testing program conducted on the collected samples is then presented (Sections 6.4 and 6.5).

6.1 Investigation Design

The site investigations that were conducted by SKM as part of this study followed a Sampling and Analysis Plan (SAP) developed by SKM in August 2004 (SKM, August 2004), which was independently reviewed prior to the commencement of the fieldwork program by Dr Bill Ryall, a NSW DEC Site Auditor employed by HLA-Envirosciences and appointed by RailCorp.

A summary of the scope of the fieldwork conducted by this study across the Macdonaldtown Triangle area is provided in **Table 5**, with the location of these boreholes shown in **Figure 5.**

- Table 5 Summary of Fieldwork

Field works	Number	Location
Groundwater wells installation	6 clustered wells (shallow and deep)	• One well located at the up-gradient northern end of the Cleaning Shed Site to monitor background conditions • Three wells located along the up-gradient northern side of the former gasworks Site to monitor water quality entering the Site
		Three wells located down-gradient of the southern boundary to monitor water quality near the StateRail property boundary
Soil Gas Sampling Wells	5 locations	Boreholes located in areas of elevated volatile compounds
Soil sampling for lab testing(Speciated TPH)	8 locations	Boreholes located in areas of suspected elevated TPH compounds. Samples were biased to those that are likely to exhibit greatest TPH contamination.
Falling head/slug tests	3 wells	Falling head tests were undertaken to confirm previous data only
Groundwater well sampling for lab testing	20	Refer Figure 5 and discussion below

A total of 31 existing wells were identified in the vicinity of the former cleaning sheds and gasworks sites, with information on their current status provided in **Table 1**. Of the existing wells, a total of 20 wells were selected for further sampling and testing. These wells and the reason for their selection are:

- Wells MW14S, MW14D, MW16S, MW16D – These five wells constitute all the functioning wells in the footpaths along Burren Street adjacent to the residential properties. These wells provide data on the quality of groundwater that has migrated to the west of the Site under the nearby residential properties;
- Wells MW17S and MW17D are located in the north-western most area of the Site;
- Wells MW06S, MW06D and MW20S are located in the northern part of the former gasworks Site near the suspected tar tank area;
- Wells MW07D and MW18D are located near the remaining gasholder structure;
- Wells MW12S, MW12D, MW13S and MW13D are located in the southern portion of the former gasworks area; and
- Wells MW03S, MW03D, MW04S, MW04D are located along the south-eastern portion of the former gasworks area.

Wells that were not selected for additional testing and the reasons for their non-selection are:

- MW08D, MW09S, MW10S, MW11S, MW19S were not selected due to access difficulties since they are located in the backyards of residential properties and are located close to other wells that are to be tested. Some of these wells are also not functioning;
- MW15S and MW15D were not selected as these wells had been sealed prior to sampling;
- MW07S near the gasholder was not selected since the well was found to be dry during previous monitoring events; and,
- MW22S, MW22D, MWX, MWY and MWZ are located in the Cleaning Shed area north of the gasworks Site and have not been sampled as part of the additional monitoring as construction type of these wells is not known. Groundwater in these areas is considered to be adequately characterised by the inclusion of monitoring wells adjacent to these locations (MW06S, MW06D, MW17S, MW17D, MW36S, MW36D MW37S and MW37D).

It should be noted that two of the proposed monitoring wells were not sampled, as the condition of these wells prevented the collection of a water sample. MW03S had been damaged and could not be accessed and MW12D could not be located. The completeness of the groundwater assessment is not considered to be impacted by an inability to sample from these monitoring locations, as the shallow aquifer in the vicinity of MW03S is characterised by sampling and analysis of MW04S, MW12S and MW13S. MW12D is located in close proximity to MW13D and is used to characterise the deep aquifer beneath the south western corner of the Former Gasworks Site. The locations of monitoring wells sampled as part of this investigation are shown on **Figure 5**.

The investigation involved the installation of 5 soil-vapour monitoring wells to a maximum depth of 2m in and around the former gas process areas. The five wells were positioned in known areas of contamination. Three soil-gas wells (MW30, MW31 & MW33) were placed close to previous groundwater monitoring wells (MW03, MW04, MW07) where shallow soil and groundwater contamination had been recorded. The other two other soil-gas wells (MW32 & MW34 were located in close proximity or down-gradient to the former retort house and gasholder structures, which represent potential sources of ground contamination.

This investigation also included the collection of soil samples from each of the soil-gas probe locations to assess the likely aromatic and aliphatic TPH concentrations at the site.

6.2 Fieldwork Procedures

6.2.1 Site Supervision

Fieldwork was supervised by a suitably qualified and experienced environmental engineer/scientist from SKM. The tasks undertaken by SKM field personnel during and after the field investigation are set out in ***SKM Work Instruction WI-CS-2 Field Supervision***. Information t gathered during the investigation are described in ***SKM Work Instruction WI-CS-3 Site Observations***

A field activity daily log was maintained by SKM field personnel throughout the Site work. A copy of the SKM's standard field procedures, Field Activity Daily Log Form ET9 and Chain of Custody documentation is provided in the SAP, with summary information provided in the following sections.

6.2.2 Drilling and Well Installation

Drilling was carried out using a solid stem drilling method by a truck mounted all terrain drill rig. Auger bits were used for drilling through soils, while tricone bits were used for drilling through rock and similar strata. Terratest Engineering Exploration undertook the drilling works.

A log was produced for each borehole location in accordance with Australian Standard AS1726-1993 *Geotechnical Site investigations*. Copies of the borehole logs produced by the SKM investigation together with copies of borehole logs produced by previous investigations at the Site are provided in **Appendix A**.

Each well was fitted with a lockable cap and finished with monument boxes or gatic covers to allow for follow up monitoring and to secure each of the wells.

A total of 15 additional groundwater wells were installed in the vicinity of the former cleaning sheds and gasworks sites. 6 locations had a shallow and deep well constructed to intersect the two-aquifer system. Each well was installed with at least 3m of screened interval within the nominated groundwater aquifer. Selected wells were placed in up gradient locations to provide information on background groundwater quality. The well locations have been selected based on the expected groundwater flow direction the potential risks associated with areas of concern and are shown in **Figure 5.**

Further details on drilling and well installation are provided in ***SKM Work Instruction WI-CS-4 Investigation Methods*** and ***WI-CS-6 Groundwater Well Design***.

6.2.3 Groundwater Sample Collection

Wells were flushed clean, developed and emptied after construction. A round of groundwater samples were collected 1 week after the development of the well. The wells were checked for phase separated hydrocarbons prior to purging and sampling. Wells were purged by removing not less than three well volumes immediately prior to sampling. Purging continued until the water quality field parameters stabilised to within ±10%. During all groundwater sampling events standing groundwater levels were recorded in AHD to determine the groundwater flow pattern. Groundwater water levels were determined with a Oil/ Water interface probe.

Water quality field parameters were measured using a Horiba U-10 Water Quality Meter. This unit has an inbuilt autocalibration system that is used to check the calibration of the unit prior to use. Sinclair Knight Merz recorded the following groundwater and aquifer parameters – conductivity, temperature, salinity, pH and dissolved oxygen.

The water samples were collected using t Sinclair Knight Merz' Standard Sampling Procedures. Dedicated low-volume Waterra Footvalves were used for sampling each of the nominated monitoring wells. Samples were collected in order of most volatile to least volatile parameters. A summary of the sample container types, preservation and the order of filling is provided in **Table 6.**

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- **Table 6 Container Types, Preservation and Order of Filling**

Analyte	Container Type	Preservation	Order of Filling (1)
BTEX, VOCs & TPH (C6-C9)	Glass jar with teflon lined lid (40ml)	Hydrochloric acid	1
SVOCs & TPH (C10-C36)	Amber glass bottle with teflon lined cap (1L)	Refrigerate	2
Speciated TPH	Amber glass bottle with teflon lined cap (1L)	Refrigerate	3
PAHs	Amber glass bottle with teflon lined cap (1L)	Refrigerate	4
Heavy metals	Clear plastic bottle (250mL)	Nitric acid	5
Phenols	Glass bottle (1L), or amber glass bottle with teflon lined cap (1L)	Sulphuric acid or refrigerate	6
Hardness	Clear plastic bottle (250mL)	Refrigerate	7

Notes:
(1) Reference US EPA (1986)

Samples were placed into appropriately preserved sampling bottles supplied by the laboratory and placed on ice. Samples for dissolved metal analyses were filtered on Site using 0.45 micron filter papers and placed in acid preserved bottles. Standard Chain of Custody (CoC) forms were used to track the release of water samples. All sampling equipment was decontaminated between sampling events.

Further details on groundwater sampling procedures are provided in ***SKM Work Instruction WI-CS-8 Groundwater Sampling***.

6.2.4 Separate Phase LNAPLs and DNAPLs

As indicated in the previous section, wells were checked for phase separated hydrocarbons prior to purging and sampling using a Solinst 122 Interface Meter. This equipment gives quick and easy determination of both floating non-conductive liquids (LNAPLS) and sinking non-conductive liquids (DNAPLs).

Further details on measuring the thickness of separate phase LNAPLS and DNAPLs are provided in ***SKM Work Instruction WI-CS-8 Groundwater Sampling***.

6.2.5 Permeability

Well permeability tests were undertaken at MW06S, MW07D and MW38D as part of this investigation. The tests were carried out at these groundwater locations to determine the expected permeability of the aquifer beneath the Site. It was considered imperative that the hydrogeological characteristics were evaluated at the Site as groundwater is the predominate mechanism for contaminant transport.

Further details on performing in-situ permeability tests are provided in ***SKM Work Instruction WI-CS-7 Aquifer Testing.***

Copies of the calculation sheets used to estimate in-situ permeability values from the insitu permeability tests are provided in **Appendix F**.

6.2.6 Soil Gas Surveys

Volatile compound concentrations in the soil-gas phase in soils were assessed using permanent soil gas monitoring bores at five locations (MW30 to MW34) at the Former Gasworks site, targeting those areas that have been identified by previous investigations as exhibiting elevated concentrations of BTEX, PAH and/or TPH compounds in soils. Procedures for testing soil-gas phase concentrations were consistent with Australian Standard AS4482.2-1999 *"Guide to the sampling and investigation of potentially contaminated soil, Part 2: Volatile substances".*

Permanent soil gas monitoring bores were installed to a maximum depth of 1.5 m below ground level.

Absorbent tubes were connected to air sampling pumps to collect soil gas vapour samples from each of the 5 locations. The air samplers operated for between 50 and 110 minutes at a flow rate of between 600 and 2000 ml/ min. The absorbent tube data provided quantitative information on the constituents and concentrations of the soil gases.

The sampling apparatus was cleaned between measurements using the following procedures:

- Brushing of contaminated soil from the sampling probe; and
- Flushing the system with clean air to ensure that all sample gases have been removed.

Further details on performing soil gas tests are provided in ***SKM Work Instruction WI-CS-12 Field Measurements and QA procedure ET-4.2 Attachment 5 "Standard Sampling Instructions for Soil Gas Sampling (Below ground surface).***

6.2.7 Soil Sampling

Boreholes were drilled using a 4-wheel drive rubber tyred rig at the same 5 locations where the soil gas probes were installed. A solid stem auger was used. An engineering log was produced for each borehole location in accordance with Australian Standard AS1726-1993 *Geotechnical Site investigations*. Copies of the SKM Engineering Logs are provided in **Appendix A** together with copies of the borehole logs produced by the previous investigations.

A soil sample from each of the five boreholes was collected for laboratory analysis and tested for TPH, BTEX and speciated TPH. The soil samples were collected as "undisturbed" samples using a split-tube push sampler. Sampling locations are shown on **Figure 5.**

Additional soil samples were also collected from the three deep boreholes to the south of the Site where groundwater wells were constructed[1]. A soil sample from each of these three boreholes was collected for laboratory analysis and tested for the full suite of potential contaminants of concern.

Further details on drilling and soil sampling are provided in ***SKM Work Instruction WI-CS-4 Investigation Methods*** and ***WI-CS-5 Soil Sampling***.

6.2.8 Decontamination

All field equipment was decontaminated in accordance with the summary procedures specified in the SAP. Further details on decontamination procedures are provided in ***SKM Work Instruction WI-CS-11 Decontamination***.

6.2.9 Survey Control

SKM utilised an Ausimage package to prepare a Site plan showing the main features and sampling point locations. Images are orthographically corrected and dimensions of building and Site boundaries are available from embedded information.

All sample locations are marked on the final plans and are logged using GPS coordinates and mapped on the geo-references aerial photographs.

Further details on survey methods are provided in ***SKM Work Instruction WI-CS-10 Survey Methods***.

6.2.10 Buried Service Location

RailCorp supplied the information in regards to underground services. SKM conducted a detailed search of third party services to ensure that any underground infrastructure was protected during field works. A qualified service locater was then engaged to clear each drilling location.

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[1] Site Auditor request as given in 3/08/04 meeting minutes

6.3 Field Tests

6.3.1 Photoionisation Screening

A photoionisation detector (PID) was used to detect and quantify organic vapours in soil samples. The PID used for this investigation was a Rae Systems Minirae 2000 PID.

The PID was used to obtain head-space concentrations of volatile gases emitted from bagged soil samples. The tests were conducted during the soil-sampling program, with the PID sampling results summarised on the borelogs in **Appendix A.** PID results were used to provide a qualitative assessment of volatile gas levels in soils and to help determine which samples would be analysed at the laboratory.

The PID was calibrated daily, with the calibration records included as **Appendix F.**

6.3.2 Soil Gas Survey

Permanent soil gas monitoring wells were installed by SKM at five location in the centre of the former gasworks site (MW30, MW32, MW31, MW33 and MW34). Soil gas samples were then collected from each well.

The sampling was undertaken in general accordance with the OSHA sampling procedures for benzene, as benzene was the primary compound of concern due to the elevated concentrations found in the soil and groundwater samples and its carcinogenic characteristics.

An SKC 226-01 sorbent tube was used to collect samples. The collection pumps were calibrated before and after sample collected to confirm the consistent flow rate of 600ml/min for benzene and 2L/min for PAHs. Each sample was run for approximately 50mins for benzene and 110mins for PAHs. A summary of the sampling undertaken from the soil gas probes is provided in **Table 7**.

- Table 7 Soil Gas Sampling Field Data

	BTEX	PAHs
MW30		
Sample Flow rate	600ml/min	2000ml/min
Sampling Time	50	110
MW31		
Sample Flow rate	600ml/min	2000ml/min
Sampling Time	50	108
MW32		
Sample Flow rate	600ml/min	2000ml/min
Sampling Time	50	110
MW33		
Sample Flow rate	600ml/min	2000ml/min
Sampling Time	53	111
MW34		
Sample Flow rate	600ml/min	2000ml/min
Sampling Time	50	111

6.3.3 Physico-chemical Water Quality Testing

A TPS Water Quality Meter measured the physico-chemical water quality in the groundwater monitoring wells during the Stage I February 2004 sampling event. This field instrument measures dissolved oxygen (DO), total dissolved solids (TDS), pH, redox, temperature and pH. This unit was calibrated prior to use on Site by EnviroEquip.

A Horiba water quality meter was used during the sampling to measure dissolved oxygen, pH, conductivity, temperature and salinity and was calibrated on Site prior to use.

All wells were purged prior to sampling on each occasion.

6.4 Laboratory Test Program

The main and check laboratories used for this investigation were ALS and Amdel, who are NATA registered chemical laboratories for the specified tests, with the exception of analysis for speciated TPH, which was undertaken by Amdel, using method E1224, which is not covered by their NATA accreditation.

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All tests were undertaken in accordance with the NEPM (1999) and ANZECC (2000) water quality guidelines.

Soil, soil-gas and groundwater samples were tested for the potential contaminants of concern as listed in **Section 6.1.1**. Groundwater samples were tested for compounds that provide data on possible degradation processes occurring at the Site. These additional compounds include BOD, COD, TOC, total nitrogen and ammonia.

A summary of the laboratory-testing program is provided below in **Table 8.**

- **Table 8 Laboratory Analysis Summary**

	Soil	Soil Gas	Groundwater	Rinsate	Duplicates			Total
				GW	Soil	Soil Gas	GW	
Heavy Metals			30	2			4	26
PAH			30	2			2	26
TPH	7	5	30	2		1	4	32
BTEX	10	5	30	2		1	4	32
Phenols			30	2			2	26
SVOC/VOC		5				1		6
Hardness			30	2			4	26
Speciated TPH			30	2			1	33

Note:
(1) Duplicates analysis was undertaken at a combined rate of 10%.

QA/QC samples were collected and analysed in accordance with the rates specified in Section 8 of Australian Standard AS4482.1-1997. These rates are:

- Blind field duplicates were tested at the main laboratory: 1 in 20 samples (5%)
- Split samples were tested at the check laboratory: 1 in 20 samples (5%)
- Rinsate blanks: 1 sample per sampling day
- Laboratory-prepared volatile trip spiked samples: 1 sample per sampling event

The locations of the boreholes and wells where the samples were collected are specified in earlier sections of this report.

6.5 Laboratory Test Methods

The chemical laboratories used for the samples collected in this investigation were:

- Soil and water samples – Amdel
- Initial ambient air screening - ALS

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- Passive air samples – ALS

All the laboratories are NATA approved, with copies of the laboratory test certificates provided in **Appendix E.** A summary of the laboratory test methods used for the range of analytes tested is provided in **Table 9.**

- **Table 9 Summary of Laboratory Test Methods**

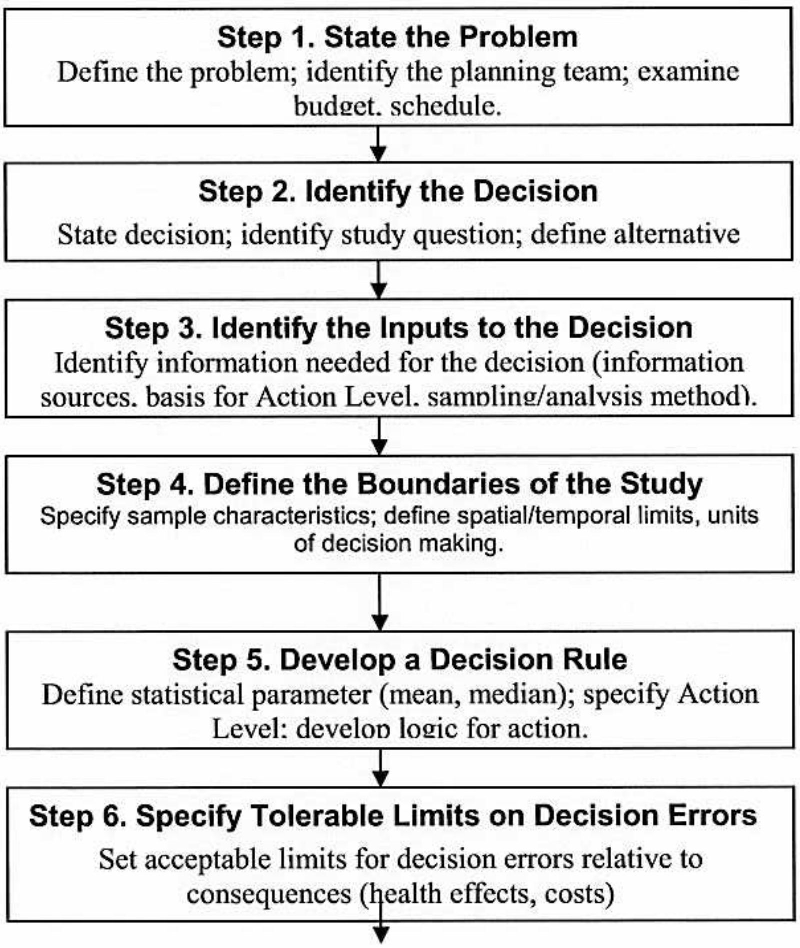
Analyte	Amdel Method Soils	Amdel Method Water	Air Test Methods
Heavy Metals	E5910	E4870/ E48501	
Total Recoverable Hydrocarbons (TPH)	E1230 & E1221	E0230/ E0221	
Benzene, Toluene, Ethyl benzene, Xylene (BTEX)	E1010	E0010	
Polycyclic Aromatic Hydrocarbons (PAH)	E1110	E0110	
PH	E3600	E2600	
Phenols/Creosols	E1140	E0140	
Semi Volatile Organic Compounds (SVOCs)	E1180	E0180	
Volatile Organic Compounds (VOCs)	E1290	E0290	
Sulphate	E3720	_	
Total and Free Cyanide	E3450/E2460	E2450/	
Initial ambient air screening for VOCs			EP091 (ALS)
Passive air samples for VOCs			US EPA 1988 TO-17 (Leeder Consulting)

7 Quality Assurance and Quality Control

7.1 Data Quality Objectives

The investigations for the Macdonaldtown Triangle health and ecological risk assessment have been designed using a Data Quality Objective (DQO) process developed by the USEPA (August 2000) *"Guidance for the Data Quality Objective Process"* and the NEPM (1999) *"Guideline on Data Collection, Sample Design and Reporting"*[2]. The Data Quality Objective (DQO) process is a seven step planning approach to develop sampling designs for data collection activities that support decision making. This process uses systematic planning and statistical hypothesis testing to differentiate between two or more clearly defined alternatives. A summary of the seven steps is presented in **Figure 14**.

- Figure 14 The DQO Process



[2] NEPC. 1999. *"Guideline on Data Collection, Sample Design and Reporting"*. Schedule B (2), National Environment Protection (Assessment of Site Contamination) Measure

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Step 7. Optimise the Design for Obtaining Data
Select resource-effective sampling and analysis plan that meets the performance criteria.

Step 1 (state the problem) is to determine whether ground contamination at and from the former gasworks site is causing unacceptable risks to human health and the environment in terms of its continued use for railway purposes.

Step 2 (the decisions) represent the principal issues that need to be assessed, which arise from the problem stated in Step 1. The issues are considered to be:

- Are contaminant concentrations at the Site and in areas surrounding the Site significantly above background levels?
- Does the concentration of contaminants exceed DEC-endorsed investigation criteria?
- Does a contaminant pose a human health or ecological risk to the receptors of concern?
- Are contaminants causing an aesthetic impact to the environment?
- Does the contamination affect the suitability of Site for current and proposed use?

Step 3 (inputs to the decisions) represent the main parameters that need to be measured by the investigation. These parameters are considered to be:

- The surface condition of the Site in terms of physical evidence of contamination;
- The presence of surface and underground structures and the potential to influence the migration of contaminants;
- Aesthetic impacts at the ground surface and at depth from contamination (ie. odour, stained materials, separate phase products in the groundwater);
- The types and distribution of contamination at the Site and surrounding areas;
- The depth of the contamination below the ground surface;
- The level of soil gas below the surface;
- The rate of flow of groundwater from the Site and the location of potential receptors;
- The ambient air quality at the Site and at properties surrounding the Site;
- The toxicity of the contaminants of concern and their persistence;
- The identification of potential receptors and the location of sensitive environments;
- The assessment of exposure period for the potential receptors of concern; and
- DEC-endorsed environmental criteria.

Step 4 (boundaries of the study) establishes the geographical extent of the investigation area and the potential receptors of concern that need to be considered by the study.

The geographical limits (ie. spatial boundaries) appropriate for the data collection and decision making in this investigation are:

- The northern boundary of the Site (the up-gradient boundary);
- Burren Street to the west of the Site;
- The edge of the Illawarra railway line to the east of the Site;
- The edge of railway land along Railway Parade to the south of the Site; and
- The upper parts of the semi-confined aquifer that occurs near the clay / fractured shale bedrock contact.

The potential receptors of ground contamination from the Site, as mentioned previously in **Section 5.6.4**, are considered to be:

- Future commercial/industrial users of the Site by RailCorp workers;
- Future maintenance / construction workers at the Site and surrounding areas;
- The community who live in residential land adjacent to the western boundary of the Site; and
- Users of any groundwater extracted from wells down-gradient of the Site.

Step 5 (decision rules) adopted by the investigation is to assess the need for additional risk assessment, remediation, or management controls in the event that contamination from the Site is found to exceed DEC-endorsed environmental criteria. This approach is consistent with the methodology described in the ANZECC & NHMRC (19992) guidelines for managing contaminated Sites, which is the basis for the SEPP55 and NEPM (1999) guidelines. This decision rule has been used as the basis for the Site-specific risk assessment.

Step 6 (tolerable limits on decisions errors) defines how the quality of the data collected by the investigation are to be assessed. These criteria are summarised in **Table 10**.

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■ **Table 10 Data Quality Evaluation Criteria**

Feature	Evaluation Criteria
Documentation and data completeness	• Site conditions properly described • Sampling locations properly described and located • Completion of field records, calibration results, chain of custody documentation, laboratory test certificates from NATA-registered laboratories • Samples are collected from all areas of potential environmental concern along the foreshore boundaries • Samples are tested for all potential contaminants of concern • Sampling events cover worst case conditions on more than one occasion
Data comparability	• Use of appropriate techniques for the sampling, storage and transportation of samples • Use of NATA certified laboratory using NEPM procedures. • Use of NATA certified check laboratory
Data representativeness	• Collection of representative samples from each sampling location
Precision and accuracy for sampling and analysis	• Use of properly trained and qualified field personnel • Blind field duplicates to be collected at a minimum rate of 1 in 10 • RPD's to be less than 30% for inorganic and 50% for organic analyses • Acceptable quality of rinsate blanks • Achieve laboratory QC criteria

Step 7 (optimisation of the data collection process) is implemented by the investigation through the following means:

- Targeted sampling at the most suspect areas of the Site;
- The investigation was conducted to a level of accuracy and confidence that was consistent with the standards specified by the DEC in their guideline titled *'Contaminated Sites Sampling Design Guidelines'* (NSW EPA, 1995), other DEC guidelines, NEPM and associated documents;
- Location of groundwater monitoring wells at most suspect locations down-gradient of the contaminant plume;
- Re-sampling of the existing wells that will provide the best data coverage for the Site and surrounding areas; and
- Collection of passive air samples from the land having the highest potential for elevated volatile gas levels.

7.2 Field Quality Assurance and Quality Control

The Quality Assurance and Quality Control (QA/QC) protocols used during the fieldwork for the Macdonaldtown Triangle are summarised in **Table 11**.

- Table 11 Field QA/QC

Field Procedure	QA Procedure Description
Sampling Team	The fieldwork was directed by Dr Ian Swane and managed by Christine Tropman, an experienced Environmental Scientist. Site personnel comprised only professionally qualified environmental scientists and engineers trained in conducting Site contamination investigations. In completing the field investigation, the Work and OH&S Plan provided a framework for meeting the Data Quality Objectives.
QA/QC System	All fieldwork was conducted in accordance with the Sinclair Knight Merz Standard Sampling Procedure and the company's ISO 9001 certified QA/QC system.
Borehole Logs	Borehole logs for each sampling location were prepared and provided in the Risk Assessment report.
Equipment Calibration	All equipment was calibrated prior to use in the field
Chain of Custody Forms	All samples were logged and transferred under appropriately completed Chain of Custody Forms.
Preservation	All samples were received at the laboratory in appropriately preserved containers, with preservation including packing samples with ice packs in eskies.
Rinsate Blanks	Rinsate blanks were collected at a rate of one per field day to determine if any cross contamination may have occurred during sampling, as specified given in Section 8 of Australian Standard AS4482.1-1997.
Blind Field Duplicates (for testing by Main Lab)	Blind field duplicate samples were prepared in accordance with procedures given in Section 8 of Australian Standard AS4482.1-1997. The frequency of blind field duplicate testing corresponds to at least 5% for both soil and groundwater samples (ie. 1 in 20 samples).
Split Samples (for Inter-Laboratory Testing)	Split samples were prepared in accordance with procedures given in Section 8 of Australian Standard AS4482.1-1997. The frequency of blind field duplicate testing corresponds to at least 5% for both soil and groundwater samples (ie. 1 in 20 samples).

7.3 Laboratory Quality Assurance and Quality Control

The primary and secondary laboratories used for this investigation were ALS and Amdel; both are NATA registered chemical laboratories for the specified tests, with the exception of analysis for speciated TPH, which was undertaken by Amdel, using method E1224, but is not covered by their NATA accreditation. All tests were undertaken in accordance with the NEPM (1999) and ANZECC (2000) water quality guidelines.

A data validation process was used to assess the effectiveness of the overall analytical process and to assess the use of data. **Table 12** outlines the data validation criteria, qualifications to the data and the overall QA/QC procedures used for the laboratory testing program.

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- Table 12 Laboratory QA/QC

Protocol	Description
Holding Times	Holding times are the maximum permissible elapsed time in days from the collection of the sample to its extraction and/or analysis. All extraction and analyses were completed within standard guidelines.
Reagent Blanks	The reagent blank sample is a laboratory prepared sample containing the reagents used to prepare the sample for final analysis. The purpose of this procedure is to identify contamination in laboratory reagent materials and assess any potential bias in sample analysis due to contaminated reagents. Contaminant concentrations must be below the analytical limits of detection in the reagents. Each analysis procedure was subject to a reagent blank analysis. The results of each indicated that the reagents were not contaminated.
Laboratory Duplicates	Laboratory duplicates are field samples that are split in the laboratory and subsequently analysed a number of times in the same batch. These sub-samples are selected by the laboratory to assess the accuracy and precision of the analytical method. ALS/Amdel undertook QA/QC procedures such as calibration standards, laboratory control samples, surrogates, reference materials, sample duplicates and matrix spikes. Intra-laboratory duplicates are performed on a frequency of 1 per 10 samples. The RPD of laboratory duplicates is 50 %, with all results within the specified criteria.
Laboratory Control Standard	A laboratory control standard is a standard reference material used in preparing primary standards. The concentration should be equivalent to a mid range standard to confirm the primary calibration. Laboratory control samples were performed on a frequency of 1 per 20 samples or at least one per analytical run.
Matrix Spikes / Matrix Spike Duplicates (MS/MSD)	MS/MSDs are field samples to which a predetermined stock solution of known concentration is added. The samples are then analysed for recovery of the known addition. Recoveries should be within the stated laboratory control limits of 70 to 130% and duplicates should have RPDs of less than 50%. The majority of RPD's were within accepted limits, with the exception of several samples which had RPD results marginally above 50%. These exceedances are not considered significant as they were close to the criteria and the majority of samples analysed were below or neat to the analytical detection limits. Laboratory control limits for phenol were consistently below the 70% criteria, ranging between 50-60%. This is not considered significant as all recorded phenol concentrations were below assessment criteria.
Blind Field Duplicates	Split samples were prepared in accordance with procedures given in **Section 7.2** of Australian Standard AS4482.1-1997. In total, 3 blind field duplicates and one triplicate water sample out of 34 samples analysed were collected. Field duplicate results are included in the summary of results tables and RPD calculations are included as Tables J - M. The majority of samples were below the RPD criteria for both organic (50%) and inorganic compounds (30%), with the following exceptions: ▪ Nickel at MW39D with an RPD of 40%; ▪ Zinc at MW39D with an RPD of 136.4%; ▪ Lead at MW04D with an RPD of 36.4%; ▪ Zinc at MW04D with an RPD of 35.8%; ▪ Pyrene at MW39D with an RPD of 120%; ▪ Benzene at MW04D with an RPD of 109.1; TPH C_{10}-C_{14} and TPH C_{15}-C_{28} at MW42D with RPDs of 95.7% and 100%, respectively. The nickel, lead, pyrene, benzene and TPH C_{10}-C_{14} RDP results are not considered to be significant, as concentrations are close to the analytical limits of the test methods. The zinc and TPH C_{15}-C_{28} RPD results are attributed to heterogeneity of samples. All results were below the water criteria except for benzene, although in this case the

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Protocol	Description
	primary duplicate was within acceptable RPD criteria. A blind soil sample duplicate was analysed for BTEX and TPH. All RPDs were below 50% with the exception of C_{16}-C_{28} with an RPD of 367%. This result is not considered significant, as concentrations were close to the limits of the analytical test methods.
Surrogate Spikes	Surrogate spikes provide a means of checking, for every analysis, that no gross errors have occurred at any stage of the procedure leading to significant analyte loss. Recoveries should be within the stated laboratory control limits of 70 to 130%.
QA/QC Conclusion	The QA/QC indicators should either all comply with the required standards or show variations that are considered to have a significant effect on the quality of the data. Based on the scope and results of the quality checking, the laboratory results are considered to be consistent and indicate that the laboratory results are reliable.

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8 Investigation Levels

This section of the report describes the various environmental investigation levels that have been adopted by this study to identify those contaminants and environmental media that require evaluation as part of a Site-specific human health and ecological assessment.

As previously mentioned in Section 2.4.1, the ANZECC & NHMRC (1992) and NEPM (1999a) guidelines[3] *define an 'Investigation Level' as "the concentration of a contaminant above which further appropriate investigation and evaluation will be required." Investigation Levels are used by to identify those contaminant(s) that should be further investigated as part of a site-specific risk assessment.*

In this risk assessment for the Former Gasworks Site Investigation Levels have been defined for the three environmental media of concern at the site, as previously identified in Section 5.6.3, these being soil, groundwater and soil gas, together with aesthetics.

8.1 Soil Investigation Levels

8.1.1 Methodology

The NSW EPA has endorsed the use of the Soil Investigation Levels (SILs) given in the 1999 NEPM *'Schedule B(1) Guideline on the Investigation Levels for Soil and Groundwater'*. The guidelines provide both Health Based Investigation Levels (HILs) and Ecologically Based Investigation Levels (EILs) for a range of land uses.

As stated in the NEPM (1999a) guidelines, health based Investigation Levels should not be considered as clean up or response levels (the concentration of a contaminant for which some form of response is required to provide an adequate margin of safety to protect public health and/or the environment) nor are they desirable soil quality criteria. These values are to be used to assess existing contamination only and are intended to prompt a site-specific assessment when they are exceeded. In addition, relevant investigation levels need to be developed when:

- *Investigation Levels* are not available for contaminants of concern and/or data to enable the derivation of guideline values;
- Site conditions, receptors and/or exposure pathways differ significantly from those assumed in the derivations of the health based or ecological investigation levels; and

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[3] NEPC. 1999. "Schedule B(4) Guideline on Health Risk Assessment Methodology". National Environment Protection (Assessment of Site Contamination) Measure 1999.

- There are significant ecological concerns (eg. critical or sensitive habitat, threatened or endangered species, parklands or nature reserves).

National Environment Health Forum (NEHF) HILs are given in the NEPM for 4 types of land uses:

- A–'Standard' residential with garden/accessible soil (home-grown produce contributing less than 10% of vegetable and fruit intake; no poultry): this category includes children's day-care centres, kindergartens, preschools and primary schools
- D–Residential with minimal opportunities for soil access: includes dwellings with fully and permanently paved yard space such as high-rise apartments and flats
- E–Parks, recreational open space and playing fields: includes secondary schools
- **F–Commercial/industrial: includes premises such as shops and offices as well as factories and industrial Sites.**

The HIL's given in the NEPC (1999a) guideline cover most of the potential contaminants of concern that are relevant to this investigation. The analytes not covered include TPH/BTEX, OPPs, asbestos, VOCs and most SVOCs. Criteria for these contaminants have been sourced from:

- NSW EPA (1994) *'Guidelines for Assessing Service Station Sites'* for petroleum hydrocarbons (TPH/BTEX). While these guidelines are for *'sensitive land use'*, such as standard residential, the NSW EPA has required these criteria be applied to other land uses unless a Site-specific risk assessment justifies the use of different criteria;
- The NSW EPA (1998) Site Auditor Guidelines included an EIL for phenol;
- Department of Health issued a letter in September 2000 to the NSW EPA advising that there be no free asbestos fibres at the ground surface; and
- The Dutch 2000 Intervention Values[4] and where not available the US EPA Table 9 Preliminary Remediation Goals (PRG)[5] have been adopted for OPPs, VOCs and SVOCs that have no relevant Australian Guidelines.

As previously mentioned in **Section 2.1**, the Former Gasworks Site will remain the property of RailCorp and continue to be zoned to allow commercial/industrial land, although it is not known what site activities will occur or if any structures/ buildings will be established on the site. This study has therefore adopted the HIL(F) soil criteria for the Site, although other criteria will be considered. The EILs provided in the NEPM (1999) guidelines represent Provisional Phytotoxicity criteria that are protective of flora. These criteria are not considered significant at this Site as there

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[4] http://www2.vrom.nl/Docs/internationaal/annexS_I2000.pdf

[5] www.epa.gov/region09/waste/sfund/prg/files/02table.pdf

is no significant vegetation present on the Site, however the criteria will be considered due to possible future landscaping requirements.

Soils that have contaminant concentrations less than both the HILs and EILs are considered to pose no hazard to both users of the Site and flora at the Site, and require no further investigation. Soils that have contaminant concentrations that exceed either the HIL or EIL require further investigation and evaluation as part of the site-specific risk assessment, as recommended in the ANZECC & NHMRC (1992) and NEPC (1999) guidelines. A summary of these criteria for the potential contaminants of concern, together with the NEPM values for the other land uses, is provided in **Table 13**. Typical background ranges for these contaminants, which are recommended in the NEPM (1999) guidelines, are also provided in the table.

- Table 13 Soil Investigation Levels (mg/kg)

Substances	Health Investigation Levels (HILs)						Ecological Investigation Levels (EILs)		Back/ ground Ranges[6]
	A[1]	B[2]	C[3]	D	E	F	REIL[4]	Interim Urban[5]	
METALS/METALLOIDS									
Arsenic (total)	100			400	200	500		20	1-50
Barium								300	100-3000
Beryllium	20			80	40	100		3	1
Cadmium	20			80	40	100		3	1
Chromium (III)	12%			48%	24%	60%		400	
Chromium (VI)	100			400	200	500		1	
Chromium (Total *7									5-1000
Cobalt	100			400	200	500			1-40
Copper	1000			4000	2000	5000		100	2-100
Lead	300			1200	600	1500		600	2-200
Manganese	1500			6000	3000	7500			
Methyl Mercury	10			40	20	50			
Mercury (inorganic)	15			60	30	75		1	0.03
Nickel	600			2400	600	3000		60	5-500
Vanadium								50	20-500
Zinc	7000			28000	14000	35000		200	10-300
ORGANICS									
Aldrin + Dieldrin	20			40-	20	50			
Chlordane	50			200	100	250			
DDT + DDD + DDE	200			800	400	1000			
Heptachlor	10			40	20	50			
Polycyclic aromatic Hydrocarbons (PAHs)	20			80	40	100			
Benzo(a)pyrene	1			4	2	5			
Phenol	8500			34000	17000	42500		70	
PCBs Total	10			40	20	50			
MONOCYCLIC AROMATIC HYDROCARBONS									
Benzene	1								
Toluene	130	130	130	130	130	130		1.4	
Ethyl benzene	50	50	50	50	50	50		3.1	
Total Xylenes	25	25	25	25	25	25		14	

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Substances	Health Investigation Levels (HILs)						Ecological Investigation Levels (EILs)		Back/ ground Ranges[6]
	A[1]	B[2]	C[3]	D	E	F	REIL[4]	Interim Urban[5]	
PETROLEUM HYDROCARBON COMPONENTS (CONSTITUENTS):									
Total Petroleum Hydrocarbons [15] C_6-C_9	65			65	65	65			
Total Petroleum Hydrocarbons C_{10}-C_{40}	1000			1000	1000	1000			
>C_{16} – C_{35} Aromatics[8]	90			360	180	450			
> C_{16} – C_{35} Aliphatics	5600			22400	11200	28000			
> C_{35} Aliphatics	5600			22400	11200	28000			
OTHER									
Boron	3000			12000	6000	15000			
Cyanides (Complex)	500			2000	1000	2500			
Cyanides (free)	250			1000	500	1250			
Phosphorus								2000	
Sulfur								600	
Sulfate[9]								2000	
Asbestos	No free asbestos fibres at ground surface								

Notes

1. Human exposure settings based on land use have been established for HILs (see Taylor and Langley 1998). These are:

   A. 'Standard' residential with garden/accessible soil (home-grown produce contributing less than 10% of vegetable and fruit intake; no poultry): this category includes children's day-care centres, kindergartens, preschools and primary schools.

   B. Residential with substantial vegetable garden (contributing 10% or more of vegetable and fruit intake) and/or poultry providing any egg or poultry meat dietary intake.

   C. Residential with substantial venerable garden (contributing 10% or more of vegetable and fruit intake); poultry excluded.

   D. Residential with minimal opportunities for soil access: includes dwellings with fully and permanently paved yard space such as high-rise apartments and flats.

   E. Parks, recreational open space and playing fields: includes secondary schools.

   F. Commercial/Industrial: includes premises such as shops and offices as well as factories and industries Sites. (For details on derivation of HILs for human exposure settings based on land use see Schedule B (7A).

2. Site and contaminant specific: on Site sampling is the preferred approach for estimating poultry and plant uptake. Exposure estimates may then be compared to the relevant ADIs, PTWIs and GDs.

3. Site and contaminant specific: on Site sampling is the preferred approach for estimating plant uptake. Exposure estimates may then be compares to the relevant ADIs, PTWIs and GDs.

4. These will be developed for regional areas by jurisdiction as required.

5. Interim EILs for the urban setting are based on considerations of phytotoxicity; ANZECC B levels, and soil survey data from urban residential properties in four Australian capital cities.

6. Background ranges, where HILs or EILs are set, are taken from the Field Geologist's Manual, compiled by D.A. Berkman. Third Edition 1989. Publisher – The Australasian Institute of Mining & Metallurgy. This publication contains information on a more extensive list of soil elements than is included in this Table. Another source of information is Contaminated Sites Monograph No. 4: Trace Element Concentrations in Soils from Rural & Urban Areas of Australia, 1995. South Australian Health Commission.

7. Valance state not distinguished – expected as Cr (III).

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8. The carbon number is an 'equivalent carbon number based on a method that standardises according to boiling point. It is a method used by some analytical laboratories to report carbon numbers for chemicals evaluated on a boiling point GC column.

9. For protection of built structures.

10. The toluene threshold concentration is the Netherlands MPC to protect terrestrial organisms in soil. This value was obtained by applying a US EPA assessment factor to terrestrial chronic No observed Effect Concentrations (NOEC) data. The MPC is an 'indicative' value (Van de Plassche *et al.* 1993; Van de Plassche & Bockting, 1993)

11. Human Health and ecologically based protection level for toluene. The threshold concentration presented here is the Netherlands intervention value for the protection of terrestrial organisms. Other considerations such as odours and the protection of groundwater may require a lower remediation criteria.

12. The ethyl benzene threshold concentration is the Netherlands MPC for the protection of terrestrial organisms in soil. No terrestrial ecotoxicological data could be found for use in the Netherlands criteria derivation. Therefore, equilibrium partitioning has been applied to the MPC for water to obtain estimates of the MPC for soil. The MPC for water has been derived from aquatic ecotoxicological data (Van de Plassche et al. 1993, Van de Plassche & Bockting, 1993).

13. Human health based protection level for ethyl benzene or total xylene as shown. The threshold concentration presented here is the Netherlands intervention value. Other considerations such as odours and the protection of groundwater may require a lower remediation criteria.

14. The xylene concentration is the Netherlands MPC for the protection of terrestrial organisms in soil. No terrestrial ecotoxicological data could be found for use in the Netherlands criteria derivation. Therefore, equilibrium partitioning has been applied to the MPC for water to obtain estimates of the MPC for soil. The MPC for water has been derived from aquatic ecotoxicological data. The concentration shown applies to total xylenes and is based on the arithmetic average of the individual xylene MPCs (Van de Plassche et al. 1993, Van de Plassche & Bockting, 1993).

15. Approximate range of petroleum hydrocarbon fractions: petrol C6-C9, kerosene C10-C18, diesel C12-C18 and lubricating oils above C18.

8.1.2 Application of Petroleum Hydrocarbon Criteria

The previous investigations collected data on total petroleum hydrocarbon (TPH) fractions in soils and groundwater. The fractions analysed were unspeciated, meaning that the TPH compounds in a given hydrocarbon range were not differentiated in terms of aliphatic and aromatic compounds. The toxicological risks posed by TPH compounds vary according to both the hydrocarbon fractions and the speciated fractions. Different reference doses have been developed for aliphatic and aromatic (and alkene) compounds to reflect the significant differences in chemical, physical and environmental fate properties. Consequently, a more accurate assessment of health risks from TPH contamination in soils could be obtained by conducting speciated TPH analysis on areas of the site suspected of having elevated TPH concentrations.

This investigation included the collection of soil samples from each of the soil-gas probe locations to assess the likely aromatic and aliphatic TPH concentrations at the site. At least one soil sample was taken from each of the vapour sampling locations and subjected to unspeciated TPH laboratory analysis as well as BTEX. A summary of the laboratory data and the results of statistical analyses are presented in **Tables G - J**.

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The data indicate that TPH was recorded in all samples apart from the sample taken at MW32. The maximum TPH concentration recorded was 2723mg/kg at MW33, which primarily consisted of a C16-C35 aromatic compounds at 2124mg/kg (represents 78% of TPH). Of the six samples where TPH concentrations were detected, 4 of the samples (ie. 66%) had high concentrations of the aromatic fractions compared to the aliphatic fractions.

The speciated TPH results indicate that the Investigation Levels for aromatic TPH fractions should be adopted in preference to the aliphatic TPH criteria because:

- A much higher proportion of samples had higher concentrations of aromatic TPH fractions than aliphatic fractions; and
- The NEPM Investigation Levels for aromatic TPH fractions are lower than for aliphatic fractions.

BTEX compounds were not detected in any of the soil samples taken during the installation of the vapour wells.

The data obtained by the soil gas monitoring also indicate that high BTEX soil vapour concentrations do not appear to be linked with high BTEX soil concentrations, suggesting that the volatile hydrocarbons that were measured in the soil vapour wells had largely migrated through the subsurface soils from areas of higher soil or groundwater contamination.

8.2 Groundwater Investigation Levels

The NSW DEC has endorsed the use of water quality criteria in the ANZECC & ARMCANZ (2000) *"Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000" and the NHMRC (2004) "Australian Drinking Water Guidelines"*. The ANZECC & ARMCANZ guidelines provide *Investigation Levels* for the protection of marine and freshwater aquatic ecosystems. The freshwater criteria are the relevant set for the Site given that the nearest water body is the headwaters of Alexandra Canal (Sheas Creek) located some 1.3km to the south of the Site where creek flows would consist of surface water drainage from the Redfern/Alexandria area (ie. non-tidal). The NHMRC (2004) guidelines provide *Investigation Levels* for the protection of human health and aesthetic considerations arising from drinking water.

Where *Investigation Levels* are not available in these guidelines for some of the potential contaminants of concern, water quality criteria have been sourced from other guidelines endorsed by the NSW DEC, which comprise:

- NEPC (1999a) *"Schedule B(1) Guideline on the Investigation Levels for Soil and Groundwater"*; and
- ANZECC (1992*) "Australian Water Quality Guidelines for Fresh and Marine Waters"*.

The ANZECC & ARMCANZ (2000) guidelines do not provide criteria for petroleum hydrocarbons C_{10}-C_{36}. For this analyte, the Dutch (2000) Mineral Oil criteria of 600 µg/L has been adopted. This *Investigation Level* has been adopted because:

- The concentrations of other more toxic hydrocarbon substances that may be detected by the TPH analysis have been individually analysed in this investigation. These other analytes comprise BTEX and PAHs;
- Dutch criteria are referred to in NSW EPA (1994) "Service Stations Guideline". No directive has been issued by the NSW DEC advising that their directive in the 1994 guideline be changed;
- The Dutch criteria were recently reviewed in 2000;
- The low reliability values given in the ANZECC guidelines are exceeding conservative and do not correspond to a 95% level of protection;
- The low reliability values given in the ANZECC guidelines were derived from a toxicological assessment of crude oil, which is not the same material as refined petroleum products. Crude oil contains a complex mix of both petroleum hydrocarbons and PAHs, with the PAHs posing a much greater risk than petroleum products as seen by the much lower criteria given in the ANZECC guidelines for PAHs compared to BTEX compounds;
- The low reliability values given in the ANZECC guidelines were derived for a marine environment rather than a freshwater environment which is more appropriate for this Site;
- The Dutch 2000 TPH criteria is between the ANZECC 2000 guideline values for benzene at a 99% and 95% level of protection in a marine environment. Since one of the most toxic substances in TPH would be benzene, it is reasonable to adopt a TPH criteria that is not less than the benzene criteria;
- No chemical laboratory in Australia is known to have a NATA-accredited test method that can reach the detection limits required by the low reliability values given in the ANZECC guidelines for crude oil; and
- There is a long precedence of using the Dutch TPH water criteria by Site Auditors and Environmental Consultants in many investigations over the past 10 years.

The ANZECC & ARMCANZ (2000) guidelines also do not provide criteria for petroleum hydrocarbons C_6-C_9. For this analyte, the Dutch (2000) Aromatic Solvents criteria of 150 µg/L has been adopted. This criteria seems appropriate since it is less than the ANZECC & ARMCANZ (2000) criteria for benzene and comparable to the toluene, ethylbenzene and xylenes criteria.

For other key contaminants where no health criteria are specified by these guidelines for drinking and recreational water, reference has been made to the USEPA's Preliminary Remedial Goals (PRGs) for Tap Water (www.epa.gov/region09/waste/sfund/prg/files/02table.pdf).

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The ANZECC & ARMCANZ (2000) guidelines provide trigger levels for four different levels of protection for fresh and marine water, namely 99%, 95%, 90% and 80%. Here, protection level signifies the percentage of species expected to be protected. The guidelines recommend that these trigger levels be used to assess existing contamination only and are intended to prompt a site-specific assessment when they are exceeded. In addition, relevant *Investigation Levels* need to be developed when:

- *Investigation Levels* are not available for contaminants of concern and/or data are not available to enable the derivation of guideline values;
- Site conditions, receptors and/or exposure pathways differ significantly from those assumed in the derivations of the health based or ecological investigation levels.
- There are significant ecological concerns (eg. critical or sensitive habitat, threatened or endangered species, parklands or nature reserves).
- Observed background groundwater levels are outside the expected range.

Since the Site is more than a kilometre from the nearest waterbody, it is considered that the 95% protection level provides an appropriate trigger level for this study.

The NEPC (1999a) guidelines also advise that groundwater trigger levels (or investigation levels) *"are to be applied at the point of extraction and as response levels at the point of use, or where there is the likelihood of an adverse environmental effect at the point of discharge"*. However, the NSW DEC (1997) Site Auditor Guidelines recommend that groundwater *Investigation Levels* should be applied at the boundary of the Site. For this investigation, it is considered that the groundwater *Investigation Levels* should be applied at the boundary of the Site for the following reasons:

- Residential properties located adjacent to the down-gradient boundary of the Site are being redeveloped with deep basements, which creates a potential exposure pathway for human receptors;
- The NSW DEC (1999) Significant Risk of Harm Guidelines assess the risk of groundwater contamination at the site boundary;
- One of the objectives of the NSW Government's Groundwater Protection Policy is to protect the quality of groundwater resources of the State, to ensure that resources can support their identified uses and values in a sustainable, and economically, socially and environmentally acceptable manner (NSW DEC, 1994); and
- The NSW EPA (1994) Service Station Guidelines recommend that *"Contaminated aquifers and contaminated aquicludes should, as far as practicable, be remediated to the condition they were in before they became contaminated"* and *"If the analyte concentrations in groundwater exceed the relevant thresholds, the groundwater should be remediated to or below the*

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threshold concentrations. If the threshold concentrations provided are not applicable, then the EPA should be consulted to determine the remediation goals".

A summary of the water quality criteria is provided in **Table 14** for the potential contaminants of concern at the Site.

- Table 14 Groundwater Investigation Levels (μg/L)

Substance	Fresh Water 95% Protection Level	Drinking Water	
		Health	Aesthetic
Metals/Metalloids			
Arsenic (total)	24 (5)	7	---
Cadmium	0.2	2	---
Chromium (III)	3.3	55000 (3)	---
Chromium (VI)	1.0	50	---
Copper	1.4	2000	1000
Iron	300	---	300
Lead	3.4	10	---
Mercury (inorganic)	0.06 (8)	0.001	
Nickel	11	20	---
Zinc	8	---	3000
PAHs			
PAHs (total)	3 (1,2)	---	---
Benzo(a)pyrene	0.05 (4)	0.01	---
Naphthalene	16	6.2 (3)	---
Fluoranthene	1 (4)	---	---
Phenanthrene	5 (4)	---	---
Anthracene	5 (4)	---	---
Benzo(a)anthracene	0.5 (4)	---	---
Benzo(k)fluoranthene	0.05 (4)	---	---
Indeno(1,2,3-cd) pyrene	0.05 (4)	---	---
Benzo(ghi)perylene	0.05 (4)	---	---
TPH & BTEX			
TPH (C6-C9)	150 (4)	---	---
TPH (C10-C36)	600 (4)	---	---
Benzene	950	1	---
Toluene	180	800	25
Ethylbenzene	50	300	3
o-Xylene	350	600	20
p-Xylene	200		
Phenols			

Substance	Fresh Water 95% Protection Level	Drinking Water	
		Health	Aesthetic
Phenol	320	22000 (3)	---
2-Methylphenol	---	1800 (3)	---
3-Methylphenol	---	1800 (3)	---
4-Methylphenol	---	180 (3)	---
2,4-Dimethylphenol	---	730 (3)	---
Other Organics			
n-Propylbenzene	---	240 (3)	
Styrene	530	30	4
Vinyl chloride	5 (4)	0.3	
Aniline	250	---	---
Dibenzofuran	---	24 (3)	---
Bis(2-ethylhexyl) phthalate	---	4.8 (3)	---
1,2,4- & 1,3,5-Trimethylbenzene	---	12 (3)	---
Other			
Cyanides (total)	7 (6)	---	---
Cyanides (free)	7	80	---
Ammonia	900	(7)	500
Sulfide	1	---	50
pH	6.5 – 9.0 (1)	---	6.5-8.5

Notes:

(1) ANZECC (1992) freshwater criteria
(2) NEPC (1999a) freshwater criteria
(3) USEPA Preliminary Remedial Goal for tap water
(4) Dutch 2000 Groundwater Intervention Value
(5) ANZECC (2000) Arsenic (III) criteria adopted for freshwater ecosystems
(6) A cyanide (total) criteria of 7 should only be used of no free cyanide results are available. If they are, then the free cyanide criteria should be used and not the total cyanide criteria.
(7) Ammonia does not pose a risk to human health since it is naturally occurring at high concentrations in the gut
(8) The 99% fresh water protection level has been adopted for inorganic mercury since the ANZECC & ARMCANZ (2000) guidelines recognise it as a chemical for which possible bioaccumulation and secondary poisioning effects should be considered.

8.3 Soil Gas Investigation Levels

Exposure standards for the occupational workplace published by Worksafe Australia have been adopted as the soil gas investigation levels for the Site. The document, *'Exposure Standards for Atmospheric Contaminants in the Occupational Environment, Worksafe Australia'*, (Worksafe

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Australia, May 1995) contain both Guidance Notes [NOHSC:3008 (1995)] and the National Exposure Standards [NOHSC:1003 (1995)]. The document and the exposure standards are updated regularly on the Worksafe Australia website. All values listed below were confirmed through a review of the exposure database

The guidelines and exposure standards detail that the air inhaled at work should not contain chemical agents at concentrations that produce adverse effects on health, safety or well being. The exposure standards represent airborne concentrations of individual chemical substances, which, according to current knowledge, should neither impair the health of nor cause undue discomfort to nearly all workers. Additionally, the exposure standards are believed to guard against narcosis or irritation that could precipitate industrial accidents.

Except where modified by consideration of excursion limits, exposure standards apply to long term exposure to a substance over an eight-hour day, for a five-day working week, over an entire working life. The exposure standards do not represent `no-effect' levels that guarantee protection to every worker and or occupier. Given the nature of biological variation and the range of individual susceptibility, it is inevitable that a very small proportion of workers who are exposed to concentrations around or below the exposure standard may suffer mild and transitory discomfort. An even smaller number may exhibit symptoms of illness.

Therefore the exposure standards are not fine dividing lines between satisfactory and unsatisfactory working conditions, but rather that they are best used to assess the quality of the working environment and indicate where appropriate control measures are required. The exposure standards listed in this publication only consider absorption via inhalation and are valid only on the condition that significant skin absorption cannot occur.

Benzene, toluene, xylene and PAHs are considered to be the key air toxics of concern at the Macdonaldtown Triangle Site, as indicated in **Section 5.6**. It is proposed that the quality of the air at the sampling locations should not exceed the Worksafe Australia occupational air quality standards given in **Table 15**.

▪ **Table 15 Occupational Exposure Standards for Atmospheric Contaminants**

Contaminant	TWA	
	Ppm	ug/m³
Benzene	5	16,000
Toluene	100	377,000
Ethyl Benzene	100	434,000
Xylene	80	350,000
Petroleum Hydrocarbons*	240	900,000
Naphthalene	10	52,000
Coal tar pitch volatiles (as benzene soluble)	---	200

Notes: * the substance requires further review by the Exposure Standards Expert Working Group.
Conversion Factors (from ATSDR)
Benzene: 1ppm = 3.24 mg/m^3 @ 20°C
Toluene: 1ppm = 3.75 mg/m^3 @ 20°C
Xylenes (mixed): 1ppm = 4.34 mg/m^3 @ 20°C

8.4 Aesthetic Criteria

The 1999 NEPM *'Schedule B(1) Guideline on the Investigation Levels for Soil and Groundwater'* advises that:

> *'There are no numeric Aesthetic Guidelines but the fundamental principle is that the soils should not be discoloured, malodorous (including when dug over or wet) nor of abnormal consistency. The natural state of the soil should be considered.'*

NSW DEC guidelines also specify the following requirements for sites:

- Any contaminant odours emanating from Site soils have been adequately addressed - refer NSW EPA (1998) Site Auditor Guidelines; and
- No floating product remains on the groundwater – refer NSW EPA (1994) Service Station Guidelines.

Discoloured soils are not considered by the NSW DEC as a quality of the environment that needs to be protected on a commercial/industrial site. Given these NEPM and NSW DEC requirements, the aesthetic criteria of relevance to the Macdonaldtown Triangle area and the Former Gasworks site in its present and future condition are considered to be:

- No malodorous materials exposed at the final ground surface;
- No malodorous gases emanating from the ground at the final ground surface into any buildings or structures to be accessed by people; and
- No floating product to remain on groundwater at or near the Site.

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9 Soil Vapour Analysis

This section of the report presents the results of a soil vapour investigation and assessment conducted at the Former Gasworks site. The purpose of these investigations was to address data gaps that existed in previous investigations, as previously discussed in Section 5.8. The results of a screening assessment are initially provided (Section 9.1), followed by the results of a soil vapour investigation (Section 9.2). The results of theoretical computer simulations are then presented in order to provide further insight into the soil vapour generation potential at the Former Gasworks site (Section 9.3), with a comparison between the field measurements and computer analysis then presented (Section 9.4).

9.1 Screening Assessment

The previous investigations identified elevated concentrations of volatile compounds in the soils and groundwater that could form an exposure pathway for contaminants. However, the amount of data that was available was not sufficient to allow a site-specific assessment to be made of the risks posed by soil vapours to the health of future site users and surrounding residents.

This study has sought to address this data gap by collecting soil-gas data at locations across the Former Gasworks site considered to pose the highest potential risks from volatile organic contamination. The investigation also targeted those potential contaminants of concern (as listed in **Section 5.6.2**) that are sufficiently toxic and volatile to present a potential risk to users of the site and adjoining properties. These compounds were identified using the screening process provided in the US EPA (February 2004) *"User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings"*.

The screening process involves a qualitative assessment of these chemicals in terms of their toxicity, volatility and whether they have been detected at elevated concentrations in soil and groundwater samples at the site. The qualitative data on the toxicity and volatility of the chemicals has been obtained from Table 1 in the US EPA (February 2004) study, while a review of the laboratory data summary tables in **Appendix B** has been used to determine whether the compounds have been found at elevated concentrations at the Former Gasworks site.

The outcomes of the screening analysis for the potential contaminants of concern at the Former Gasworks site are provided in **Table 17A**. In the table, the volatile chemicals that present the greatest risks to the site and surrounding properties are those that are considered to be sufficiently toxic and volatile and present at elevated concentrations. The assessment has identified two groups of chemicals that meet these conditions at the Former Gasworks site, these being PAH compounds (acenaphthene, benz(b)fluoranthene, chrysene, fluorene, naphthalene, pyrene) and monocyclic aromatic compounds (benzene, toluene, ethylbenzene and xylenes).

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- **Table 17A Screening Assessment for Soil Vapour Assessment**

CAS No.	Chemical	Is Chemical Sufficiently Toxic ?	Is Chemical Sufficiently Volatile ?	Is Chemical Present at Elevated Levels ?
PAHs				
83329	Acenaphthene	YES	YES	YES
120127	Anthracene	NO	YES	YES
56553	Benz(a)anthracene	YES	NO	YES
50328	Benzo(a)pyrene	YES	NO	YES
205992	Benzo(b)fluoranthene	YES	YES	YES
207089	Benzo(k)fluoranthene	NO	NO	YES
218019	Chrysene	YES	YES	YES
53703	Dibenz(a,h)anthracene	YES	NO	NO
86737	Fluorene	YES	YES	YES
91203	Naphthalene	YES	YES	YES
129000	Pyrene	YES	YES	YES
Monocyclic aromatic hydrocarbons				
71432	Benzene	YES	YES	YES
108883	Toluene	YES	YES	YES
100414	Ethylbenzene	YES	YES	YES
108383	m-Xylene	YES	YES	
95476	o-Xylene	YES	YES	YES
106423	p-Xylene	YES	YES	
Other Chemicals				
108952	Phenol	YES	NO	NO
7439976	Mercury (elemental)	YES	YES	NO

Note: Source of qualitative toxicity and volatility data from US EPA (February 2004)

For these 10 target chemicals, the area where volatile gas emissions are likely to be of most concern at the site has been identified on the basis of the water quality in the shallow aquifer and the soil concentrations in the unsaturated soils located above the water table. The condition of the deeper aquifer and deeper soils are not considered as critical in the vapour assessment since the volatile concentrations in the shallow aquifer would tend to include the contributions made by the vertical migration of volatiles from deeper saturated soils and deeper aquifers. This is because the volatile vapours produced by these deeper sources would tend to be absorbed in the shallow groundwater and be accounted in its water quality.

A review of the water quality in the shallow aquifer has found that the highest concentrations of the target chemicals are located towards the centre of the former gasworks where the gasholders and purifiers operated. The data shows that an intermittent plume of volatile chemical contamination has formed in the shallow aquifer, which is defined by the results obtained from the shallow monitoring wells MW03S, MW06S, MW07S and MW20S. Practically all other wells have shown non-detectible concentrations of these target chemicals, the only exceptions being some wells with relatively minor PAH concentrations (MW04S naphthalene = 5µg/L; MW12S naphthalene = 2µg/L, acenaphthene = 9µg/L, fluorene = 15µg/L, phenanthrene = 8µg/L; MW13S acenaphthene = 5µg/L, fluorene = 7µg/L, phenanthrene = 2µg/L, MW36S pyrene = 2µg/L; MW37S acenaphthene = 14µg/L, fluorene = 15µg/L). The results of computer analyses presented in **Section 9.3** also show that these low PAH concentrations do not influence the outcome of the risk analysis.

A summary of the PAH and BTEX concentrations that have been measured in the three rounds of groundwater testing for the shallow aquifer plume are summarised in **Table 17B** with the estimated extent of the plume shown in **Figure 15.**

- **Table 17B Levels of Target Volatiles Measured in Shallow Aquifer Plume**

	MW03S			MW06S			MW07S			MW20S			Average
	5/11/00	4/10/01	2/3/05	5/11/00	4/10/01	2/3/05	5/11/00	4/10/01	2/3/05	5/11/00	4/10/01	2/3/05	
Benzene	74	0			17	0		704			0	0	114
Toluene	0	0			0	0		0			0	0	0
Ethylbenzene	28	0			8	0		213			7	0	37
Xylenes	15	0			72	0		417			5	0	73
Naphthalene	86	0			0	24		1460			23	9	229
Acenaphthene	2	0			0	0		14				4	3
Fluorene	1	0			0	0		15				3	3
Pyrene	0	0			0	2		0				0	0
Chrysene	0	0			0	0		0				0	0
Benzo(b,k) fluoranthene	0	0			0	0		0				0	0

Note: All units in ug/L

With regard to the shallow unsaturated soils located in this area, the laboratory data indicate the soils have very low BTEX concentrations but highly variable PAH concentrations. The soil boreholes located in the shallow plume area are SB03, SB04, SB06, SB18, MW03S, MW06S, MW07S, MW20S and MW30-MW34. **Table 17C** provides a summary of all available laboratory results for the target volatile chemicals tested in soil samples taken in the plume area at a depth of 0 – 1.5m.

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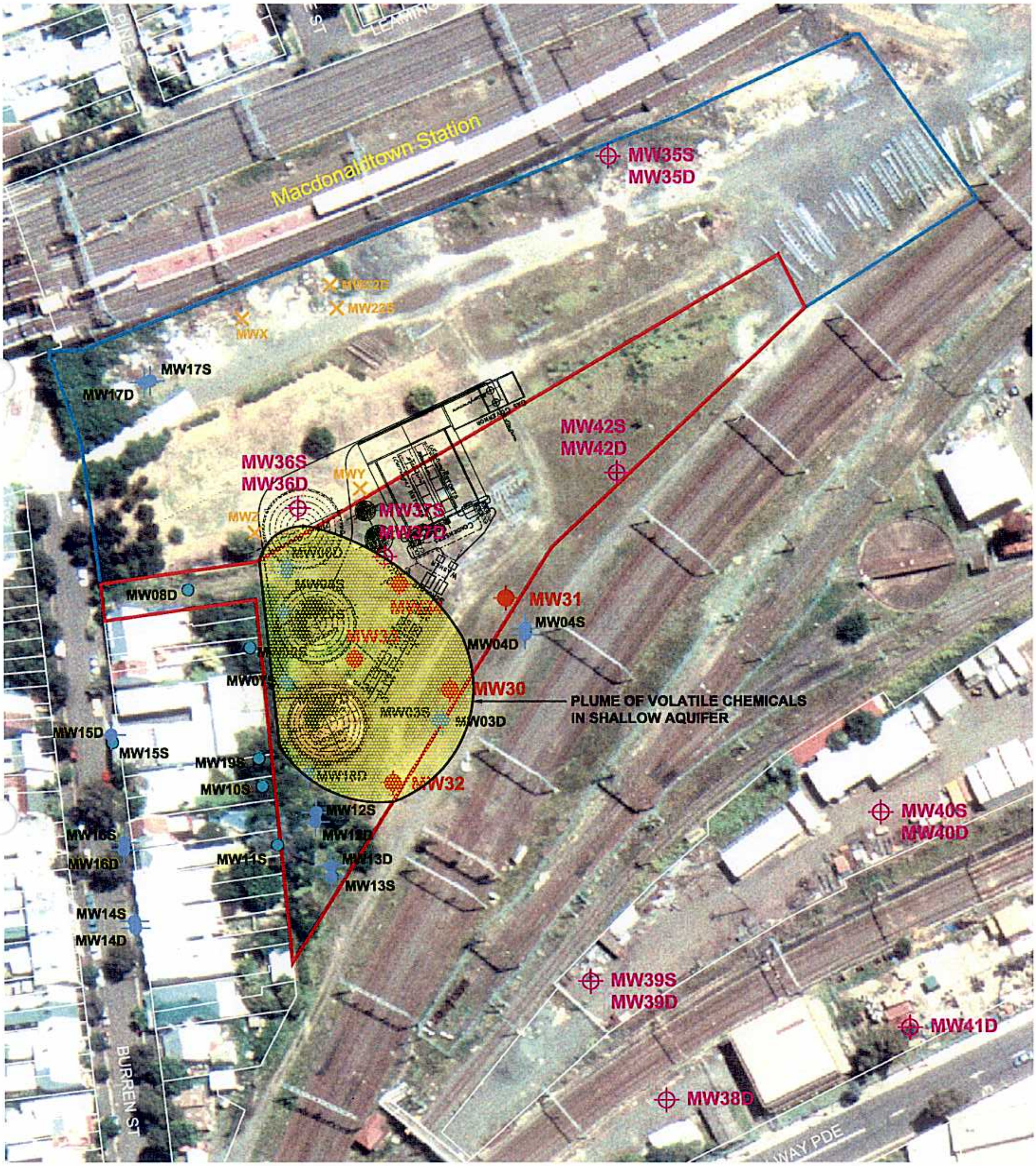
Figure 15
EXTENT OF VOLATILE CHEMICAL PLUME IN SHALLOW AQUIFER
Macdonaldtown Risk Assessment



LEGEND

- GASWORKS SITE
- CLEANING SHED SITE
- CH2MHILL MONITORING WELL LOCATIONS
- CH2MHILL MONITORING WELL LOCATIONS NOT PREVIOUS IDENTIFIED
- SKM GROUNDWATER MONITORING WELL LOCATIONS (1 DEEP AND 1 SHALLOW)
- SOIL VAPOUR MONITORING WELLS

0 10 20 30 40 50 60 m

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- **Table 17C Volatile Chemical Results for Shallow Unsaturated Soils in Plume Area**

	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	SKM	SKM	Average
	SB03	**SB03**	**SB04**	**SB04**	**SB06**	**SB06**	**SB18**	**MW20S**	**MW30**	**MW32**	
	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	Oct 2001	Dec 2004	Dec 2004	
	0.00-0.10	1.00-1.10	0.00-0.10	0.70-0.80	0.20-0.30	0.30-0.40	0.20-0.30	0.9-1.0	0-0.45	1.2	
Benzene	0	0		0	0	0	0	0	0	0	0.0
Toluene	0	0		0	0	0	0	0	0	0	0.0
Ethylbenzene	0	0		0	0	0	0	0	0	0	0.0
Total Xylenes	0	0		0	3	0	0	0	0	0	0.3
Naphthalene	3.4	0	0	28	99	0	280	0			51.3
Acenaphthene	0.8	0	0	12	29	0	33	0			9.4
Fluorene	4.2	0	0	66	120	0	120	0.5			38.8
Pyrene	48	0	0	240	320	20	600	12.7			155.1
Chrysene	21	0	0	80	96	9.2	200	6.5			51.6
Benzo[b,k]fluoranthene	37	0	0	170	250	26	310	8			100.1

All units in mg/kg

The intermittent BTEX levels measured in the shallow groundwater and the very low BTEX levels measured in the shallow soils suggests that the source of the volatile contaminants measured in the shallow aquifer may be from deeper sources that cause the volatile contamination to migrate vertically after heavy rainfall periods.

9.2 Additional Soil Vapour Investigation

A soil vapour investigation was undertaken as part of this risk assessment to obtain measured soil vapour concentrations in the area of the shallow groundwater plume described in the previous section. The investigation involved the installation of 5 soil-gas monitoring probes(MW30-MW34) located in and around this area, as shown by **Figure 15**. MW30 and MW31 were placed close to previous drilled monitoring wells MW03S where shallow groundwater contamination had been recorded. MW33 was located in close proximity to MW07S where the most significant groundwater contamination was observed. MW34 was located in close proximity to the former retort house and MW20S, while MW32 was positioned down gradient of the former gasholder structures and MW20S.

The vapour wells were installed in December 2004 along with the additional groundwater wells. The sampling of these wells was undertaken in March 2005, allowing contaminant vapours to accumulate within the well casing for a period of three months. No purging was undertaken prior to sampling. The wells were sampled with SKC 226-01 tubes for BTEX and SKC 226-30-04 tubes for PAHs. Both tubes comprising two sections of sorbent matrix to measure possible 'breakthrough'. The laboratory test results found all BTEX and PAH compounds were detected in the front sections of tubes, with no 'breakthrough' recorded in the back section of the tube.

Summary tables of the chemical analyses performed on the soil samples are provided in **Table 18A** and **Table 18B,** with copies of the laboratory test certificates provided in **Appendix E.**

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- **Table 18A BTEX Soil Vapour Results**

BTEX Concentration in Air by SKC sampling - μg/m³								
	Sampling Flow Rate (ml/min)	Sampling Time (mins)	Sampling Volume (m³)	Benzene	Toluene	Ethyl Benzene	m&p – xylene	o-xylene
Assessment Criteria[(1)]				**16,000**	**377,000**	**434,000**	**350,000**	
MW30 (Front)	600	50	0.03	<16.7	14,400	<16.7	<50	
MW30 (Back)	600	50	0.03	<16.7	<16.7	<16.7	<50	
MW31 (Front)	600	50	0.03	<16.7	263	<16.7	<50	
MW31 (Back)	600	50	0.03	<16.7	<16.7	<16.7	<50	
MW32 (Front)	600	50	0.03	16.7	1,527	<16.7	<50	
MW32 (Back)	600	50	0.03	<16.7	<16.7	<16.7	<50	
MW33 (Front)	600	52	0.0312	<16.0	<32.1	<16.7	<50	
MW33 (Back)	600	52	0.0312	<16.0	<16.0	<16.7	<50	
MW34 (Front)	600	50	0.03	<16.7	28,000	<16.7	<50	
MW34 (Back)	600	50	0.03	<16.7	<16.7	<16.7	<50	

[shaded box] Concentrations exceed assessment criteria

16.7 Contaminant mass recorded above laboratory detection limits

- **Table 18B PAH Soil Vapour Results**

PAH Concentration in Air by SKC sampling – ug/m³								
	Sampling Flow Rate (ml/min)	Sampling Time (mins)	Sampling Volume (m³)	Naphthalene	Pyrene	Benz(a) anthracene	Chrysene	Benzo(a) pyrene
MIL								200
MW30 (Front)	2000	110	0.220	2.73	<0.454	<0.454	<0.454	<0.454
MW30 (Back)	2000	110	0.220	<0.454	<0.454	<0.454	<0.454	<0.454
MW31 (Front)	2000	108	0.216	2.78	<0.463	<0.463	<0.463	<0.463
MW31 (Back)	2000	108	0.216	<0.463	<0.463	<0.463	<0.463	<0.463
MW32 (Front)	2000	110	0.220	2.27	<0.454	<0.454	<0.454	<0.454
MW32 (Back)	2000	110	0.220	<0.454	<0.454	<0.454	<0.454	<0.454
MW33 (Front)	2000	111	0.222	2.70	<0.450	<0.450	<0.450	<0.450
MW33 (Back)	2000	111	0.222	<0.450	<0.450	<0.450	<0.450	<0.450
MW34 (Front)	2000	111	0.222	5.41	<0.450	<0.450	<0.450	<0.450
MW34 (Back)	2000	111	0.222	1.35	<0.450	<0.450	<0.450	<0.450

[shaded box] Concentrations exceeding MIL value

NOTE: All other PAH contaminants were below laboratory detection limits

In these tables the results are compared with the volatile gas Investigation Levels adopted for this study (**Section 8.4**), which correspond to the Worksafe Australia Exposure Standards for Atmospheric Contaminants in the Occupational Environment.

All test results measured concentrations of BTEX and PAHs well below the Workcover Exposure Guidelines. BTEX concentrations were found to be below the laboratory detection limits at most sampling locations. The maximum benzene concentration was recorded at MW32 where the concentration was measured at the detection limit of 16.7 $\mu g/m^3$. Toluene was recorded at MW30, MW32 and MW34 and o-xylene recorded at MW32.

These results suggest there may be a low risk that soil-gas vapours at the former gasworks site are an environmental media of concern because:

- All test results measured concentrations of BTEX and PAHs well below the Workcover Exposure Guidelines;
- The locations sampled targeted areas of the site considered to have the highest potential for containing elevated volatile soil-gas levels; and
- The contaminant vapours were allowed to collect within the headspace of the monitoring well for a period of 3 months prior to sampling. This situation represents to some degree the accumulation of vapours in a poorly ventilated room constructed above the Site.

However, it is recognised that the available data are limited and it is likely that significant variations could occur if additional sampling rounds were conducted. This is because of the inherent sensitivity of the test to minor variations in test procedures and environmental conditions, as is evidenced by such factors as:

- The soil vapour tests were conducted at only five discrete locations across the former gasworks site and it is likely that the results do not represent the worst-case;
- The groundwater test data that have been collected on three occasions between 2000 and 2005 show a high degree of variability; and
- The high toluene levels measured in the soil vapour tests appear to be inconsistent with the soil and groundwater data that show relatively low toluene levels below *Investigation Levels*, as shown by the exceedances summarised in **Table 21 (Section 11.1)**.

In order to address these uncertainties, a computer analysis of the soil vapour generation potential of contamination in the shallow soils and aquifer at the Former Gasworks site has been undertaken, with the results presented in the following section.

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9.3 Computer Simulation of Soil Vapour Generation Potential

A theoretical analysis of soil vapour generation potential at the Former Gasworks site has been undertaken using the Johnson and Ettinger (1991) one-dimensional analytical solution to convective and diffusive vapour transport into spaces. The solution calculates the vapour generated from sources of soil and groundwater contamination and provides an estimated attenuation coefficient that relates the vapour concentration in the indoor space to the vapour concentration at the source of contamination. The analysis performed in this study has used the spreadsheet model developed for the US EPA (February 2004), which is available on their website.

The model can be constructed as both a steady-state solution to vapour transport (infinite or non-diminishing source) or as a quasi-steady-state solution (finite or diminishing source). Inputs to the model include chemical properties of the contaminant, saturated and unsaturated zone soil properties and structural properties of the building. The model has been used to estimate soil vapour concentrations in the area where the soil vapour tests were conducted in March 2005.

The Johnson and Ettinger (1991) one-dimensional analytical solution is able to account for soil vapours generated by both soil and groundwater contamination. The source vapour concentration (C_{source}) for groundwater contamination is given by the equation:

$$C_{source} = H'_{TS}\, C_w \quad \text{..........(1)}$$

where:

C_{source}	=	Vapour concentration at the source of contamination (g/cm^3-v)
H'_{TS}	=	Henry's law constant at the system (groundwater) temperature (dimensionless)
C_W	=	Groundwater concentration (g/cm3-w)

The dimensionless form of the Henry's law constant at the system temperature (ie. at the average soil/groundwater temperature) is estimated using the Clapeyron equation:

$$H'_{TS} = \{\exp[-(\Delta H_{v,TS} / R_c)(1/T_s - 1/T_R)]\, H_R\} / (R \times T_s) \quad \text{..........(2)}$$

where:

$\Delta H_{v,TS}$	=	Enthalpy of vapourisation at the system temperature (cal/mol)
T_s	=	System temperature (°K)
T_R	=	Henry's law constant reference temperature (°K)
H_R	=	Henry's law constant at the reference temperature (atm-m^3/mol)
R_c	=	Gas constant (=1.9872 cal/mol - °K)
R	=	Gas constant (=8.205E-05 atm-m^3/mol - °K)

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The enthalpy of vapourisation at the system temperature is calculated from the Lyman equation given in the US EPA (February 2004) manual.

The source vapour concentration (C_{source}) for soil contamination is given by the equation:

$$C_{source} = (H'_{TS}\, C_R\, \rho_b) / (\theta_w + K_d\, \rho_b + H'_{TS}\, \theta_a) \quad \text{.................................(3)}$$

where:

C_{source}	=	Vapour concentration at the source of contamination (g/cm^3-v)
H'_{TS}	=	Henry's law constant at the system (soil) temperature (dimensionless)
C_R	=	Initial soil concentration (g/g)
ρ_b	=	Soil dry bulk density (g/cm^3)
θ_w	=	Soil water-filled porosity (cm^3/cm^3)
Kd	=	Soil-water partition coefficient (cm3/g)
θ_a	=	Soil air-filled porosity (cm^3/cm^3)

The stratigraphic model used in the computer analysis has been based on average conditions that occur across that part of the former gasworks site where elevated volatile concentrations have been measured in the soils and groundwater. The boreholes located within this area are SB03, SB04, SB06, SB18, MW03S, MW06S, MW07S, MW20S and MW30-MW34. These boreholes show that the average depth to the shallow aquifer water table is approximately 1.5m, which is comparable to the depth reached by the soil gas wells MW30-MW34 sampled in March 2005. Furthermore, the volatile contaminants present in the unsaturated shallow soils can occur throughout the shallow soil profile. This means that the soil-gas monitoring wells that were tested in March 2005 should have measured the source concentration of volatile gases given off by the shallow groundwater (C_{source}). As previously explained, the deeper aquifer and deeper soils are not considered in this vapour analysis since any vapours generated by these materials should be reflected by the water quality in the shallow aquifer.

The input parameters used in the model are:

- Depth below grade to water table = 1.5m
- Soil profile = Clay
- Average soil/groundwater temperature = 15°C
- Vadose zone soil dry density = 1.5t/m^3 (program default value)
- Vadose zone soil total porosity = 0.43 (program default value)
- Vadose zone soil water-filled porosity = 0.215 cm^3/cm^3 (program default value)

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The computer model was first used to calculate the relationship between contaminant concentrations in the groundwater and the resulting source vapour concentrations. The groundwater concentrations used in the analysis cover the ranges that have been measured in the plume area for the three rounds of groundwater monitoring conducted at the site, as presented previously in **Table 17B**. The results of the analyses for BTEX are provided in **Figure 16** and for the six target PAHs in **Figure 17**.

- **Figure 16 Relationship Between Groundwater and Source Vapour Concentrations for BTEX Contamination in the Shallow Groundwater Aquifer**

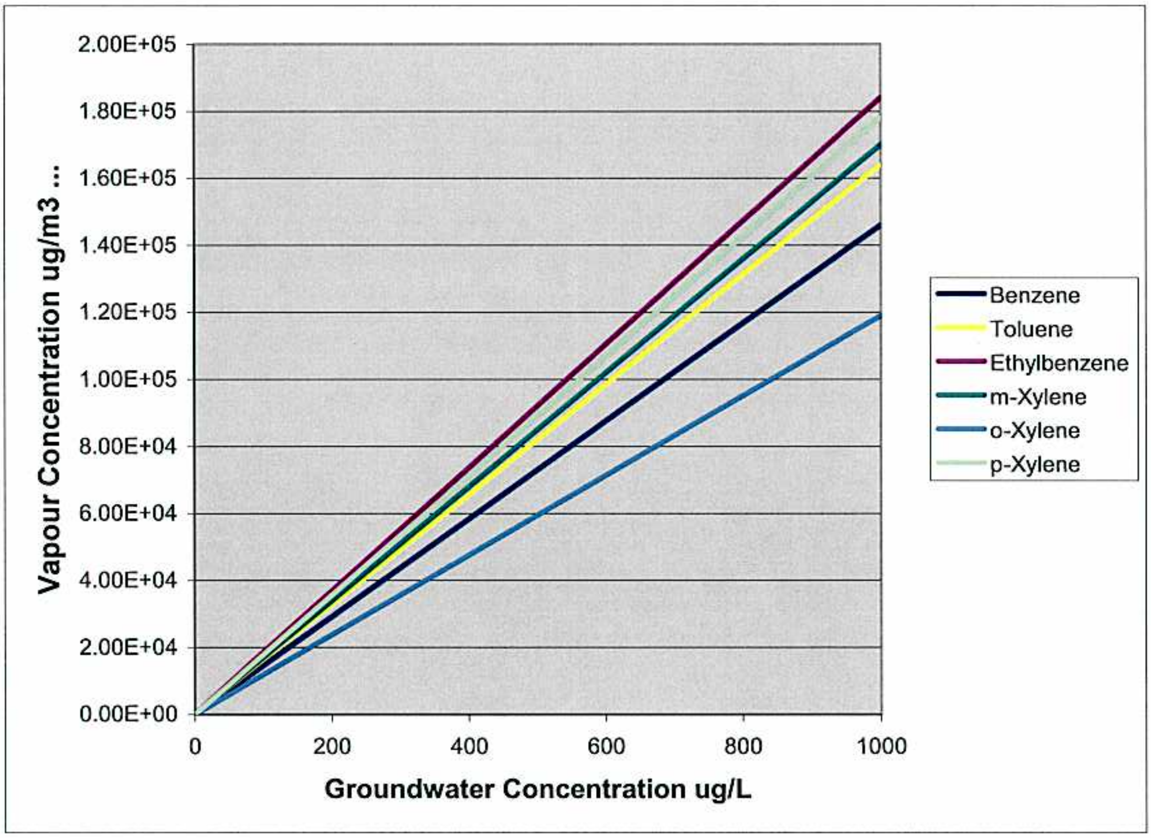
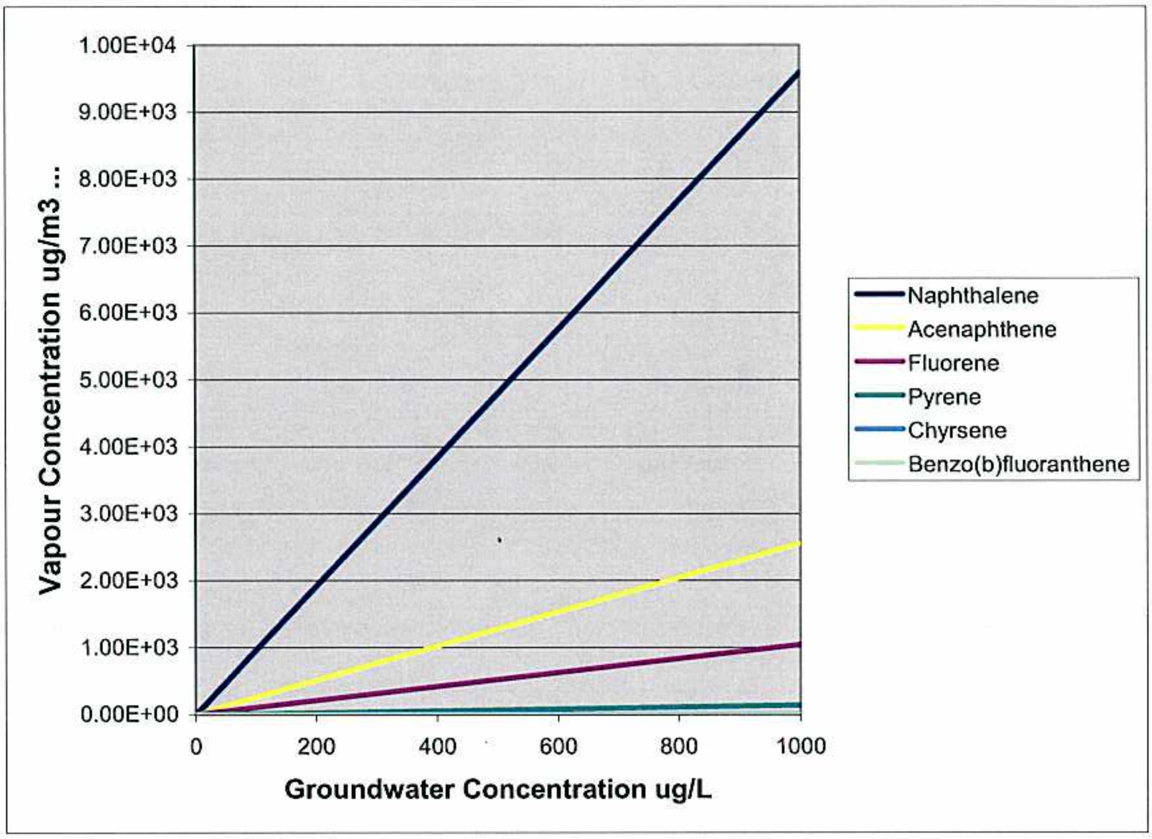


Figure 17 Relationship Between Groundwater and Source Vapour Concentrations for Target PAH Contamination in the Shallow Groundwater Aquifer



The results of the shallow groundwater analysis show:

- There is a linear relationship between volatile groundwater concentrations and the source vapour concentrations that would be measured near the water table;
- Each of the BTEX compounds generate similar source vapour concentrations, as shown by the clustered lines in **Figure 16**;
- There is a wide divergence in the vapour generating potential between the six target PAH compounds. **Figure 17** shows naphthalene to generate by far the highest vapours of all the PAH compounds, with benzo(b)fluorene and chrysene generating very little vapour; and
- The BTEX compounds are capable of generating much higher soil vapour concentrations that any of the PAH compounds. This is shown by the data provided in **Table 18C**, which provides a comparison of the predicted soil vapour concentrations that would be generated by 100µg/L of each target compound.

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- **Table 18C Comparison of Soil Vapour Concentrations for Target Volatile Compounds at 100μg/L in Groundwater**

Target Chemical	Soil Vapour Concentrations (μg/m³)	Generation Potential Ratio (Benzene = 1)
Benzene	1.46E+04	1
Toluene	1.64E+04	1.12
Ethylbenzene	1.84E+04	1.26
m-Xylene	1.70E+04	1.16
o-Xylene	1.19E+04	0.815
p-Xylene	1.78E+04	1.22
Naphthalene	9.59E+02	0.0657
Acenaphthene	2.55E+02	0.0175
Fluorene	1.04E+02	0.00712
Pyrene	1.39E+02	0.000952
Chyrsene	0.603	0.0000413
Benzo(b)fluoranthene	0.158	0.0000108

The computer model was then used to calculate the relationship between contaminant concentrations in the unsaturated shallow soils and the resulting source vapour concentrations. Only the six target PAHs were considered in this analysis since the laboratory data measured only very low BTEX concentrations in the soil samples collected from this area, as previously shown in **Table 17C**. The soil PAH concentrations used in the analysis cover the ranges that have been measured in the plume area, with the results of the analyses for the six target PAHs presented in **Figure 18**.

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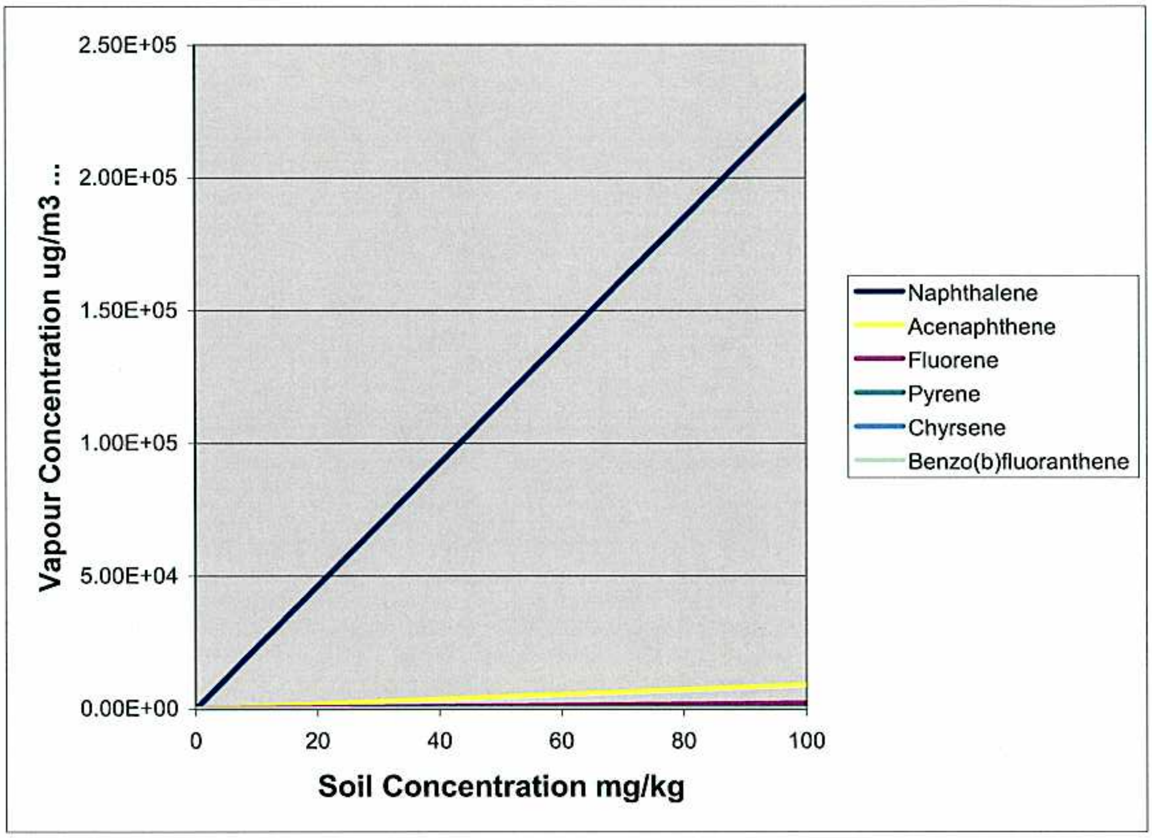
- **Figure 18 Relationship Between Soil and Source Vapour Concentrations for PAH Contamination in the Unsaturated Soils in the Shallow Plume Area**



The results of the shallow unsaturated soil analysis show similar trends to the groundwater analysis, namely:

- There is a linear relationship between volatile soil concentrations and the source vapour concentrations that would be measured in the shallow unsaturated soil layer above the water table; and
- There is a wide divergence in the vapour generating potential between the six target PAH compounds. **Figure 18** shows naphthalene to generate by far the highest vapours of all the PAH compounds, with benzo(b)fluorene and chrysene generating very little vapour.

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9.4 Comparison between Field Measurements and Computer Analysis

The results of the computer analysis have been used to predict the range of soil vapour measurements that could have been expected to have been measured by the soil-gas monitoring wells that were installed at the Former Gasworks site. The analysis has used the range of volatile contaminant concentrations that have been measured in the shallow groundwater aquifer in the plume area, as previously presented in **Table 17B**. The results of the analysis are presented in **Table 18D**, where a comparison is also provided with the soil vapour results that were measured in the field, as previously presented in **Tables 18A** and **18B**.

- **Table 18D Comparison between Measured and Predicted Soil Vapour Concentrations in the Area of the Volatile Contaminant Plume**

Target Chemical	Measured Groundwater Concentration (μg/L)	Measured Soil Concentration (mg/kg)	Measured Soil Vapour Concentration (μg/m³)	Predicted Soil Vapour Concentration (μg/m³)
Benzene	nd – 704	nd	nd – 16.7	nd - 1.03E+05
Toluene	nd	nd	nd – 28,000	Nd
Ethylbenzene	nd – 213	nd	nd	nd – 3.92E+04
m-Xylene o-Xylene p-Xylene	nd – 417	nd	nd	nd - 6.49E+04 (1)
Naphthalene	nd - 1460	nd - 280	nd – 5.41	nd – 6.61E+05
Acenaphthene	nd – 14	nd - 33	nd	nd – 3.04E+03
Fluorene	nd – 15	nd - 120	nd	nd – 2.48E+03
Pyrene	nd – 2	nd - 600	nd	395
Chyrsene	nd	nd - 200	nd	12.1
Benzo(b)fluoranthene	nd	nd - 310	nd	4.90

Notes:

(1) Predicted total xylene concentration based on average concentrations given by computer model for m-, o- and p-Xylene.

Comparison of the results from the computer analysis and the field measurements shows that highly variable field results are to be expected given the highly variable volatile concentrations that have been measured in the shallow groundwater and unsaturated soils at the Former Gasworks site. The low soil gas levels measured in wells MW30-MW34 in March 2005 are consistent with the low groundwater concentrations that were measured in the last monitoring undertaken also in March 2005 and the low soil concentrations that have been measured in the plume area.

However, the computer analysis shows that much higher soil gas vapours may be present at the site than were measured by the investigation. This is because the results of the computer analyses show that much higher soil gas levels may occur if the higher volatile concentrations measured in the earlier groundwater monitoring rounds and/or higher soil concentrations measured in some shallow soil samples are more representative of site conditions. Due to this high degree of variability, there is potential for elevated levels of soil gas vapours to be emitted from the ground surface of the site and the exposure pathway from volatile soil vapours needs to be included in this risk assessment.

The analysis also shows that the primary source of BTEX in the soil vapour at the volatile plume area is likely to be from the shallow groundwater, since no significant BTEX levels have been measured in the shallow soils. On the other hand, the analyses show that the primary source of the six target PAHs in the soil vapour at the volatile plume area is likely to be from the unsaturated shallow soils, due to the relatively higher PAH concentrations in these soils compared to the shallow groundwater. For example, 98% of the naphthalene concentrations in the soil vapour are predicted by the computer analysis to come from the unsaturated shallow soils compared to the shallow groundwater based on the average concentrations measured in the plume area.

10 Assessment of Groundwater Contamination

This section of the report presents the results of the groundwater contamination assessment for the Former Gasworks site and surrounding areas. The assessment initially describes the hydrogeological conditions that were revealed by the investigations, which includes consideration of the hydrogeological system, permeability, groundwater flow direction and intrinsic water quality. An assessment is then provided of the background groundwater quality, followed by an assessment of groundwater contamination. Conclusions drawn from the assessment are then presented.

Summary tables of the chemical analyses performed on the groundwater samples are provided in Tables E and F, with copies of the laboratory test certificates provided in Appendix E.

10.1 Hydrogeological System

The groundwater investigations have confirmed the nature of the hydrogeological system that operates at the Site and surrounding areas is consistent with the regional groundwater system described in technical literature, as reviewed in **Section 3.4**.

The investigation has shown that the geological sequence at the Site comprises fill material underlain by lower permeability clays, which are underlain by weathered to competent shale. There are considered to be two main water-bearing strata at the Site, the first is the layer of fill material above the clay and the second is the shale bedrock. Fill material was encountered to a depth of 3.5m in the southern portion of the site at BH1. In the vicinity of the former retort house fill material was encountered to a maximum depth of 2.3 m. Elsewhere on the Site, clays and weathered shale generally occur below 1-2 m. Investigations indicate that the shale aquifer extends to a depth of at least 15 m, but the base of the aquifer could not be established.

The shale bedrock probably operates as a semi-confined aquifer at the Site due to the presence of an overlying clay layer at a depth of between 1-10 m. This clay layer was encountered in all locations across the Site, with the exception of those locations in the vicinity of the former retort house where refusal was encountered on concrete or brick material.

Underground structures are considered to have a significant affect on the hydrogeological system at the Site. These structures include:

- The large gasholder that was constructed to a depth of more than 4 m below ground level;
- Underground tar tanks located between the gasholders and retort house at the northern end of the gasworks area, which may still remain at the site; and

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- Underground pits and basements associated with the former retort house, which may still remain at the site.

10.2 Permeability

Slug tests were carried out on three wells (MW06S, MW07D and MW38D) at the Site in March 2005 to provide an estimate of the permeability of the underlying soils and therefore the likelihood of any potential contamination migrating off Site. The calculations are based on equations given in the NAVFAC DM-7.1 (May 1982) *"Soil Mechanics Design Manual 7.1"*. The equation calculates insitu permeability values from falling head tests conducted in the wells. The slug test carried out on the shallow well recorded an average permeability of 1.4×10^{-5} m/s for the clay layer. The results for deep wells provided mean permeability estimates between 1.0×10^{-5} and 3.0×10^{-5} m/s.

10.3 Groundwater Heads & Flow Direction

The data provided in the previous site investigations indicated that groundwater flows in a south to south-easterly direction towards the Illawarra railway, which is consistent with the regional groundwater system described in the technical literature, as previously described in **Section 3.4**. However, the data also show significant variations in the shallow ground water flow due to sub-surface obstructions (i.e. former gasholder structure and drains).

The investigations established groundwater flow directions from measurements of the free-standing water levels in the groundwater monitoring wells. These levels were obtained from depth measurements made by SKM that were converted to elevations from survey information collected by the registered surveyors Douglas Gow & Associates. The surface levels of the monitoring wells and groundwater in Australian Height Datum (AHD) are shown below in **Table 19,** with a contour plot of the deep groundwater elevation data across the Site and surrounding areas provided in **Figure 19**.

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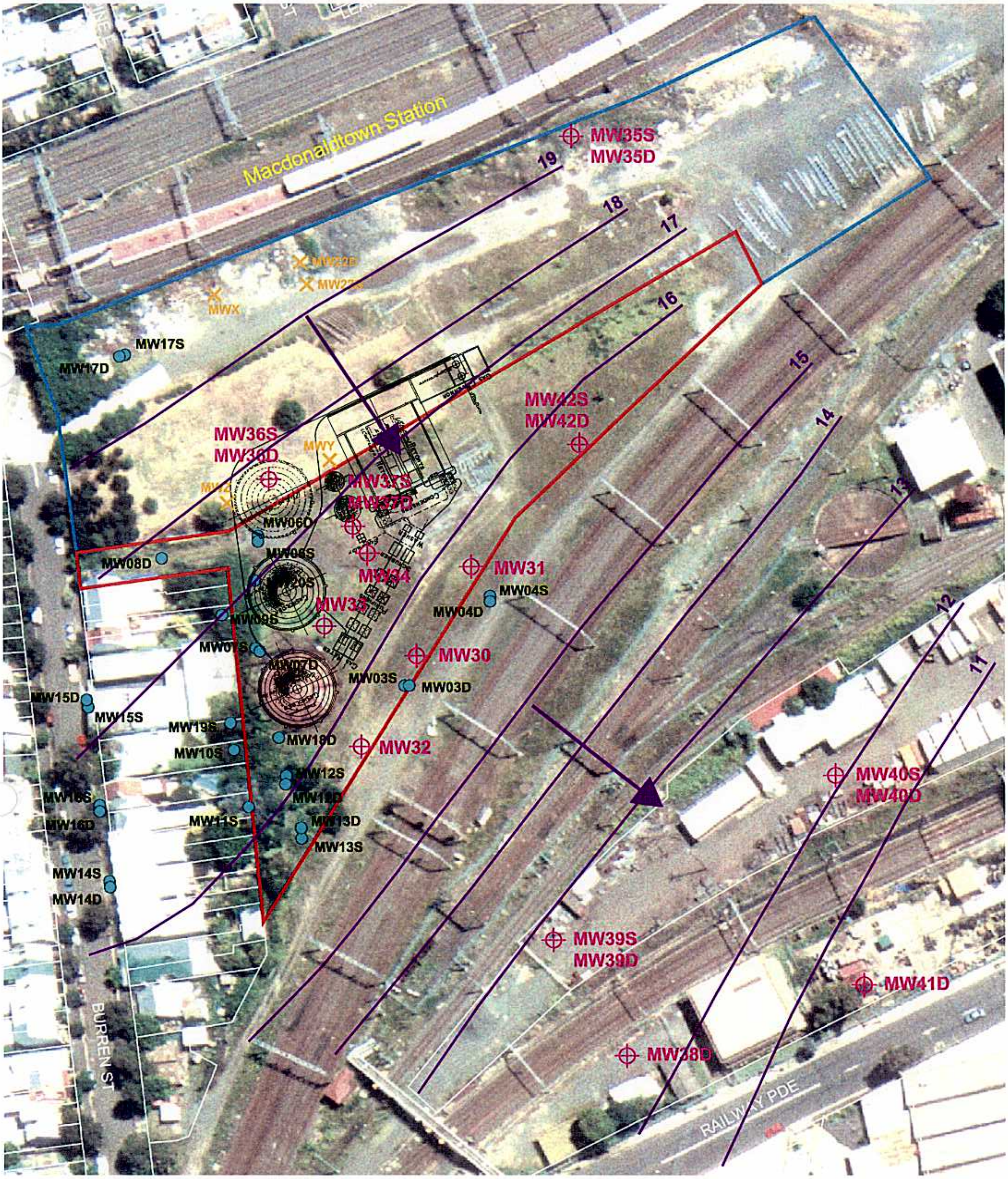
Figure 19
INFERRED DEEP GROUNDWATER CONTOURS AND FLOW DIRECTION
Macdonaldtown Risk Assessment



LEGEND

- GASWORKS SITE
- CLEANING SHED SITE
- CH2MHILL MONITORING WELL LOCATIONS
- CH2MHILL MONITORING WELL LOCATIONS NOT PREVIOUS IDENTIFIED
- SKM GROUNDWATER MONITORING WELL LOCATIONS (1 DEEP AND 1 SHALLOW)
- SOIL VAPOUR MONITORING WELLS

0 10 20 30 40 50 60 m

N

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- **Table 19 Groundwater Elevations**

Monitoring Well	Surface Level (AHD)	Groundwater Level (AHD)
Shallow Wells		
MW03S	18.38	17.34
MW04S	18.4	17.57
MW06S	18.96	17.63
MW12S	19.99	15.87
MW13S	19.5	19.50
MW14S	16.19	14.49
MW16S	16.655	15.05
MW17S	21.36	18.75
MW20S	19.66	18.93
MW35S	20.402	18.39
MW36S	20.238	17.54
MW37S	18.696	17.89
MW39S	15.746	13.60
MW40S	16.024	13.73
MW42S	18.484	17.88
Deep Wells		
MW03D	18.33	15.40
MW04D	18.37	19.22
MW06D	18.97	17.34
MW07D	19.59	17.25
MW12D	20.02	20.02
MW13D	19.47	15.88
MW14D	16.16	16.16
MW17D	21.33	19.56
MW18D	19.49	16.40
MW35D	20.375	19.28
MW36D	20.257	20.26
MW37D	18.615	17.31
MW38D	14.298	12.34
MW39D	15.73	12.77
MW40D	16.005	12.33
MW41D	13.675	10.56
MW42D	18.592	15.44

The data indicate that the groundwater hydraulic head is highest at the northern end of the Site and progressively decreases towards to the south and east, which indicates that the general groundwater flow is to the south-east. However, the rate at which the hydraulic head decreases does vary.

The data have allowed estimates to be made of the hydraulic gradients that operate at the Site and surrounding areas, the hydraulic gradient (i) being head loss (H) divided by distance (D) over which the head loss is measured.

The highest hydraulic gradient of 3.1×10^{-2} was calculated across the western end of the Site between wells MW17S (northern) and MW12S (southern), where a drop of 3.4 m in hydraulic head occurs over a distance of 110 m. The lowest hydraulic gradient of 1.3×10^{-2} was calculated between wells MW20S and MW03S (southeast flow direction), where a drop of 1.41 m in hydraulic head occurs over a distance of 105 m. The variation in head difference between the wells is likely to be due to the presence of the gasholder and its affect on shallow groundwater flow. Hence, the average flow head difference is believed to be within these limits.

These results together with the permeability estimates provided in the previous section indicate that the shallow flow velocities at the Site vary between 6.2 and 13.7 m/year, while the deep flow velocities to the Site are probably between 12.2 and 36.5 m/year.

The flow rates for the deep aquifer have been compared against estimates obtained from back-calculations based on the length of the contaminant plume revealed by the groundwater sampling data and the period of time since the gasworks first commenced operation. The groundwater quality data indicate that the PAH contaminants have given rise to the largest plume, presumably because PAHs are more resistant to biodegradation processes compared to other organic contaminants such as BTEX compounds. The data indicate that the PAH plume extends some 160m to the south-east of the tar tanks/gasholder. The historical data (**Section 4**) indicate that the gasworks commenced operation in 1892 and that the travel time for the plume is some 113 years. Assuming that the plume was first formed when the gasworks commenced operations, the average flow velocity is estimated to be 1.4m/year, which is about an order of magnitude lower than estimated from the in-situ permeability tests. This result may indicate that the permeability of soils/bedrock estimated from the in-situ permeability tests is too high and that a permeability of between 1.4×10^{-6} and 3.4×10^{-6} m/s may be more representative of the deep aquifer materials.

For the shallow aquifer, the data indicate that the PAH plume extends some 75m to the south-east of the tar tanks/gasholder. The average flow velocity is estimated to be 0.66m/year, which again is about an order of magnitude lower than estimated from the in-situ permeability tests. This result may again indicate that the permeability of the shallow soils estimated from the in-situ permeability tests is too high and that a permeability of between 6.8×10^{-7} and 1.6×10^{-6} m/s may be more representative of the shallow aquifer materials.

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10.4 Physical/Chemical Water Quality

The results of the intrinsic water quality tests conducted at the Site are summarised in **Table 20** and indicate that the groundwater at the Site has a slightly variable pH, which probably reflects the variable nature of the fill material. The salinity measurements varied between 0.01 % and 0.7 %.

Table 20 Intrinsic Water Quality Test Results

Sample	Water Depth (mbg)	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp (°C)	Salinity (%)	Comments
Sampling in March 2005							
Shallow Wells							
MW03S	1.04	-	-	-	-		-
MW04S	0.83	5.48	0.442	9.06	22.9	0.01	Grey, black slight naphthalene odour
MW06S	1.33	6.05	0.578	6.34	23.6	0.02	Red, orange, moderate odour
MW12S	4.12	4.23	0.738	-	24.8	0.03	Red, orange, slight odour
MW13S	3.745	4.27	0.852	5.45	22.1	0.03	Red, orange silty, no odour
MW14S	1.704	4.31	0.98	7.3	22.9	0.04	Slight orange colour, no odour
MW16S	1.610	4.59	1.96	8.21	21.3	0.09	Slight orange colour, no odour
MW17S	2.615	5.84	0.419	9.6	21.6	0.01	Red, orange, no odour
MW20S	0.735	6.26	0.91	7.52	22.8	0.04	Black turbid, moderate odour
MW35S	2.015	5.03	2.01	8.94	22.3	0.09	Brown, no odour
MW36S	3.295	5.31	0.735	8.87	21.3	0.03	Orange, no odour
MW37S	0.805	6.3	1.22	7.1	22.7	0.05	Brown silty, no odour
MW39S	2.145	6.00	0.835	6.49	23.9	0.03	Orange, no detectable odour
MW40S	2.294	5.97	0.728	9.1	23.7	0.03	Light brown, no odour
MW42S	0.6	6.19	0.762	10.3	22.3	0.03	Clear, no odour
Deep Wells							
MW03D	2.93	5.56	3.82	9.13	21.8	0.19	Clear, hydrocarbon odour
MW04D		5.85	0.419	10.95	22.4	0.01	Clear, toluene odour
MW06D	1.63	4.94	2.41	4.47	20.3	0.11	Clear, slight odour
MW07D	2.342	5.59	1.1	7.89	19.7	0.04	Clear, moderate hydrocarbon odour
MW12D	-	-	-	-	-	-	Well broken
MW13D	3.595	4.27	0.852	5.45	22.1	0.03	Red/orange silty, no odour
MW14D	0	5.07	2.26	5.02	21.3	0.1	Grey black, no odour
MW17D	1.775	5.69	1.4	10.87	22.9	0.06	Slightly brown, no odour
MW18D	3.09	5.32	0.717	8.65	20.4	0.03	Clear, slight odour
MW35D	1.1	5.81	3.42	-	18.8	0.17	Grey silty, no odour
MW36D		5.09	2.5	9.17	20.4	0.12	Grey silty, sulphur odour
MW37D	1.31	5.25	3.32	9.26	20.3	0.16	Dark grey silty, hydrocarbon odour
MW38D	1.96	5.03	3.25	9.29	22.4	0.16	Grey silty

Sample	Water Depth (mbg)	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp (°C)	Salinity (%)	Comments
Sampling in March 2005							
MW39D	2.965	5.17	2.92	5.34	20.8	0.16	Grey, black, silty – moderate odour
MW40D	3.679	5.38	1.08	8.96	21.8	0.03	Clear, no odour
MW41D	3.12	6.03	1.01	9.14	21.5	0.04	Grey, no odour
MW42D	3.155	5.36	1.14	9.30	20.1	0.65	Grey silty, no odour

Dissolved oxygen levels were generally between 4.5 and 11 mg/L, which suggests that the main source of groundwater at the Site is infiltrating precipitation. The high oxygen percentage also possibly indicates that there is limited bacterial activity at the Site, as generally, low dissolved oxygen levels are considered to be a sign of microbiological activity. In suitable environmental conditions the identified organic compounds may undergo aerobic degradation through microbiological consumption. The increased consumption of carbon source would also result in a reduction of dissolved oxygen levels in groundwater.

10.5 Background Water Quality

Data on background water quality is provided in previous investigations undertaken at the North Eveleigh Workshop area, with a summary of the data is provided in **Table N**. Data on background groundwater quality in the area of the Site was also obtained from the results of laboratory tests conducted on water samples collected from wells located up-gradient of the Site (wells MW17S, MW17D, MW35S and d MW35D). **Section 5.2** also provides information relating to background water quality in the vicinity of the Site.

The groundwater quality data summarised in **Tables E - F** indicates that background water quality generally meets the groundwater assessment criteria specified in **Section 8.2** for drinking water. Petroleum hydrocarbon and volatile/ semi-volatile organic compound concentrations were below the freshwater ecosystem and drinking water criteria, although there were several heavy metal exceedances.

Four up-gradient wells located along the northern boundary of the former cleaning shed site (MW17D, MW17S, MW35D and MW35S) reported heavy metal concentrations above 95% protection level trigger values for the protection of aquatic ecosystems. The following analyte concentrations exceeded the nominated guidelines:

- Cadmium (up to 0.0003mg/L - freshwater criteria of 0.0002mg/L);

- Copper (up to 0.005mg/L - freshwater criteria of 0.0014mg/L);
- Nickel (up to 0.014mg/L - freshwater criteria of 0.008mg/L); and
- Zinc (up to 0.325mg/L - freshwater criteria of 0.008mg/L).

These concentrations are considered to be consistent with groundwater quality in an urban environment due to the diffuse contamination caused by the use of copper and galvanised water pipes, and galvanised steel in building construction. No further consideration of copper and zinc background levels are considered necessary.

These background concentrations indicate that the use of the NSW EPA-endorsed groundwater acceptance criteria specified in **Section 8.2** are relevant for this Site and no further consideration of cadmium, copper, nickel and zinc background water quality is considered necessary, except for concentrations above background water quality data.

Based on ADWG 1996 and average TDS values (>1000), the groundwater is not suitable for domestic use.

10.6 Heavy Metals and Inorganics

The heavy metal and inorganic laboratory results are summarised in **Tables E and F**. Heavy metal concentrations detected above the adopted ANZECC and ARMCANZ (2000) investigation criteria are shown on **Figure 20**.

Heavy metal impact is widespread across the Site with elevated zinc concentrations recorded at all sampling locations. The deep and shallow wells located along the northern boundary of the Site recorded concentrations of cadmium, copper, nickel, lead and zinc above the adopted assessment criteria. However, based on the up-gradient location of the wells and background levels discussed in **Section 10.5**, these concentrations are considered to be representative of background concentrations.

On site concentrations of cadmium, copper, lead and nickel were found to be highest at MW37D. However, concentrations were significantly lower in the adjacent shallow aquifer well MW37S. Similar exceeding concentrations were also found off site, well beyond the southern boundary.

The highest zinc concentration recorded at the Site was 1570 µg/L at MW13S, located in the south western portion of the site. Zinc concentrations increased beyond the southern boundary, beneath the Illawarra rail line at MW39S and MW42S (2230 and 869 µg/L respectively).

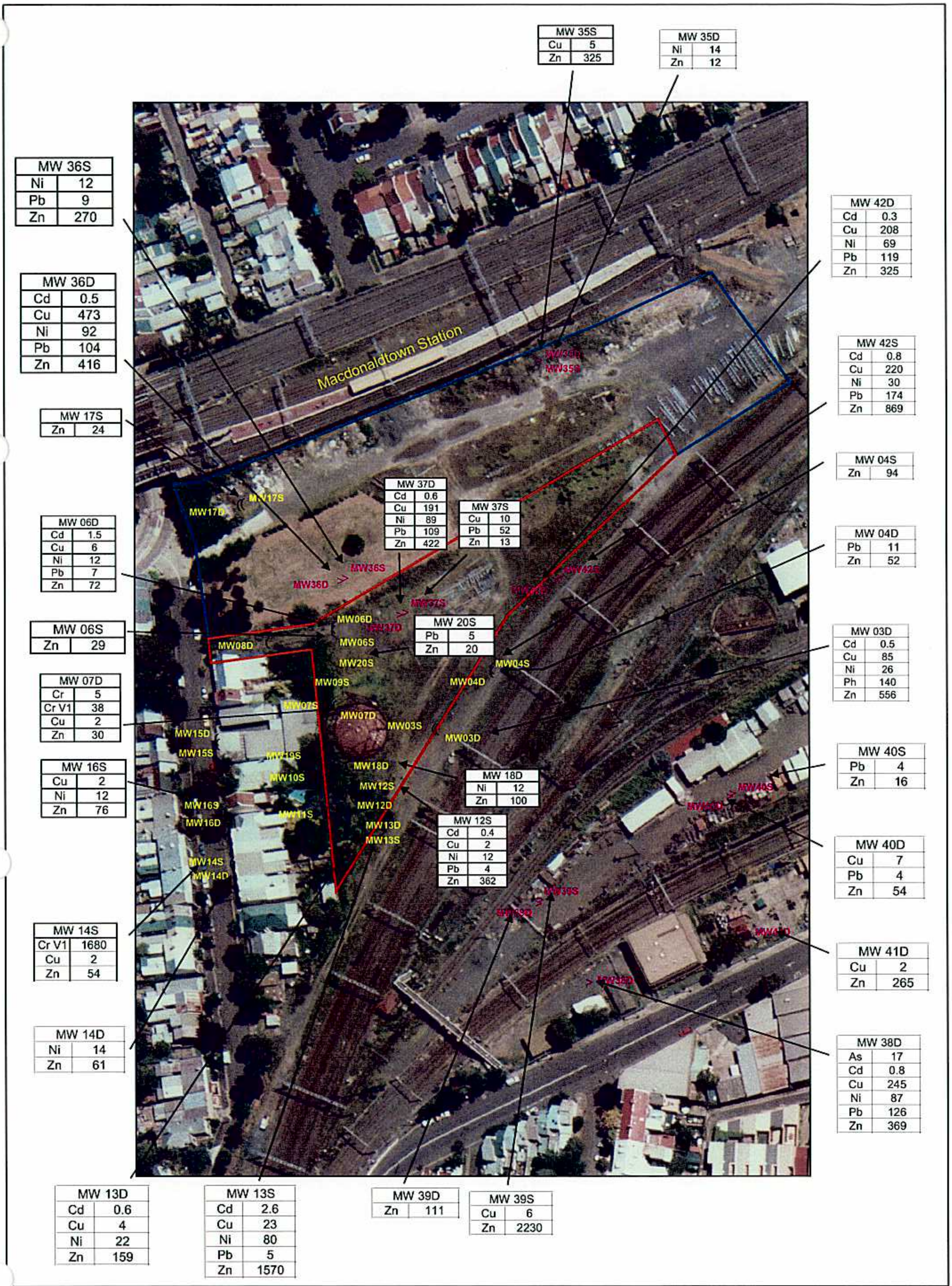

Figure 20
Heavy Metal Exceedances in 2005 Investigation (Exceed ANZECC Freshwater Trigger Values in ug/L)

1:1,250

0 12.5 25 50
Metres

AUSIMAGE
SKM

The highest chromium (6+) concentration was recorded off site at MW14S (1680 µg/L), located within the residential area, beyond the western boundary and beneath the Burren Road pathway. Lower chromium (6+) concentrations still above the adopted guidelines were recorded onsite at MW07D (38 µg/L), located near the former gasworks main pit.

10.7 Light-End Hydrocarbons

The additional groundwater investigations targeted the assessment of light-end hydrocarbon contamination at the Site and surrounding areas. This group of compounds comprise TPH C_6-C_9 fractions, BTEX and VOCs, with the laboratory results summarised in **Tables E - F.** A site figure showing light-end hydrocarbon exceedances across the Site and surrounding area is provided as **Figure 21.**

The NSW DEC does not currently endorse guidelines for the assessment of TPH C_6-C_9 in groundwater. However, TPH C_6-C_9 concentrations in MW03D, MW04D and MW07D exceed the solubility of this range in water, which are reported in the March 1999 version of the Risk-Integrated Software for Cleanups (RISC) computer model to be 5.4mg/L for C_6-C_8 (aliphatic) and 0.43mg/L for C_8-C_{10} (aliphatic).

High VOC concentrations above the site investigation criteria were measured in deep wells located in the area of the former tar tank and gasholder area. These wells comprised MW03D, MW04D, MW07D and MW12D. In this area the exceedances were measured in benzene and ethylbenzene, which are indicative of light-end hydrocarbons from tarry wastes produced at a gasworks site. Concentrations of these compounds in the shallow wells were much lower. This data supports the conclusion that the source of the groundwater contamination appears to be tarry wastes that were and possibly continue to be stored in former tar tanks and the gasholder annulus.

The groundwater investigations indicate that the plume of light-end hydrocarbon contamination in the deeper aquifer appears to be located entirely on railway-owned land. The plume appears to begin near the northern boundary of the Former Cleaning Shed and Gasworks areas and extends in a south-west direction for a distance of some 125m. The data indicate that the down-gradient edge of the plume is located at the Illawarra rail line. The lateral extent of the plume appears to be confined in the west to the sewer main located adjacent to the rear boundary of the residential properties, while to the plume is estimated to extend 50m to the east of the former tar tank area.

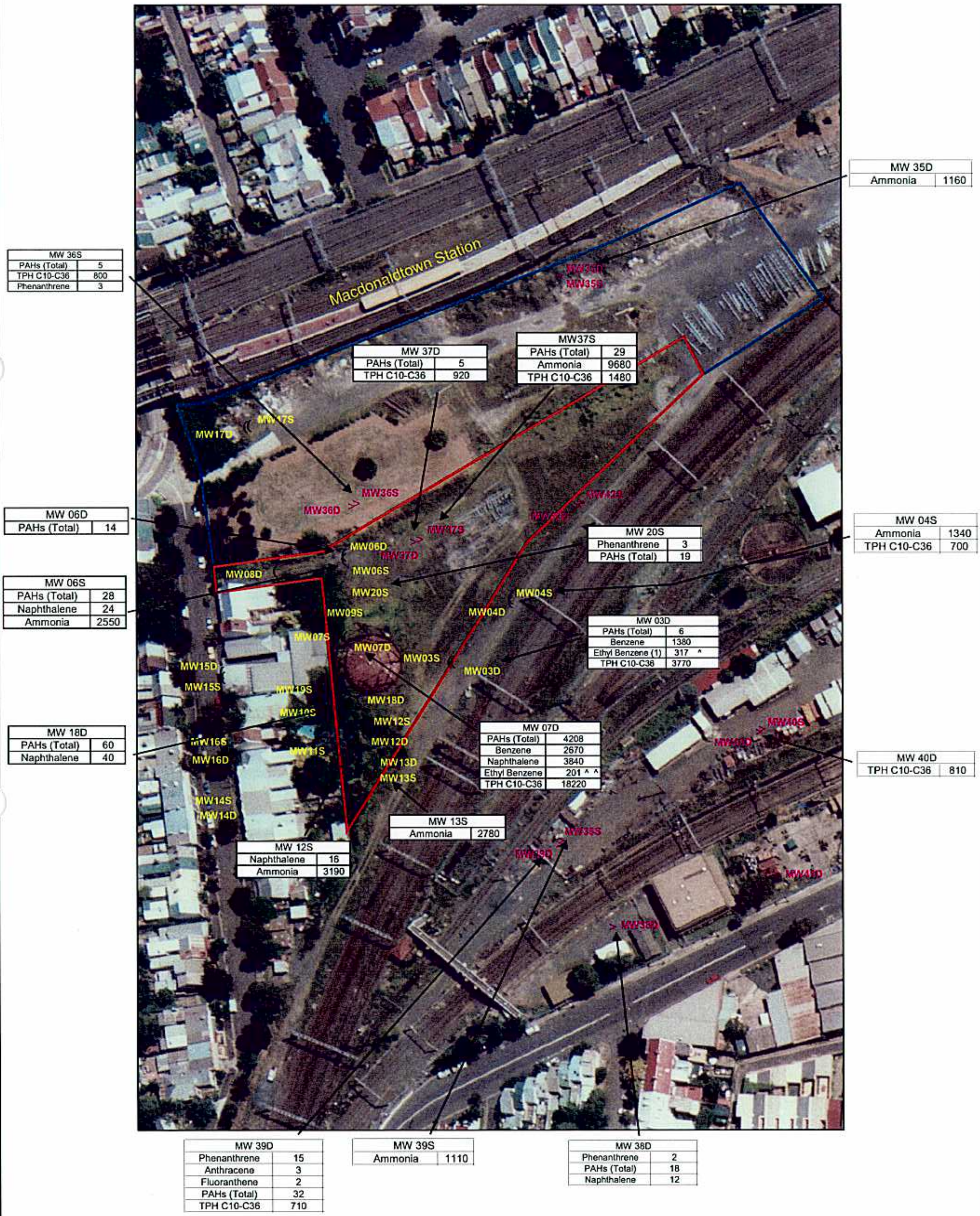

Figure 21
Organic Exceedances in 2005 Investigation in ug/L

1:1,250

0 12.5 25 50
Metres

AUSIMAGE
SKM

10.8 Middle to Heavy-End Hydrocarbons

The additional groundwater investigation targeted the assessment of middle to heavy end hydrocarbon contamination at the Site and surrounding areas. This group of compounds comprise the TPH C_{10}-C_{36} fraction, PAHs, SVOCs, phenols and cresols, with the laboratory results summarised in **Tables E - F.** A site figure showing middle to heavy-end hydrocarbon exceedances across the Site and surrounding area is provided as **Figure 21.**

High PAH and TPH C10-C36 concentrations above the site investigation criteria were measured in both shallow and deep wells located in the area of the former tar tank and gasholder area, with the highest concentrations measured in the deep wells. The main PAH compound present was the lighter-end compound naphthalene, which is consistent with its high solubility in water. The highest concentrations of middle to heavy end hydrocarbons were measured in wells MW03D, MW04D and MW07D. This data supports the conclusion that the source of the groundwater contamination appears to be tarry wastes that were and possibly continue to be stored in former tar tanks and the gasholder annulus.

The highest off site TPH C_{10}-C_{36} concentrations were recorded beyond the southern boundary at MW04S, MW39D and MW40D (700, 710 and 810 μg/L respectively). These concentrations exceed the solubility range of these compounds in water, which are reported in the March 1999 version of the Risk-Integrated Software for Cleanups (RISC) computer model to be 0.034mg/L for C_{10}-C_{12}, 7.6×10^{-4}mg/L for C_{12}-C_{16} and 1.3×10^{-6}mg/L for C_{16}-C_{35}.

The groundwater investigations indicate that the plume of middle to heavy-end hydrocarbon contamination in the shallow aquifer appears to be located entirely on railway-owned land. The shallow plume appears to begin near the northern boundary of the Former Cleaning Shed and Gasworks areas and extends in a south-west direction for a distance of some 75m. The data indicate that the down-gradient edge of the plume is located at the East Hills Line at the southern edge of the site boundary. The lateral extent of the plume appears to be confined in the west to the sewer main located adjacent to the rear boundary of the residential properties, while to the plume is estimated to extend 50m to the east of the former tar tank area.

The extent of the middle to heavy-end hydrocarbon plume in the deeper aquifer appears to be larger than the shallow aquifer. While the northern, eastern and western boundaries of the plume are similar to the shallow plume, the down-gradient extent of the plume appears to cover a distance of some 160m from the former tar tank area, with its edge near the southern boundary of railway land along Railway Parade. The data indicate that the deep aquifer plume is located entirely on railway-owned land.

10.9 Other Parameters

Ammonia exceeded the adopted guidelines at MW35D with a concentration of 1160 ug/kg. Well MW35D is located up-gradient from the Site and is considered to represent background concentrations of the area.

The highest ammonia exceedences were recorded on site at MW37S, MW13S and MW12S (9680, 2780 and 3190 µg/L respectively). Lower concentrations still above the nominated guidelines were recorded beyond the southern boundary at MW04S and MW39S (1340 and 1110 µg/L respectively).

Based on the shallow depth of these wells, ammonia concentrations may represent leaching process associated with the site fill layer.

10.10 Nature of Groundwater Contamination

This most recent round of groundwater monitoring is considered to support the following conclusions with regard to groundwater contamination.

10.10.1 Light-End Hydrocarbons (TPH C_6-C_9, BTEX & VOCs)

High levels of light-end petroleum hydrocarbons (TPH C_6-C_9 and BTEX) are present in the groundwater at locations close to the former gasworks, in the vicinity of the former gasholder No.2 and the location of possible tar tanks. Contaminant concentrations significantly exceed the freshwater ecosystem criteria and exceed the solubility capacity of water causing the excess contamination to exist as free product that floats on the water table. However, there has not been any evidence of phase separated hydrocarbons at the site.

10.10.2 Middle to Heavy End Hydrocarbons

Although high concentrations of low-end hydrocarbon contamination were recorded during previous investigations at the Macdonaldtown Triangle area, minimal middle to high-end contamination was detected by the additional investigation conducted by SKM. The only significant detection were detectable concentrations of bis(2-ethylhexyl) phthalate (950µg/L) recorded along the eastern boundary of the adjacent Former Gasworks area at MW03D.

10.10.3 Metals & Inorganics

The data indicates that heavy metal contamination at the Site is widespread with concentrations elevated above Trigger Values for 95% Protection of Freshwater Species. The highest cadmium, copper, lead, nickel and zinc concentrations were recorded on site at locations near to the former gas production process areas and beyond the southern boundary.

Chromium (6+) concentration above the nominated guidelines was recorded off site at MW14S located off site within the residential area. Lower chromium (6+) concentrations still above the adopted guidelines were recorded onsite at MW07D, located near the former gasworks main pit.

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11 Data and Exposure Assessment

This section of the report provides the results of data and exposure assessments, which represent the first two steps in a site-specific risk assessment for ground contamination at the Former Gasworks site. The methodology that has been used was previously described in Section 2.4. The data assessment (Section 11.1) reviews the site data provided in the earlier sections of this report. The exposure assessment then identifies the exposure pathways and potential receptors (Section 11.2), from which estimates are developed of the exposure concentrations (Section 11.3) and exposure durations (Section 11.4) followed by the calculation of estimates for contaminant intakes (Section 11.5).

11.1 Data Collection and Evaluation

The potential sources of contamination at the Macdonaldtown Triangle area were identified in **Section 5.6.1** to correspond to the former use of the area as a gasworks and railway-related activities. The potential sources and laydown mechanisms for contamination at the Macdonaldtown Triangle Area are considered to be:

- Dumping of waste materials from the former gasworks operation (eg. ash, spent oxide, coke, tar, ammoniacal liquors);
- Dumping of waste materials from former railway uses (eg. ash);
- Leakage of liquid wastes from pits, tanks and gas holders (eg. tars, phenolic wastes, ammoniacal liquors);
- Spillage of lead-based paint from former structures and train maintenance;
- Spillage of chemicals used for train cleaning (eg. solvents);
- Spillage of oils and greases from former train usage and maintenance;
- Atmospheric deposition of contaminants from the heavy industrial use of the general Erskineville/Macdonaldtown/Redfern area;
- Importation of contaminated fill; and
- Migration of contaminated groundwater from railway operations up-gradient of the site such as at the former Eveleigh railyards.

Assessments of the investigation data are provided in previous sections for soils **(Sections 5.7.1 & 9.2)**, groundwater (**Sections 5.7.2 & 10**), and soil gas (**Section 9**). Assessments of the quality of the investigation data have also been provided (**Sections 5.7.3 & 7**).

Section 5.6.2 identifies a range of potential contaminants of concern at the Site. The investigations have subsequently identified those contaminants that have been measured at concentrations in soils and groundwater that exceed the *Investigation Levels* defined in **Section 8**. The samples collected

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at the Former Gasworks site exceeding the soil and groundwater *Investigation Levels* are summarised in **Table 21**.

- **Table 21 Sample Exceedances of Soil & groundwater Investigation Levels at the Former Gasworks Site**

Location	Environmental Media	Contaminant	Concentration	Investigation Level	Type
SB02	Fill	Total PAHs	142-203 mg/kg	100 mg/kg	Health
		BaP	14 - 35 mg/kg	5 mg/kg	
SB03	Fill	TPH (C10-C36)	5,020 mg/kg	1,000 mg/kg	
		Total PAHs	295 mg/kg	100 mg/kg	
		BaP	27 mg/kg	5 mg/kg	
SB04	Fill	TPH (C10-C36)	12,100 mg/kg	1,000 mg/kg	
		Total PAHs	1697 mg/kg	100 mg/kg	
		BaP	140 mg/kg	5 mg/kg	
SB06	Fill	TPH (C10-C36)	20,000 mg/kg	1,000 mg/kg	
		Total PAHs	137-2374 mg/kg	100 mg/kg	
		BaP	30-190 mg/kg	5 mg/kg	
SB07	Fill	TPH (C10-C36)	14,400 mg/kg	1,000 mg/kg	
		Total PAHs	1145-2079mg/kg	100 mg/kg	
		BaP	26-200 mg/kg	5 mg/kg	
		Xylene	29-32 mg/kg	25 mg/kg	
SB08	Fill	BaP	7 mg/kg	5 mg/kg	
	Natural Soil	BaP	5.4 mg/kg	5 mg/kg	
SB10	Fill	Total PAHs	112 mg/kg	100 mg/kg	
		BaP	11 mg/kg	5 mg/kg	
SB12	Fill	BaP	5.8 mg/kg	5 mg/kg	
	Natural Soil	Total PAHs	224.4 mg/kg	100 mg/kg	
		BaP	8.4 mg/kg	5 mg/kg	
BH13	Fill	TPH (C10-C36)	7,100 mg/kg	1,000 mg/kg	
		Total PAHs	413 mg/kg	100 mg/kg	
		BaP	39 mg/kg	5 mg/kg	
		Benzene	1.6 mg/kg	1 mg/kg	
BH14	Fill	Benzene	4.6 mg/kg	1 mg/kg	
		Xylene	48 mg/kg	25 mg/kg	
BH15	Fill	TPH (C10-C36)	4,390 mg/kg	1,000 mg/kg	
		Total PAHs	378 mg/kg	100 mg/kg	
		BaP	16 - 58 mg/kg	5 mg/kg	

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- **Table 21 (cont'd) Sample Exceedances of Soil & groundwater Investigation Levels at the Former Gasworks Site**

Location	Environmental Media	Contaminant	Concentration	Investigation Level	Type
BH16	Fill	BaP	11 mg/kg	5 mg/kg	Health
SB18	Fill	TPH (C10-C36)	38,400 mg/kg	600 mg/kg	
		Benzene	7 mg/kg	1 mg/kg	
		Ethylbenzene	80 mg/kg	50 mg/kg	
		Xylene	210 mg/kg	25 mg/kg	
		Total PAHs	2161-3953 mg/kg	100 mg/kg	
		BaP	28-220 mg/kg	5 mg/kg	
MW04	Natural	Benzene	4 mg/kg	1 mg/kg	
TPA	Fill	Benzene	1.6 mg/kg	1 mg/kg	
		Xylene	65 mg/kg	25 mg/kg	
		Total PAHs	537 mg/kg	100 mg/kg	
		BaP	8.4 mg/kg	5 mg/kg	
		TPH (C6-C9)	100 mg/kg	65 mg/kg	
		TPH (C10-C36)	3,200 mg/kg	600 mg/kg	
TPC	Fill	Total PAHs	751 mg/kg	100 mg/kg	
		BaP	8.4 mg/kg	5 mg/kg	
		Xylene	48 mg/kg	25 mg/kg	
TPD	Fill	BaP	6.2 mg/kg	5 mg/kg	
A29 (Adjacent to MW10S)	Fill	Total PAHs	131 mg/kg	100 mg/kg	
		BaP	12.3 mg/kg	5 mg/kg	
		TPH (C10-C36)	1,654 mg/kg	1,000 mg/kg	
MW10S	Fill	BaP	5.7 mg/kg	5 mg/kg	
MW12D	Fill	BaP	7.7 mg/kg	5 mg/kg	Health
	Groundwater	TPH (C6-C9)	960 µg/L	150 µg/L	Aquatic
MW13S	Fill	TPH (C10-C36)	6,444 mg/kg	1,000 mg/kg	Health
		Total PAHs	346 mg/kg	100 mg/kg	
		BaP	34.9 mg/kg	5 mg/kg	
MW20S	Fill	BaP	6.1 mg/kg	5 mg/kg	
MW33	Natural	>C16-C35 Aromatics	2,124 mg/kg	450 mg/kg	
MW37S	Groundwater	TPH (C10-C36)	1,480 µg/L	600 µg/L	Aquatic
MW37D	Groundwater	Naphthalene	18 µg/L	16 µg/L	Aquatic Aesthetic
		TPH (C10-C36)	920 µg/L	600 µg/L	Aquatic

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- **Table 21 (cont'd) Sample Exceedances of Soil & groundwater Investigation Levels at the Former Gasworks Site**

Location	Environmental Media	Contaminant	Concentration	Investigation Level	Type
MW04S	Groundwater	TPH (C10-C36)	700 µg/L	600 µg/L	Aquatic
MW04D	Groundwater	Naphthalene	54 µg/L	16 µg/L	Aquatic Aesthetic
		TPH (C6-C9)	1040 µg/L	150 µg/L	Aquatic
MW03D	Groundwater	Naphthalene	629 µg/L	16 µg/L	Aquatic Aesthetic
		Benzene	1,380 µg/L	1 µg/L	Aquatic Health
		Ethylbenzene	317 µg/L	3 µg/L	Aquatic Health
		TPH (C6-C9)	28800 µg/L	150 µg/L	Aquatic
		TPH (C10-C36)	3,770 µg/L	600 µg/L	Aquatic
MW07S	Groundwater	TPH (C6-C9)	2170 µg/L	150 µg/L	Aquatic
MW07D	Groundwater	Naphthalene	3,840 µg/L	16 µg/L	Aquatic Aesthetic
		Benzene	2,670 µg/L	1 µg/L	Aquatic Health
		Ethylbenzene	201 µg/L	3 µg/L	Aquatic
		TPH (C6-C9)	1280 µg/L	150 µg/L	Aquatic
		TPH (C10-C36)	18,220 µg/L	600 µg/L	Aquatic
MW12S	Groundwater	Naphthalene	16 µg/L	16 µg/L	Aquatic Aesthetic
		TPH (C6-C9)	373 µg/L	150 µg/L	Aquatic
MW18D	Groundwater	Naphthalene	40 µg/L	16 µg/L	Aquatic Aesthetic
		TPH (C6-C9)	210 µg/L	150 µg/L	Aquatic
MW06S	Groundwater	Naphthalene	24 µg/L	16 µg/L	Aquatic Aesthetic
		TPH (C6-C9)	177 µg/L	150 µg/L	Aquatic
MW06D	Groundwater	Benzene	16 µg/L	1 µg/L	Aquatic Health
		TPH (C6-C9)	200 µg/L	150 µg/L	Aquatic
MW36S	Groundwater	TPH (C10-C36)	800 µg/L	600 µg/L	Aquatic
MW36D	Groundwater	Naphthalene	82 µg/L	16 µg/L	Aquatic Aesthetic

The data provided in **Table 21** and the assessment provided in **Section 5.7.1** indicate that the main contaminants of concern for a site-specific risk assessment at the Former Gasworks site are, for soils:

- PAHs particularly benzo(a)pyrene;
- TPH C10-C36; and
- Benzene and xylenes.

For groundwater, the main contaminants of concern are:

- TPH C_6-C_9 & C_{10}-C_{36};
- Benzene and ethylbenzene; and
- PAHs particularly naphthalene.

The data also indicate that the environmental media of concern are the fill layer, underlying natural material and groundwater. The investigations have found that soil gas is not an environmental media of concern due to the low levels of volatile organic compounds (BTEX and light-end PAHs) that have been measured (**Section 9.1**).

In addition to the volatile contaminants of concern, benzo(a)pyrene, ammonia and heavy metals have also been detected in the groundwater at concentrations significantly exceeding the adopted site investigation criteria, indicating that these are also contaminants of concern.

For volatile soil vapours, the study presented in **Section 9** concluded that much higher soil gas vapours than were measured by the investigation may be present at the site. This is because the results of computer analyses showed that much higher soil gas levels may occur if the higher volatile concentrations measured in the earlier groundwater monitoring rounds and/or higher soil concentrations measured in some shallow soil samples are more representative of site conditions. Due to this high degree of variability, there is potential for elevated levels of soil gas vapours to be emitted from the ground surface of the site. For volatile soil vapours, a screening assessment provided in **Section 9.1** found that the main contaminants of concern at the Former Gasworks site are PAH compounds (acenaphthene, benz(b)fluoranthene, chrysene, fluorene, naphthalene, pyrene) and monocyclic aromatic compounds (benzene, toluene, ethylbenzene and xylenes).

11.2 Exposure Pathways & Potential Receptors

The study has identified 7 potential migration pathways for ground contamination at the Former Gasworks site, these being:

- Groundwater transport;
- Impacted groundwater extracted for beneficial use;
- Volatilisation from shallow soils and/or groundwater and vapour transport into buildings;

- Volatilisation from shallow soil and/or groundwater and vapour transport to outdoor air;
- Contaminant source in surface soils (fill layer); and
- Leaching to groundwater and migration.

The exposure media include shallow soil, groundwater, surface water, indoor air and outdoor air. The exposure routes include ingestion, dermal adsorption and inhalation.

The conceptual site contamination model, previously described in **Section 5.6.4**, has identified the potential receptors of ground contamination from the Former Gasworks site to be:

- Future long-term commercial/industrial users of the Former gasworks site (RailCorp workers);
- Future maintenance / construction workers at the Former Gasworks site and surrounding areas;
- The community who live in residential land adjacent to the western boundary of the site (**Figure 4**), off-site construction workers and users of any groundwater extracted from wells down-gradient of the site; and
- Freshwater aquatic ecosystems in the headwaters of Alexandra Canal.

Freshwater aquatic ecosystems have been included as a potential receptor in this study even though the nearest water body is Alexandra Canal (Sheas Creek) located some 1.3km to the south. This is because there is a risk that extracted groundwater could be discharged into the stormwater system that would discharge into the headwaters of Alexandra Canal. An example of such an exposure pathway is the possible interception of contaminated groundwater by drainage systems inside the Eastern Suburbs/Illawarra railway line tunnel that is located approximately 100m from the southern boundary of the Macdonaldtown Triangle area or from deep basements in the residential properties to the west of the Former Gasworks site, as shown in **Figure 4**.

The potential exposure pathways for each of these receptors have been assessed and summarised in **Table 22**.

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Table 22 Exposure Pathway Analysis

Source Media	Migration Pathway	Exposure Media	Exposure Routes	Potential receptors
Outdoor air	None	Outdoor air	Inhalation	None
Indoor air	None	Indoor air	Inhalation	None
Surface Water	None	Surface water	Ingestion dermal adsorption during swimming	None
Groundwater	**Impacted groundwater extracted or intercepted**	**Groundwater**	**Ingestion & dermal adsorption**	**Construction workers; Surrounding community; Freshwater ecosystems**
	Volatilisation during showering	Indoor air	Inhalation	None
	Groundwater transport	**Groundwater**	**Ingestion & dermal adsorption**	**Construction workers; Surrounding community; Freshwater ecosystems**
	Groundwater transport followed by volatilisation during showering	Indoor air	Inhalation	None
	Volatilisation and vapour transport into buildings	**Indoor air**	**Inhalation**	**Construction workers; Site workers; Surrounding community**
	Volatilisation and vapour transport to outdoor air	**Outdoor air**	**Inhalation**	**Construction workers; Site workers; Surrounding community**
Soil (surface & subsurface)	**Contaminant source in surface soils (fill layer)**	**Surface soil**	**Ingestion & dermal adsorption**	**Construction/maintenance workers; Site workers**
	Volatilisation and vapour transport	**Outdoor air**	**Inhalation**	**Construction workers; Site workers; Surrounding community**
	Volatilisation and vapour transport	**Indoor air**	**Inhalation**	**Construction workers; Site workers; Surrounding community**
	Leaching to g/water & migration	**Groundwater**	**Ingestion & dermal adsorption**	**Construction workers; Surrounding community; Freshwater ecosystems**
	Leaching to g/water, migration then volatilisation during showering	Indoor air	Inhalation	None

Legend: Potential exposure pathway for Former Gasworks site (shaded)

The main exposure pathways for future long-term site workers at the Former Gasworks site are considered to be:

- Ingestion and dermal contact with contaminated surface soils;
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated soils in the unsaturated zone above the shallow aquifer; and
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated groundwater in the shallow aquifer.

Future site workers are unlikely to be ingest or have dermal contact with contaminated groundwater because:

- The water table in the shallow aquifer is on average approximately 1.5m below the ground surface;
- Groundwater is unlikely to be extracted for beneficial reuse due to the availability of good quality mains water and the poor quality of the groundwater at the site; and
- The likely low yield of groundwater bores in the area due to the low permeability of the shale and shallow depth to bedrock.

A long-term Site Management Plan (SMP) will need to be placed on the Former Gasworks site in order to ensure that the risk to site workers from ingestion or dermal contact with contaminated groundwater remains low. Restrictions that would need to be part of an SMP include a prohibition on the extraction and reuse of groundwater at the Former Gasworks site and a prohibition on the construction of drained basements or deep pits that intersected the groundwater table. These recommendations are included in **Section 14.2** of this report.

The main exposure pathways for construction workers at the Former Gasworks site are considered to be the same as those for long-term site workers plus the ingestion and dermal contact with contaminated groundwater. This additional exposure pathway has been included because of the potential for excavations to extend deeper than 1.5m and past the shallow aquifer water table.

Construction workers at the site may also be subjected to volatile soil gas vapours and inhalation of dusts, particularly when excavating in highly contaminated areas such as near areas that contained tar pits, retorts and gasholders. However, a site-specific risk assessment has not been undertaken for these exposure pathways since these health risks should be managed as part of an occupational health and safety plan covering any earthworks conducted at the Former Gasworks site. The requirement for such safety procedures will need to be incorporated into the long-term SMP to be placed on the Former Gasworks site. This recommendation is included in **Section 14.2** of this report.

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The main exposure pathways for residents and off-site construction workers at properties surrounding the Former Gasworks site are considered to be:

- Ingestion and dermal contact with contaminated groundwater;
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated soils in the unsaturated zone above the shallow aquifer; and
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated groundwater in the shallow aquifer.

Surrounding residents are considered to have a low risk from ingestion and dermal contact with contaminated near-surface soils because:

- It is understood that RailCorp has removed contaminated soils from the properties adjacent to the western site boundary under a remediation program completed in 2005; and
- Access to the Former Gasworks site is restricted to authorised personnel, who would largely be on-site workers.

A long-term SMP will also need to be placed on the Former gasworks site in order to ensure that the risk to the surrounding residential community from on-site soil contamination remains low. Restrictions that would need to be part of an SMP include the erection and maintenance of security fencing and controlling site access. These recommendations are included in **Section 14.2** of this report.

The main exposure pathways for the freshwater ecosystems in the headwaters of Alexandra Canal are considered to be the extraction and discharging of contaminated groundwater to the stormwater system that would be discharged into the headwaters of Alexandra Canal.

11.3 Exposure Concentrations

The exposure pathway analysis presented in **Table 22** identified five migration pathways for potential receptors to be exposed to contamination from the Former Gasworks site. These pathways are:

- Groundwater transport;
- Extracted and intercepted groundwater;
- Volatilisation and vapour transport from contaminated soils and groundwater; and
- Contaminated surface soils; and
- Leaching to groundwater and migration.

This section of the risk assessment provides estimates of the exposure concentrations applicable for each of these migration pathways.

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11.3.1 Groundwater Transport

The groundwater assessment presented in **Section 10** found that groundwater at the Former Gasworks site is contaminated primarily with PAHs, TPH, benzene, ethylbenzene and heavy metals. The available data indicate that the primary source of this contamination is most likely to be tarry liquid wastes and dumped material that remain in the area of the former tar wells, gasholders and retort house, as shown in **Figure 4**. This is because:

- The historical data (**Section 4**) indicate that the former tar wells are located in the Former Gasworks area close to the southern boundary of the Former Cleaning Shed site, while the northern end of the former retort house appears to extend some 10-15m into the Former Cleaning Shed site;
- Experience gained in remediating other gasworks sites in NSW suggest that tarry waste materials may remain at the base of the gasholder annulus and tar tanks that were not cleaned out when the former gasworks facilities were demolished;
- The historical data also indicate that the bulk of the Former Cleaning Shed site consisted of a above ground structures such as a large train storage shed and rail track, which do not represent potential sources of the tarry liquid wastes; and
- The groundwater quality in the monitoring wells in the northern portion of the Former Cleaning Shed site (ie. MW17S, MW17D, MW35S and MW35D) is generally consistent with background water quality, as discussed in **Section 10.5**.

The groundwater assessment also indicates that the groundwater level in the shallow aquifer at the Former Gasworks site is located some 1 to 4m below the present ground surface and flows in south to south-easterly direction. This is shown by the piezometric contours for the deep aquifer presented in **Figure 19**, which are similar to the shallow aquifer as shown by the groundwater elevation data in **Table 19 (Section 10.3)**. The higher groundwater contaminant concentrations occur near the gasholder wells, which form an artificial groundwater rise and recharge source. The groundwater in the deeper aquifer is by its very nature also located at depth below the shallow aquifer.

The groundwater in both aquifers appears not to flow towards the residential properties located along the eastern side of Burren Street, who represent the closest community receptors. This groundwater flow direction is shown in **Figure 19** by the orientation of the piezometric contours and the absence of exceedances of the Groundwater Investigation Levels in wells located to the south-west of the Former gasworks site (eg. wells MW08-MW11) and in the residential area to the west (eg. wells MW14-MW16). A sewer main is also known to run inside the western site boundary in a south-easterly direction, which may also be acting as a groundwater cut-off drain. The drain is understood to be several metres below the ground surface.

The results indicate that potential on-site receptors (site workers) should not be exposed to contaminated groundwater in the Former Gasworks site for the case where the shallow and deep groundwater systems are not disturbed and altered. This is because the level of the shallow groundwater has been measured to be some 1 to 4m below the present ground surface and the deep aquifer is located below the shallow aquifer. The case where the groundwater system is to be intercepted by deep excavations is addressed in the following section (**Section 11.3.2**).

These results also indicate that potential off-site receptors should not be exposed to contaminated groundwater from the Former Gasworks site for the case where the current groundwater system is not disturbed and altered. This is because the contaminated groundwater flows in south to south-easterly direction and not towards the residential properties located along the eastern side of Burren Street. The data also indicate that the groundwater plumes are contained within railway-owned land and that the down-gradient edge appears not to have migrated into properties on the southern side of Railway Parade. The case where the groundwater system is to be disturbed and altered is addressed in the following section (**Section 11.3.2**).

The available data are considered to support the conclusion that the exposure concentrations for the migration pathway of *"groundwater transport"* from the Former Gasworks site are below the *Investigation Levels* and require no site-specific risk analysis to be undertaken for this migration pathway.

11.3.2 Intercepted or Extracted Groundwater

The available information indicates there are no groundwater wells in the local area that have the potential to affect the groundwater system at the Former Gasworks site. This information includes:

- The search of DIPNR licensed groundwater extraction wells in the local area;
- Site data that indicates no groundwater extraction is currently occurring in the Macdonaldtown Triangle area; and
- The groundwater investigation data indicate the groundwater flows are to the south and south-east and are not being affected by any known underground structure (eg. tar tank, gas holder annulus, sewer main) or extraction well.

However, the present groundwater system at the Former Gasworks site could be disturbed in a number of ways by future developments occurring both at the site and in the local area. These scenarios include:

- Scenario 1 - The installation of a DIPNR licensed groundwater extraction well at either the Former Gasworks site or a nearby off-site area;
- Scenario 2 - The digging of a deep excavation that needs to be temporarily dewatered at either the Former Gasworks site or a nearby off-site area during the construction period; and

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- Scenario 3 - Leakage through a basement or other type of underground structure constructed below the water table.

Scenario 1

This study considers Scenario 1 is unlikely because:

- Mains water is the source of all potable water in the area;
- The background quality of water from the Wianamatta Shales in the inner city area is poor due to its naturally high salinity content and the broad-scale impacts caused by the industrial use of the surrounding areas in addition to the Former Gasworks site; and
- The likely low yield of groundwater bores in the area due to the low permeability of the shale and shallow depth to bedrock.

Scenario 2

Scenario 2 could occur during the construction of a deep trench for the installation of buried services or a deep basement. The excavation would need to be deeper than 1.5m, since this is the average depth down to the top of the shallow aquifer.

Scenario 2 has the potential for contaminated groundwater from the Former Gasworks site to be intercepted. Conservative estimates of potential exposure concentrations are considered to be given by the five wells located along the western side of the site, these being MW06S, MW06D, MW07S, MW07D, MW12S, MW12D, MW18S, MW18D and MW20S. The locations of these wells and a summary of exceedances measured by the 2005 investigation were previously shown in **Figures 20** and **21 (Section 10)**.

These 9 wells are considered most relevant for these exposure scenarios since the groundwater investigations have found them to give the highest contaminant concentrations and because they are located near the western boundary of the site and adjacent to the adjacent residential properties. These wells have elevated contaminant levels since they are located in the area where the most likely groundwater contaminant sources are located, these being tarry wastes that may remain in the buried tar tanks and in the gasholder in the north-western corner of the Former Gasworks site.

For most potential contaminants of concern, these 9 wells provide a total of 15 groundwater sample results for this critical area of the site. As previously mentioned in **Section 10**, these contaminant levels vary significantly both between locations, between shallow and deep aquifer, and between sampling events. Due to this variability, the data does not support the development of a sophisticated contaminant groundwater flow model that could be used to provide probabilistic estimates of exposure concentrations to construction workers for this exposure scenario.

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In this risk assessment, this issue has been addressed by adopting the maximum concentrations for assessing the risks posed to on-site receptors and the average concentrations for assessing the risks posed to off-site receptors. The maximum values correspond to a mix of groundwater samples collected from the shallow and deep aquifer. This approach is considered to be both practical and conservative for the potential receptors of concern. These concentrations are summarised in **Table 23,** with the contaminants listed corresponding to those found to exceed the *Groundwater Investigation Levels* together with other contaminants that have also been found in the groundwater and need to be included to account for risks posed by chemical mixtures.

- **Table 23 Exposure Concentrations for Receptors Exposed to Extracted Groundwater (Units µg/L)**

Substances	Threshold Concentrations		Average Values (1)	Maximum Values (1)
	Freshwater Ecology	Health		
HEAVY METALS				
Arsenic (total)	24	7	3.1	23.0
Cadmium	0.2	2	0.2	1.5
Chromium	3.3	55000	3.4	43.0
Copper	1.4	2000	3.6	14.0
Lead	3.4	10	1.9	7.0
Nickel	11	20	7.5	19.0
Zinc	8	---	76.9	362.0
Cyanide	7	80	132.0	479.0
BTEX				
Benzene	950	1	637.9	6370.0
Toluene	180	800	13.8	117.0
Ethylbenzene	50	300	29.3	213.0
Total Xylene	70	600	66.6	417.0
Total Petroleum Hydrocarbons				
Total TPH C10-C36	600	---	2245.6	18220.0
Polycyclic Aromatic Hydrocarbons				
Naphthalene	16	6.2	361.7	3840.0
Phenanthrene	5		1.1	8.0
Total PAHs	3		406.3	4208.0
Ammonia	900		1126.0	3190.0

Note:
(1) Wells in database comprise MW06S, MW06D, MW07S, MW07D, MW12S, MW12D, MW18S, MW18D, MW20S, MW20D

The substances presented in **Table 23** are together considered to define the mixture of contaminants that would need to be considered in assessing health-risks to the potential receptors. Ammonia has also not been included as a risk to human health since the Drinking Water *Investigation Level* is based on aesthetic rather than health considerations and the human gut contains high ammonia concentrations.

Construction workers would be the main potential receptor for this scenario since it is possible that some limited manual work would need to be undertaken in water-filled trenches.

Freshwater ecosystems in the headwaters of Alexandra Canal are not considered to be potential receptors given that groundwater at the Former Gasworks site is contaminated and should not be discharged to the off-site stormwater system. Any groundwater intercepted by construction works would need to be managed on-site. A long-term SMP will need to be placed on the Former Gasworks site in order to ensure that any intercepted groundwater is retained and managed on-site. These recommendations are included in **Section 14.2** of this report.

Scenario 3

Scenario 3 could occur if a deep basement or structure was to be constructed below 1.5m, due to the potential for concrete structures to crack and leak including those that are designed as a tanked structure. The potential receptors for this exposure scenario would be the surrounding residential community and freshwater ecosystems.

An estimate of the exposure concentrations for Scenario 3 has been made by performing a screening assessment that involves comparing the likely flow of water that would seep out from cracks into a deep basement to the total amount of groundwater that would flow from west to east across a residential property located on the eastern side of Burren Street adjacent to the Former Gasworks site. If the amount of seepage water coming out of basement cracks is estimated to be a negligible proportion of the total groundwater flow occurring across the property (say less than 10%), then the exposure concentrations in the groundwater would be the same as the background water quality flowing onto the site along the northern boundary. On the other hand, if the amount of seepage water is found to be a significant proportion of the total groundwater flow across the property (say >10%), then more detailed groundwater modelling would be required in order to determine whether the crack seepage is sufficient to cause contaminated groundwater from the Former gasworks site to reverse direction and flow to the west and into an adjacent residential property.

In this analysis, the crack-to-total area of the basement walls has been taken from the value recommended by the US EPA (February 2005) in their use guidelines for soil vapour analysis, this being a value of 4.0E-04 (dimensionless). The surface area of the basement walls has been taken to be $25m^2$, which corresponds to the entire 10m length of a typical residential property along the western site boundary and a typical 2.5m high basement. This gives a total crack area along this basement wall of $0.01m^2$, which corresponds to a total crack width of 4mm crack extending from the roof to the floor of the basement.

Estimates of the groundwater hydraulic head and flow velocity across the Former Gasworks site have been provided in **Section 10.3**. The hydraulic head was estimated to vary between $1.3x10^{-2}$ and $3.1x10^{-2}$, while the groundwater is estimated to travel at 6.2 to 36.5m/year. Using Darcy's equation, the amount of groundwater that is presently flowing eastwards across the 10m wide property boundary over a 2.5m depth interval (height of submerged basement) is estimated to vary between 17.7 and 104 L/hour.

For the 4mm wide crack, the hydraulic head is conservatively assumed to be 1, which corresponds to a drop of 2.5m over a 2.5m distance into the clay soil or shale bedrock behind the basement wall. Again using Darcy's equation, the amount of groundwater that would seep out from the crack and into the basement is estimated to vary between 0.36 and 1.1 L/hour. This crack seepage rate corresponds to 1 to 2% of the total amount of groundwater that currently flows through a residential property, which is considered to be negligible. The analysis shows that leakage through a basement or other type of underground structure constructed below the water table in the adjoining residential properties should not cause contaminated groundwater to migrate from the Former Gasworks site towards the adjacent residential properties and potentially into tanked basements.

It is considered that this screening assessment supports the conclusion that the exposure concentration for Scenario 3 corresponds to the background water quality, as measured up-gradient of the Former Gasworks site. It is therefore considered that this exposure scenario can be discounted and that the potential receptors (ie. the surrounding residential community and freshwater ecosystems) should not be affected.

11.3.3 Volatilisation & Vapour Transport from Contaminated Groundwater or Soils

From the results of the soil vapour investigation presented in **Section 9**, it was concluded that highly variable field results are to be expected given the highly variable groundwater concentrations that have been measured at the site. The low soil gas levels measured in wells MW30-MW34 in March 2005 are consistent with the low levels of volatile contaminants that were measured in the last groundwater monitoring round undertaken in March 2005. However, the computer analysis showed that much higher soil gas vapours may be present at the Former gasworks site if the higher groundwater concentrations that were measured in earlier monitoring rounds together with the higher concentrations measured in shallow soil samples are more representative of site conditions. Due to this high degree of variability, the exposure pathway from volatile soil vapours has been included in this risk assessment.

The main risks posed by volatilisation and vapour transport from contaminated groundwater and soils are to human receptors that occupy buildings erected on or close to the contaminant sources due to impacts to indoor air quality. This is because soil vapours can enter buildings through cracks and openings in the floor and basement walls and accumulate within the building spaces. Impacts to ambient air quality outside buildings are less due to the much greater amount of dispersion that occurs in the open air. Consequently, this site-specific risk assessment has examined the potential impacts to indoor air quality from contaminated soils and groundwater at the Former Gasworks site.

The analysis has involved the use of a computer model to estimate the indoor air vapour concentrations that may result from the migration of volatile chemicals from the shallow soils and groundwater at the Former Gasworks site. The computer model is based on the Johnson and Ettinger (1991) one-dimensional analytical solution to convective and diffusive vapour transport into spaces, as previously used in the computer simulations of the field investigations. The analysis performed in this study has used the spreadsheet model developed for the US EPA (February 2004), which is available on their website.

The analysis has adopted one-dimensional steady-state conditions, which are conservative assumptions since the contaminant source is taken to extend across the whole area and does not diminish over time. The US EPA (February 2004) user manual provides the equations that are used to define:

- The mass transfer attenuation coefficient (α);
- The theoretical building ventilation rate ($Q_{building}$);
- The volumetric flow rate of soil gas entering the building (Q_{soil});
- The equivalent radius of the floor-wall seam crack (r_{crack}); and
- The equivalent Peclet number for transport through the building foundation.

The steady-state vapour-phase concentration of the contaminant in the building ($C_{building}$) is calculated as:

$$C_{building} = \alpha\, C_{source} \qquad \text{...(4)}$$

where:

$C_{building}$ = Vapour concentration at the contaminant in the building (g/cm^3-v)

C_{source} = Vapour concentration at the source of contamination (g/cm^3-v)

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The US EPA spreadsheet model has been used to estimate exposure concentrations for two exposure scenarios, these being:

- Scenario 1 – On-site workers; and
- Scenario 2 – Off-site residents on properties bordering the Former Gasworks site along the eastern side of Burren Street.

Scenario 1 – On-site Workers

This exposure scenario examines the impacts of volatilisation and vapour transport from contaminated groundwater and soils to on-site workers who may work in buildings erected at the Former Gasworks site. The analysis has used the average soil profile established for the volatile contaminant plume used in the computer simulations in **Section 9.3**. The stratigraphic input parameters used in the model are:

- Depth below grade to water table = 1.5m
- Soil profile = Clay
- Average soil/groundwater temperature = 15°C
- Depth below grade to bottom of enclosed space floor = 0.15m (program default value)
- Vadose zone soil dry density = 1.5t/m^3 (program default value)
- Vadose zone soil total porosity = 0.43 (program default value)
- Vadose zone soil water-filled porosity = 0.215 cm^3/cm^3 (program default value)

The soil contamination is assumed to be uniformly spread throughout the shallow unsaturated fill layer down to the water table. This means that the soil contamination would extend to the underside of building foundations, which have been assumed to be shallow foundations that are buried to a nominal depth of 0.15m. All other parameters used in the model are calculated using the various theoretical equations.

For the purpose of the analysis, the Former Gasworks site has been divided into two areas. The first area corresponds to the shallow aquifer plume of volatile chemicals that is located towards the centre of the site, as previously shown in **Figure 15**. In this area, the main sources of soil vapours are the volatile chemicals present in the groundwater in the shallow aquifer and in the shallow unsaturated soils.

The second area is the remainder of the Former Gasworks site where the levels of volatile chemicals in the shallow aquifer are low and the main source of volatile contamination is the unsaturated fill and shallow soils located above the water table at an average depth of 1.5m. **Table 23B** provides a summary of all available laboratory results for the target volatile chemicals tested in soil samples taken outside the plume area at a depth of 0 – 1.5m.

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For each of these two areas, predicted indoor air concentrations have been calculated using two sets of contaminant concentrations, these being the average and maximum concentrations for the shallow groundwater and shallow unsaturated soils. A summary of the results for the Plume Area and Outside Plume Area are provided in **Tables 23C** and **23D**, respectively.

- **Table 23B Volatile Chemical Results for Shallow Unsaturated Soils Outside Plume Area**

	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL
	BH01	**SB02**	**SB02**	**SB07**	**SB07**	**SB08**	**SB08**	**BH10**	**BH10**	**BH11**
	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000
	0.00-0.10	0.00-0.10	0.20-0.30	0.00-0.10	1.40-1.50	0.00-0.10	1.00-1.10	0.00-0.10	0.3	1.20-1.30
Benzene	0			0	0		0		0	
Toluene	0			0	0		0		0	
Ethylbenzene	0			0	8		0		0	
Total Xylenes	0			0	**32**		0		0	
Naphthalene	0	0.6	0	51	650	1.8	7	1.2	0	
Acenaphthene	0	0	0	15	41	0	1.4	0	0	
Fluorene	0	0.6	0.5	78	61	1.2	3.6	1.6	0	
Pyrene	4.4	25	40	290	54	8.4	13	19	4.6	
Chrysene	2	8	10	89	14	3.4	5.2	7.8	2.6	
Benzo[b,k]	3	18	35	270	30	7	9	14	5	

	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL
	BH12	**BH12**	**BH13**	**BH13**	**BH14**	**BH14**	**BH14**	**BH15**	**BH15**	**BH15**
	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000
	0.00-0.10	0.90-1.00	0.00-0.10	0.20-0.30	0.00-0.10	0.20-0.30	0.90-1.00	'0.00-0.10	0.20-0.30	0.90-1.00
Benzene				**1.6**		0	**4.6**		0	0
Toluene				5		0	0		0	0
Ethylbenzene				0		0	26		0	0
Total Xylenes				9		0	**48**		0	0
Naphthalene	0.8	0	0.5	5	0	0	3.8	0.7	1.6	0
Acenaphthene	0	0	0	1	0	0	0	0	1.2	0
Fluorene	0	0	0	4.6	0	0	0	0	2.8	0
Pyrene	7	0	6.6	67	5.2	0	0	11	56	2.2
Chrysene	3.6	0	2.6	25	2	0	0	5	29	1
Benzo[b,k]	8	0	6	56	6	0	0	16	60	3

	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL
	BH16	**BH16**	**SB18**	**TPC**	**TPD**	**TP99**	**TP99**	**A25 (5)**	**A29 (4)**	**A31 (3)**
	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	April 2000	Oct 2001	Oct 2001	Oct 2001
	0.00-0.10	0.90-1.00	0.20-0.30	1	0.2	0.0-0.10	0.20-0.30	0.0-0.10	0.0-0.10	0.0-0.10
Benzene	0	0	0	0	0	0	0	0	0	0
Toluene	0	0	0	5	0	0	0	0	0	0
Ethylbenzene	0	0	0	9	0	0	0	0	0	0
Total Xylenes	0	0	0	**48**	0	0	0	0	0	0
Naphthalene	0.7	0	280	520	0.6	0	0	0	0.6	0
Acenaphthene	0	0	33	21	0	0	0	0	0	0
Fluorene	0.5	0	120	27	0	0	0	0	0.5	0
Pyrene	12	0	600	32	13	0	1.8	0	24.7	9.7
Chrysene	5.4	0	200	9.2	6.2	0	1.2	0	12.7	5.6
Benzo[b,k] fluoranthene	13	0	310	12	11	0	2	0	20	8

	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	SKM	Maximum	Average
	MW10S	**MW11S**	**MW12D**	**MW13S**	**MW13D**	**MW18D**	**MW31**		
	Oct 2001	Oct 2001	Oct 2001	Oct 2001	Oct 2001	Oct 2001	Dec 2004		
	0.9-1.1	0.6-0.8	1.4-1.5	0.9-1.0	1.4-1.5	1.4-1.5	0.50-0.95		
Benzene	0	0	0	0	0	0	0	4.6	0.2
Toluene	0	0	0	0	0	0	0	5	0.4
Ethylbenzene	0	0	0	0	0	0	0	26	1.6
Total Xylenes	0	0	0	0	0	0	0	48	5.1
Naphthalene	0	0	0	9.7	0	0		650	43.9
Acenaphthene	0	0	0	1	0	0		41	3.3
Fluorene	0	0	0.5	4.2	0	0		120	8.8
Pyrene	12	4.9	9.1	63.3	1.2	0		600	39.9
Chrysene	6.7	2.4	4.2	26.9	0.8	0		200	14.0
Benzo[b,k] fluoranthene	9	3	9	46	2	0		310	28.3

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- **Table 23C Predicted Indoor Air Concentrations for Plume Area**

Target Volatile Chemical	Source Concentration (Average)		Indoor Air Concentration (ug/m^3)		
	Groundwater (µg/L)	Soil (mg/kg)	Groundwater Source	Soil Source	Total
Benzene	114	0	0.32	0	0.32
Toluene	0	0	0	0	0
Ethylbenzene	37	0	0.102	0	0.102
Xylenes	73	0.3	0.205	6.06	6.27
Naphthalene	229	51.3	0.133	12.8	12.9
Acenaphthene	3	9.4	6.52E-4	0.18	0.181
Fluorene	3	38.8	2.93E-4	0.156	0.146
Pyrene	0	155.1	0	0.011	0.011
Chrysene	0	51.6	0	6.48E-04	6.48E-04
Benzo(b,k) fluoranthene	0	100.1	0	1.69E-04	1.69E-04

Target Volatile Chemical	Source Concentration (Maximum)		Indoor Air Concentration (ug/m^3)		
	Groundwater (µg/L)	Soil (mg/kg)	Groundwater Source	Soil Source	Total
Benzene	704	0	1.98	0	1.98
Toluene	0	0	0	0	0
Ethylbenzene	213	0	0.585	0	0.585
Xylenes	417	3	1.17	60.6	60.7
Naphthalene	1460	280	0.848	32.0	32.8
Acenaphthene	14	33	3.04E-03	0.633	0.636
Fluorene	15	120	1.46E-03	0.221	0.222
Pyrene	2	600	2.84E-05	0.020	0.020
Chrysene	0	200	0	6.48E-04	6.48E-04
Benzo(b,k) fluoranthene	0	310	0	1.69E-04	1.69E-04

Note:
Refer **Table 17B** for shallow groundwater source concentrations and **Table 17C** for shallow unsaturated soil source concentrations

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- Table 23D Predicted Indoor Air Concentrations for Outside Plume Area

Target Volatile Chemical	Source Concentration (Average)		Indoor Air Concentration (ug/m^3)		
	Groundwater (µg/L)	Soil (mg/kg)	Groundwater Source	Soil Source	Total
Benzene	0	0.2	0	11.1	11.1
Toluene	0	0.4	0	13.3	13.3
Ethylbenzene	0	1.6	0	35.3	35.3
Xylenes	0	5.1	0	103	103
Naphthalene	0	43.9	0	10.9	10.9
Acenaphthene	0	3.3	0	6.33E-02	6.33E-02
Fluorene	0	8.8	0	3.54E-02	3.54E-02
Pyrene	0	39.9	0	2.83E-03	2.83E-03
Chrysene	0	14.0	0	6.48E-04	6.48E-04
Benzo(b,k) fluoranthene	0	28.3	0	1.69E-04	1.69E-04

Target Volatile Chemical	Source Concentration (Maximum)		Indoor Air Concentration (ug/m^3)		
	Groundwater (µg/L)	Soil (mg/kg)	Groundwater Source	Soil Source	Total
Benzene	0	4.6	0	256	256
Toluene	0	5	0	167	167
Ethylbenzene	0	26	0	574	574
Xylenes	0	48	0	970	1018
Naphthalene	5	650	2.90E-03	32.0	32.0
Acenaphthene	14	41	3.04E-03	7.86E-04	3.83E-03
Fluorene	15	120	1.46E-03	0.221	0.222
Pyrene	2	600	2.84E-05	2.01E-02	2.01E-02
Chrysene	0	200	0	6.48E-04	6.48E-04
Benzo(b,k) fluoranthene	0	210	0	1.69E-04	1.69E-04

Note:
Refer **Appendix B** for shallow groundwater source concentrations and **Table 23b** for shallow unsaturated soil source concentrations

The computer analyses indicate that the highest indoor volatile concentrations would be produced in most contaminant scenarios by xylenes, benzene and naphthalene.

The computer analyses indicate that the highest indoor air volatile concentrations would be generated in the area of the site where the shallow unsaturated soils are most contaminated rather than where the shallow groundwater aquifer is most contaminated. This is because the soils are able to contain a much greater amount of volatile contaminants compared to groundwater where only dissolved phase contamination is present. Furthermore, the analysis has assumed that the contamination in the shallow soils is distributed throughout the soil layer and occurs at the underside of building foundations, whereas the shallow groundwater is located at a depth of 1.5m. Consequently, the highest indoor air concentrations are predicted to occur Outside the Plume Area, since the levels of BTEX and PAH contamination in the soils Outside the Plume Area are higher than in the Plume Area.

The indoor air concentrations predicted by the computer analysis for all contaminant scenarios are less than the occupational air exposure standards given in **Section 8.3** by several orders of magnitude. This is shown in **Table 23E,** which compares the predicted indoor air concentrations given in **Tables 23C** and **23D** with the occupational exposure standards from **Table 15.**

- Table 23E Comparison of Predicted Indoor Air Concentrations with Occupational Exposure Standards

Target Volatile Chemical	Plume Area		Outside Plume Area		Occupational TWA (µg/m3)
	Average Source Levels	Maximum Source Levels	Average Source Levels	Maximum Source Levels	
Benzene	0.32	1.98	11.1	256	16,000
Toluene	0	0	13.3	167	377,000
Ethylbenzene	0.102	0.585	35.3	574	434,000
Xylenes	6.27	60.7	103	1018	350,000
Napthalene	12.9	32.8	10.9	32.0	52,000
Acenaphthene	0.181	0.636	6.33E-02	3.83E-03	200 (1)
Fluorene	0.146	0.222	3.54E-02	0.222	
Pyrene	0.011	0.020	2.83E-03	2.01E-02	
Chrysene	6.48E-04	6.48E-04	6.48E-04	6.48E-04	
Benzo(b,k) fluoranthene	1.69E-04	1.69E-04	1.69E-04	1.69E-04	

Notes
(1) Based on Worksafe TWA for coal tar pitch volatiles

Since the predicted indoor air concentrations are well below the occupational exposure standards, the risks posed by the volatilisation and vapour transport to on-site workers are considered to meet current regulatory requirements. Consequently, no further analysis of this exposure pathway has been undertaken in this site-specific risk assessment.

Scenario 2 – Off-site Residents

This exposure scenario examines the impacts of volatilisation and vapour transport from contaminated groundwater and soils to off-site residents on properties bordering the Former Gasworks site along the eastern side of Burren Street. The most critical condition for this exposure scenario would be impacts to the indoor air quality from soil and groundwater contamination situated near the common boundary between the Former Gasworks site and the residential properties. The boreholes and wells that would define these levels of contaminants are MW9S, MW10S, MW11S and MW19S.

Soil vapours generated in other parts of the Former Gasworks site should pose a low risk to the adjacent residential properties since the investigation has found that groundwater flows in the shallow and deep aquifer at the site are directed to the south and south-east away from the residential properties (**Section 10.3**). Furthermore, analyses predict that typical leaks in tanked basements constructed at the residential properties should not cause any significant change in these groundwater flow directions (**Section 11.3.2**).

The four wells located along the residential boundary measured non-detectible levels of the target BTEX and PAHs chemicals in the shallow aquifer. The soil samples collected from the fill layer at these locations also showed non-detectible BTEX concentrations but elevated PAH concentrations at some locations, which are summarised in **Table 23F**.

- **Table 23F PAH Concentrations Measured in Fill Layer Along Site Boundary with Residential Properties**

Investigator	CH2M HILL	CH2M HILL	CH2M HILL	CH2M HILL	**Average**
SAMPLE ID	**MW09S**	**MW10S**	**MW11S**	**MW19S**	
Date of Sampling	Oct 2001	Oct 2001	Oct 2001	Oct 2001	
Depth (m)	1.3-1.4	0.9-1.1	0.6-0.8	1.2-1.3	
Benzene	nd	nd	nd	nd	nd
Toluene	nd	nd	nd	nd	nd
Ethylbenzene	nd	nd	nd	nd	nd
Total Xylenes	nd	nd	nd	nd	nd
Naphthalene	nd	nd	nd	nd	nd
Acenaphthene	nd	nd	nd	nd	nd
Fluorene	nd	nd	nd	nd	nd
Pyrene	nd	12	4.9	3.6	6.8
Chrysene	nd	6.7	2.4	1.8	3.6
Benzo[b,k]fluoranthene	nd	9	3	3	5.0

All units in mg/kg

In this study, the maximum PAH soil concentrations measured in these soil samples have been taken to represent the PAH concentrations in soils that would rest against basement walls that may be constructed along the common boundary with the Former Gasworks site.

The soil profile used in the computer analysis is the same as was adopted for Scenario 1. The analysis has modelled the vertical basement wall as a horizontal slab founded directed over the soil, which should over-estimate the indoor air concentrations. The results of the computer analysis are summaries in **Table 23G**.

▪ **Table 23G Predicted Indoor Air Concentrations for Residential Basement**

Target Volatile Chemical	Source Concentration (Average)		Indoor Air Concentration (ug/m^3)		
	Groundwater (µg/L)	Soil (mg/kg)	Groundwater Source	Soil Source	Total
Benzene	0	0	0	0	0
Toluene	0	0	0	0	0
Ethylbenzene	0	0	0	0	0
Xylenes	0	0	0	0	0
Naphthalene	0	0	0	0	0
Acenaphthene	0	0	0	0	0
Fluorene	0	0	0	0	0
Pyrene	0	12	0	8.51E-04	8.51E-04
Chrysene	0	6.7	0	6.48E-04	6.48E-04
Benzo(b,k) fluoranthene	0	9	0	1.69E-04	1.69E-04

Ambient air quality criteria for the target PAHs are not available from Australian while the WHO (2000) guidelines only provide a criteria for benzo(a) pyrene. However, the US EPA (2005) provides Preliminary Remedial Goals (PRGs) for the target PAH chemicals in ambient air. These criteria are:

- Pyrene = 110 µg/m^3
- Chrysene = 0.92 µg/m^3
- Benzo(b,k)fluoranthene = 0.0092 – 0.092 µg/m^3

The results show that the predicted indoor air quality in basements on residential properties would be well below the US EPA PRGs by a factor of 10^2 to 10^7 times. Since the predicted indoor air concentrations are well below the occupational exposure standards, the risks posed by the volatilisation and vapour transport to residents on adjacent properties are considered to meet current regulatory requirements. Consequently, no further analysis of this exposure pathway has been undertaken in this site-specific risk assessment.

11.3.4 Contaminated Surface Soils

The assessment of soil contamination data at the Former Gasworks site (**Section 5.7.1**) showed that exposure concentrations from soil contaminants at the site are determined by the fill layer since the contaminant levels in the underlying natural soils are generally lower and are at greater depth. The data indicate that the fill layer is mainly contaminated with high levels of PAHs and TPH C_{10}-C_{36} distributed over much of the site. This is indicated by the 95% UCL estimates of the true mean, which are:

- Total PAHs = 586 mg/kg (SAC = 100 mg/kg)
- Benzo(a)pyrene = 38.7 mg/kg (SAC = 5 mg/kg)
- TPH C_{10}-C_{36} = 8,010 mg/kg (SAC = 1,000 mg/kg)

Hot-spots are considered to be present at individual sampling locations where the contaminant concentration exceeds 250% of the *Soil Investigation Level*, as recommended in the NEHF (1998) guidelines. In the fill layer, hot-spots were found to be contaminated by benzene and xylenes in addition to PAHs and TPH C_{10}-C_{36}.

Contamination in the fill layer was found to be highest in samples located near to the former tar tanks and gasholders (SB03, SB04, SB06, SB07), retorts and gas converter (TP44, TPA, BH13, BH15) and the gas scrubbers (SB18), as shown in **Figure 7**.

Section 11.2 identified the potential receptors of contaminants from the on-site soils to be Site Workers and Construction/Maintenance Workers. The exposure concentrations for Site Workers are considered to be best represented by the 95% UCL true mean estimates, since the exposure period is a relatively long period of time (ie. 30 year exposure period as given by NEPC, 1999e). On the other hand, the exposure concentrations for Construction/Maintenance Workers are considered to be best represented by the maximum hot-spot concentrations due to the shorter exposure period. A summary of these exposure concentrations for the two potential receptors of on-site soil contamination is provided in **Table 24.**

- **Table 24 Exposure Concentrations for Receptors Exposed to Surface Soils**

Substance	Human Health Industrial Criteria (mg/kg)	Hot-spot Criteria (mg/kg)	Soil Concentrations (mg/kg)	
			Site Worker	Construction/ Maintenance Worker
Total PAHs	100	250	586	3953
Benzo(a)pyrene	5	12.5	39	220
TPH (C10-C36)	1,000	2,500	8010	38,400
Benzene	1	2.5	0.8	7
Total Xylenes	25	62.5	21	210

The five contaminants listed in the table correspond to those found to exceed either the HIL F Industrial soil criteria or the hot-spot criteria. When considered together, these contaminants should account for risks posed by chemical mixtures. The other potential contaminants of concern were found to be much lower concentrations and have not been considered further in the contaminated soil exposure scenario.

11.3.5 Leaching to Groundwater & Migration

The potential exposure intakes from contaminants leaching into the groundwater from impacted soils and buried wastes are considered to be accounted for in the exposure intakes due to other migration pathways associated with groundwater from the Former gasworks site. These other exposure pathways comprise groundwater transport (**Section 11.3.1**) and intercepted/extracted groundwater (**Sections 11.3.2 & 11.4.1**). This is because leaching to groundwater has been occurring since the Macdonaldtown Triangle area was first developed by RailCorp more than 100 years ago and gasworks operations ceased in the mid-1970's (refer **Section 4**). The groundwater quality across the Former Gasworks site would have reached a steady-state condition for the more persistent contaminants (eg. heavy metals, benzo(a)pyrene, heavy-end TPHs), while the concentrations of contaminants having a higher degradation potential (eg. BTEX, naphthalene, light-end TPHs) should be gradually decreasing.

This steady-state or gradually degrading condition of contaminants at the Former Gasworks site is demonstrated by the fact that the groundwater investigation data indicate that the contaminant plume is contained within railway-owned land and has not migrated into the residential properties to the west of the site or south of Railway Parade.

On account of these factors, no further consideration of this migration pathway has been made in this site-specific risk assessment.

11.4 Estimates of Exposure Intakes

11.4.1 Methodology

The NEPC (1999e) "*Guideline on Exposure Scenarios and Exposure Settings*" specifies default exposure settings to be used for a range of land uses that were adopted in the NEPM guidelines. The land uses that are most relevant to this study are 'Standard' residential (NEPM A) and commercial/industrial (NEPM F) land uses, with a summary of the default settings provided in **Table 25A**.

- Table 25A Default NEPM Exposure Settings

'Standard' Residential Land Use (NEPM A)	Commercial/Industrial Land Use (NEPM F)
24 hours/day 365 days/year 70 years occupancy duration	8 hours/day 5 days/week 48 weeks/year 30 years duration

The NEPC (1999) "*Guideline on Health Risk Assessment Methodology*" allows a site-specific risk assessment to adopt different exposure settings provided they are appropriate and ensure that transient (short term) and other important exposure scenarios are not obscured by the use, for example, of average lifetime exposures. This is important in the Australian context where Acceptable Daily Intake values from the WHO have been used to establish Health-based Investigation Levels. The duration and magnitude of exceedances of the ADIs must be obvious in exposure assessments[6].

Exposure frequency and duration are used to estimate the total time of exposure. Recommended default exposure values provided in the technical literature have been adopted in this site-specific risk assessment where appropriate and available for each receptor. An example of such a publication is the US EPA (July 2004) *"Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)"*, which supersedes the earlier US EPA (January 1992) guideline.

Where default exposure values are not appropriate or available, professional judgement has been used together with activity factors available from the technical literature such as the US EPA publication *"Exposure Factors Handbook Volume III, Activity Factors"* (US EPA, August 1997).

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[6] Refer Section 6.5 in NEPC (1999a)

While this reference is some 10 years old, it remains the current US EPA policy on exposure factors as confirmed by a check of their website in April 2006.

The 95th percentile value has been used for exposure time if statistical data are available. In the absence of statistical data (which is usually the case), reasonable conservative estimates of exposure time have been used. This approach follows the recommendations made by the US EPA (December 1989) *"Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A)"*, which remains current US EPA policy.

The exposure frequencies and durations derived by the analysis have been combined with the exposure concentrations provided in **Section 11.3** to derive the daily intakes for each potential receptor.

11.4.2 Target Receptors

The analysis of exposure concentrations given in **Section 11.3** concluded that present and possible future site conditions have reduced the number of potential migration pathways for contamination at the Former Gasworks site from the seven identified in **Table 22** to two, these being:

- Impacted groundwater that is intercepted by excavations made by construction workers at the Former Gasworks site (**Section 11.3.2**); and
- Contaminant source in surface soils (fill layer) that may be ingested or dermally absorbed by construction workers or site workers at the Former gasworks site (**Section 11.3.4**).

For each of these potential migration pathways, estimates have been made of the contaminant exposure durations for each of the potential receptors. The estimates that are provided in the following sub-sections comprise:

- On-site construction workers exposed to contaminated groundwater (**Section 11.4.3**);
- Off-site construction workers exposed to contaminated groundwater (**Section 11.4.4**);
- Construction workers exposed to contaminated surface soils (**Section 11.4.5**); and
- Site workers exposed to contaminated soils (**Section 11.4.6**).

11.4.3 On-site Construction Workers Exposed to Contaminated Groundwater

The assessment of contaminant exposure durations for a construction worker at the Former Gasworks site has assumed that workers follow good occupational health practices such as washing hands before eating and rest breaks and they minimise unnecessary exposure to contaminants (eg. no drinking of groundwater). The main exposure route for a construction worker would then be in the form of dermal contact as could be experienced by a plumber or labourer working in a trench containing groundwater.

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Recommended default exposure values and activity factors are not available in the technical literature for construction workers having dermal exposure to contaminated groundwater. The nearest comparable exposure scenarios where exposure durations are specified are for showering/bathing and swimming, with the exposure values summarised in **Table 25B**.

- Table 25B US EPA Recommended Dermal Exposure Values for Adults

Exposure Parameter	Central Tendency Scenario		RME Scenario (3)	
	Showering/ Bathing (1)	Swimming (2)	Showering/ Bathing (1)	Swimming (2)
Event frequency (events/day)	1	1	1	1
Exposure frequency (days/yr)	350	5	350	150
Event duration (hr/event)	0.25	0.5	0.58	1

Notes:

(1) US EPA (July 2004)
(2) US EPA (January 1992)
(3) RME – Reasonable maximum exposure

It is considered reasonable to assume that the length of time that an adult worker would have their hands immersed in groundwater in a given day should be no more than an adult swimming. On this basis, the event duration for a construction worker dermally exposed to contaminated groundwater at the site has been taken to be 1 hour per day, which corresponds to the RME swimming exposure scenario. It is assumed that the worker would have an exposure frequency of 5 days per week for a sufficiently long period for a TDI to apply.

The organic compounds listed in **Table 23** are the analytes that have been considered in the analysis since dissolved heavy metals have a low dermal absorption potential (US EPA, January 1992) and ammonia is at relatively low concentrations and does not pose a significant health-risk. The maximum concentrations that have been measured in the groundwater investigations have been adopted in this analysis, as previously described in **Section 11.3.2**. These organic contaminants and the exposure concentrations are:

- Benzene = 6370 µg/L
- Toluene = 117 µg/L
- Ethylbenzene = 213 µg/L
- Total Xylene = 417 µg/L
- TPH C_{10}-C_{36} = 18,220 µg/L

- Naphthalene = 3840 μg/L

The daily intake of these organic compounds from dermal contact with groundwater at the Former Gasworks site has been estimated using the US EPA dermal exposure model, which is given in the document *"Dermal Exposure Assessment: Principles and Applications"* US EPA (January 1992).

The chemical properties of relevance to the US EPA dermal contact model for water exposure to organic contaminants are:

- Permeability coefficient for the chemical from water through the skin (K_P);
- Partition coefficient between octanol and water (dimensionless) (K_{OW}); and
- The molecular weight of the contaminant (MW).

The US EPA Dermal Exposure Assessment[7] provides values of these chemical properties for the contaminants of concern except TPH C_{10}-C_{36}. For the purposes of the assessment, the naphthalene parameters have been adopted for TPH C_{10}-C_{36}. A summary of these chemical properties is provided in **Table 25C**.

- **Table 25C Summary of Chemical Properties for Organic Contaminants**

Substance	K_p (cm/hr)	Log K_{ow}	MW
Benzene	0.021	2.13	78.1
Toluene	0.045	2.73	92.1
Ethylbenzene	0.074	3.15	106.2
Total Xylenes	0.080	3.20	106.2
TPH C_{10}-C_{36}	0.069	3.30	128.2
Naphthalene	0.069	3.30	128.2

The chemical intake from immersion of a worker's skin in groundwater is estimated from the US EPA model by firstly calculating the dimensionless B parameter given by the equation:

$$B = K_{OW} / 10^4$$

The diffusivity of the contaminant within the skin membrane (D_{SC}) is then calculated using the equation:

$$\log [D_{SC} / l_{SC}] = -2.72 - 0.0061\ MW \quad \text{.................................(5)}$$

where:

l_{SC} = Thickness of the stratum corneum = 10^{-3} cm

7 Refer Table 5-7 in US EPA (January 1992)

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Substituting the values for l_{SC} and MW gives:

$$D_{SC} = l_{SC} \times 10^{(-2.72-0.0061MW)} \ cm^2/hr \quad \text{......(6)}$$

The time lag for organic contaminants to penetrate the skin is then calculated using the equation:

$$\tau = (l_{SC})^2 / (6D_{SC}) \quad \text{......(7)}$$

The time it takes for the absorption to reach a steady-state (t*) is then calculated using the equation:

$$t^* = 2.4 \times \tau \quad \text{for the case where } B \leq 0.1 \quad \textbf{......(8)}$$

For an event time (t_{event}) > t*, the dose absorbed per unit area per event (DA_{event}) is given by the equation:

$$DA_{event} = K_P \,.\, C_v \,.\, \{t_{event} / (1 + B) + 2\tau\, [(1 + 3B)/(1 + B)]\} \quad \text{.....(9)}$$

where:

DA_{event}	=	Dose absorbed per unit area per event (mg/cm^2-event)
K_P	=	Permeability coefficient from water (cm/hour)
C_v	=	Concentration of chemical in water ($mg/cm^3 = 1 \times 10^{-6}$ µg/L)
t_{event}	=	Duration of event (hour/event) = 1 hr

If t_{event} < t*, then DA_{event} is given by the equation:

$$DA_{event} = 2 \,.\, K_P \,.\, C_v \,.\, \sqrt{[(6 \,.\, \tau \,.\, t_{event})/\pi]} \quad \text{.................... (10)}$$

The daily dose (DD) from dermal contact with chemicals in soil or water is estimated from the equation:

$$DD = DA_{event} \times SA \quad \text{.................... (11)}$$

where:

DD	=	Daily dose (mg-day)
DA_{event}	=	Dose absorbed per unit area per event (mg/cm^2-event)
SA	=	Skin surface area available for contact (cm^2)

For a worker who immerses his hands in groundwater, the US EPA[8] recommends a skin surface area of $0.084m^2$ ($840cm^2$).

The results of the calculations and the estimated daily doses for on-site construction workers exposed to extracted groundwater at the Former Gasworks site are provided in **Table 26**.

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[8] Section 6.2.5 in US EPA (August 1997)

- Table 26 Estimates of Dermal Intake for On-site Construction Workers Exposed to Intercepted Groundwater from the Former Gasworks Site

Substance	B	Dsc (cm^2/hr)	τ (hr)	t* (hr)	DA_{event} (mg/cm^2-event)	DD (mg/day)
Benzene	0.013	6.362E-07	0.262	0.629	2.039E-04	1.713E-01
Toluene	0.054	5.226E-07	0.319	0.765	8.697E-06	7.305E-03
Ethylbenzene	0.141	4.287E-07	0.389	0.933	2.910E-05	2.444E-02
Total Xylenes	0.158	4.287E-07	0.389	0.933	6.183E-05	5.194E-02
TPH (C10-C36)	0.200	3.148E-07	0.530	1.271	2.528E-03	2.124E+00
Naphthalene	0.200	3.148E-07	0.530	1.271	5.329E-04	4.476E-01

11.4.4 Off-Site Construction Workers Exposed to Contaminated Groundwater

The daily contaminant intakes for off-site construction workers exposed to contaminated groundwater have been calculated using the average groundwater concentrations presented in **Table 23** in **Section 11.3.2** and the methodology described in **Section 11.4.3**. The results of the calculations and the estimated daily doses for off-site construction workers exposed to extracted groundwater at an adjoining residential property are provided in **Table 26B**.

- Table 26B Estimates of Dermal Intake for Off-site Construction Workers Exposed to Intercepted Groundwater from the Former Gasworks Site

Substance	B	Dsc (cm^2/hr)	τ (hr)	t* (hr)	DA_{event} (mg/cm^2-event)	DD (mg/day)
Benzene	0.013	6.362E-07	0.262	0.629	2.042E-05	1.716E-02
Toluene	0.054	5.226E-07	0.319	0.765	1.026E-06	8.617E-04
Ethylbenzene	0.141	4.287E-07	0.389	0.933	4.003E-06	3.362E-03
Total Xylenes	0.158	4.287E-07	0.389	0.933	9.875E-06	8.295E-03
TPH (C10-C36)	0.200	3.148E-07	0.530	1.271	3.116E-04	2.618E-01
Naphthalene	0.200	3.148E-07	0.530	1.271	5.020E-05	4.216E-02

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11.4.5 Construction Workers Exposed to Contaminated Surface Soils

The two exposure routes for construction workers in contact with contaminated soil are listed in **Table 22** as ingestion and dermal adsorption.

Ingestion

The amount of soil ingestion for an adult is given in Australian guidelines (ANZECC/NHMRC, 1992; NEPC, 1999a) as 25 mg soil/day. The contaminant concentrations for construction/ maintenance workers exposed to surface soils at the Former Gasworks site are those given in **Table 24** in **Section 11.3.4**, these being total PAHs 3953mg/kg, benzo(a)pyrene 220mg/kg, TPH C_{10}-C_{36} 38,400mg/kg, benzene 7mg/kg and total xylenes 210mg/kg. The estimated exposure intakes by ingestion for a construction/maintenance worker are calculated to be:

Total PAHs	= 98.8 μg / day
Benzo(a)pyrene	= 5.50 μg / day
TPH C_{10}-C_{36}	= 960 μg / day
Benzene	= 0.175 μg / day
Total Xylenes	= 5.25 μg / day

Dermal Adsorption

The dermal absorption of contaminants from the soil by construction workers has been calculated using the US EPA dermal exposure model given in the document *"Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment"* (US EPA, July 2004).

The dose absorbed per unit area per event (DA_{event}) is given by the equation:

$$DA_{event} = C_{soil} \cdot CF \cdot AF \cdot ABS_d \quad \ldots\ldots(12)$$

where:

DA_{event}	=	Dose absorbed per unit area per event (mg/cm^2-event)
C_{soil}	=	Chemical concentration in soil (mg/kg)
CF	=	Conversion factor (10^{-6} kg/mg)
AF	=	Adherence factor of soil to skin (mg/cm^2-event)
ABS_d	=	Dermal absorption fraction

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The daily dose (DD) from dermal contact with chemicals in soil or water is estimated using Equation (11).

The C_{soil} contaminant concentrations used in the analysis are those given in **Table 24** in **Section 11.3.4** for "construction/maintenance workers'. An AF value of 0.3 has been adopted, which corresponds to the 95th percentile default value recommended by the US EPA[9] for construction workers. The ABS_d values provided for PAHs and semivolatile organic compounds have also been adopted from the US EPA guideline[10], the values being:

- Benzo(a)pyrene and other PAHs = 0.13
- Semivolatile organic compounds = 0.10

The skin surface area (SA) used in the analysis was 4860cm^2, which is the sum of the 50th percentile areas recommended by the US EPA[11] for adult male hands (990cm^2), forearms (1310cm^2) and lower legs (2560cm^2).

The results of the calculations and the estimated daily doses for construction workers dermally exposed to contaminated surface soils at the Former Gasworks site are provided in **Table 27.**

- **Table 27 Estimates of Dermal Intake for Construction Workers Exposed to Contaminated Surface Soils at the Former Gasworks Site**

Substance	Csoil (mg/kg)	CF (kg/mg)	AF (mg/cm^2)	ABSd	DA_{event} (mg/cm^2-event)	DD (mg/day)
Benzene	7	1.00E-06	0.30	0.1	2.100E-07	1.021E-03
Total Xylenes	210	1.00E-06	0.30	0.1	6.300E-06	3.062E-02
TPH (C10-C36)	38400	1.00E-06	0.30	0.1	1.152E-03	5.599E+00
Total PAHs	3953	1.00E-06	0.30	0.13	1.542E-04	7.493E-01
Benzo(a)pyrene	220	1.00E-06	0.30	0.1	8.580E-06	4.170E-02

11.4.6 Site Workers Exposed to Contaminated Soils

The two exposure routes for construction workers in contact with contaminated soil are listed in **Table 22** as ingestion and dermal adsorption.

9 Refer Exhibit 3-3 in US EPA (July 2004)
10 Refer Exhibit 3-4 in US EPA (July 2004)
11 Refer Exhibit C-1 in US EPA (July 2004)

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Ingestion

The amount of soil ingestion for an adult is given in Australian guidelines (ANZECC/NHMRC, 1992; NEPC, 1999a) as 25 mg soil/day. The contaminant concentrations for Site Workers exposed to surface soils at the Former Gasworks site are those given in **Table 24** in **Section 11.3.4**, these being total PAHs 586mg/kg, benzo(a)pyrene 39mg/kg, TPH C_{10}-C_{36} 8,010mg/kg, benzene 0.8mg/kg and total xylenes 21mg/kg. The estimated exposure intakes by ingestion for a Site Worker are calculated to be:

Total PAHs	= 14.7 μg / day
Benzo(a)pyrene	= 0.975 μg / day
TPH C_{10}-C_{36}	= 200 μg / day
Benzene	= 0.020 μg / day
Total Xylenes	= 0.525 μg / day

Dermal Adsorption

The daily intake by long-term site workers from dermal contact with surface soils at the Former Gasworks site has been estimated using the same methodology as used in **Section 11.4.5**. The C_{soil} contaminant concentrations used in the analysis are those given in **Table 24** in **Section 11.3.4** for "site workers'. The AF, ABS_d and SA values remain the same as used in the previous analysis.

The results of the calculations and the estimated daily doses for site workers dermally exposed to contaminated surface soils at the Former Gasworks site are provided in **Table 28**.

- **Table 28 Estimates of Dermal Intake for Site Workers Exposed to Contaminated Surface Soils at the Former Gasworks Site**

Substance	Csoil (mg/kg)	CF (kg/mg)	AF (mg/cm^2)	ABSd	DA_{event} (mg/cm^2-event)	DD (mg/day)
Benzene	1	1.00E-06	0.30	0.1	2.400E-08	1.166E-04
Total Xylenes	21	1.00E-06	0.30	0.1	6.300E-07	3.062E-03
TPH (C10-C36)	8010	1.00E-06	0.30	0.1	2.403E-04	1.168E+00
Total PAHs	586	1.00E-06	0.30	0.13	2.285E-05	1.111E-01
Benzo(a)pyrene	39	1.00E-06	0.30	0.1	1.521E-06	7.392E-03

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12 Toxicity Assessment

This section of the report provides toxicity assessments for the contaminants that are the subject of the site-specific risk assessment, as identified in Section 11. The assessment forms the third step in the site-specific risk assessment for ground contamination at the Former Gasworks site. The methodology that has been used was previously described in Section 2.4. These contaminants comprise PAHs (Section 12.1), benzene (Section 12.2), toluene (Section 12.3), ethylbenzene (Section 12.4), xylenes (Section 12.5) and petroleum hydrocarbons (Section 12.6).

12.1 PAHs

General

The NHMRC (2004) *"Australian Drinking Water Guidelines"* and the WHO (2000) *"Air Quality Guidelines for Europe"* advise that PAHs are widespread throughout the environment. They are formed in forest fires and in the combustion of fossil fuels and are present in emissions from coke ovens, gasworks, aluminium smelters and motor vehicles.

Food is the major source of intake of PAHs. Highest concentrations occur in smoked foods, leafy vegetables and the burnt fat of metals. Intake from foods is extremely variable but significantly higher than from drinking water.

Toxicology

Most of the toxicological literature deals specifically with benzo(a)pyrene (BaP). Few studies are available for the other PAHs. Some PAHs have been found to be carcinogenic by non-oral routes, but others are known to have low potential for carcinogenicity. Estimates of the relative potency of PAH indicator compounds are provided by the WHO INCHEM (1998) environmental health study and more recently by Fitzgerald (1998), which are summarised in **Table 30**.

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Table 30 Toxicity Equivalence Factors for PAHs

Compound	Range of Relative Potencies
Benzo(a)pyrene	1
Dibenz(a,h)anthracene	4
Benz(a)anthracene	0.1
Benzo(b)fluoranthene	0.1
Benzo(k)fluoranthene	0.1
Indo(1,2,3-c,d)pyrene	0.1
Anthracene	0.001
Benzo(g,h,i)perylene	0.1
Chrysene	0.1
Acenaphthene	0.001
Acenaphthylene	0.001
Fluoranthene	0.01
Fluorene	0.001
Naphthalene	0.001
Phenanthrene	0.001
Pyrene	0.001

Reference: Fitzgerald (1998)

BaP is absorbed principally through the gastrointestinal tract and the lungs. The rate of absorption increases with increased intake of polyunsaturated fatty acids. BaP is rapidly distributed to the organs and may be stored in mammary and adipose tissue. Metabolism occurs mainly in the liver.

The International Agency for Research on Cancer (IARC) has concluded that BaP is probably carcinogenic to humans (Group 2A).

Human Health Criteria

The WHO or Australian health authorities have not published health criteria that specify acceptable intakes for PAH substances. Recourse has therefore been made to the USEPA (2002) PRGs, which provide health criteria for PAHs in terms of Reference Doses for non-carcinogenic contaminants and Slope Factors (SF) for carcinogenic contaminants.

A Reference Dose (RfD) is defined (NEPC, 1999a) as *"an estimate (with uncertainty factors spanning perhaps an order of magnitude) of the daily exposure (mg/kg body weight/day) to the general human population (including sensitive sub-groups) that is likely to be without an appreciable risk of deleterious effects during a life time of exposure. It is derived from the NOAEL or the LOAEL by application of uncertainty factors that reflect various types of data used to* *estimate RfD and an additional modifying factor, which is based on professional judgement of the entire data base of the chemical (IRIS, 1996)".*

RfDs are provided in units of mg/kg body weight-day while SFs are provided in 1/(mg/kg body weight-day).

The US EPA PRGs provide RfDs and SFs for ingestion (oral) soil (RfDo) and inhalation (RfDi) together with skin absorption factors for soil. A summary of these RfD/SF values for individual PAH compounds that are included in the US EPA PRG assessment is provided in **Table 31**.

- Table 31 US EPA Reference Doses & Slope Factors for PAHs

Compound	SFo 1/(mg/kg-day)	SFi 1/(mg/kg-day)	Skin Absorption Factor
Benzo(a)pyrene	7.3E+00		0.13
Dibenz(a,h)anthracene	7.3E+00		0.13
Benz(a)anthracene	7.3E-01		0.13
Benzo(b)fluoranthene	7.3E-01		0.13
Benzo(k)fluoranthene	7.3E-02		0.13
Indeno(1,2,3-c,d)pyrene	7.3E-01		
Chrysene	7.3E-03		0.13
Compound	**RfDo (mg/kg/day)**	**RFDi (mg/kg/day)**	**Skin Absorption Factor**
Anthracene	3.0E-01	3.0E-01	
Acenaphthene	6.0E-02	6.0E-02	
Acenaphthylene			
Fluoranthene	4.0E-02	4.0E-02	0.13
Fluorene	4.0E-02	4.0E-02	
Naphthalene	2.0E-02	8.6E-04	
Phenanthrene			
Pyrene	3.0E-02	3.0E-02	
PAHs (general)			0.13

A study by Fitzgerald (1998) that appears in the Fourth National Workshop on the Health Risk Assessment and Management of Contaminated Sites in Australia developed a guideline dose for BaP using actual tumour dose-response data from laboratory studies. The study recommended a guideline dose of 9.5μg/day for a 70kg adult and 1.8μg/day for a 2.5 year old child (13.2kg).

Ecological Health

The ANZECC (1992) guidelines report that concentrations of PAHs in aquatic ecosystems are generally highest in sediments, intermediate in aquatic biota and lowest in the water column. Studies have found that sorption to suspended particles and bed sediments is the primary removal mechanism for high-molecular weight PAHs, whereas volatilisation and transport were the primary mechanisms for low-molecular weight PAHs. Mixed microbial population in sediment water systems may degrade some PAHs, with degradation progressively decreasing with increasing molecular weight.

PAHs are known to affect survival, growth, metabolism and initiate tumour formation in many organisms. In birds and mammals, effects include reduced embryo survival, development effects, mutagenesis, carcinogenesis, and teratogenesis. Aquatic invertebrates (particularly crustaceans) are sensitive to PAHs. Sublethal effects include inhibited reproduction and emergence.

In fish, PAHs may be tumorigenic. However, most fish rapidly metabolise and excrete PAHs, thus limiting toxicity.

12.2 Benzene

General

The NHMRC (2004) *"Australian Drinking Water Guidelines"* and the WHO (2000) *"Air Quality Guidelines for Europe"* advise that benzene is present in petrol, motor vehicle emissions, is used as a cleaning solvent and is a by-product of the coal gasification process. When released to surface waters, benzene rapidly volatilises to the air. It is a colourless liquid at room temperature with a density of 0.87 g/cm^3 at 20°C.

Inhalation accounts for more than 99% of the exposure of the general population, whereas intake from food and water is minimal.

Toxicology

Benzene is rapidly and efficiently absorbed and widely distributed throughout the body. It is metabolised predominantly into phenol by the liver and also be bone marrow.

Human health data are mainly from studies where benzene had been inhaled. Exposure to high concentrations in air can cause death. Lower concentrations can induce toxic effects, with white blood cells being most sensitive. There is considerable evidence that occupational exposure to low benzene concentrations for periods as short as 12 months may result in leukaemia.

In animal studies, benzene caused leukaemia and other cancers when administered orally and by inhalation to rats and mice. It can also induce chromosome damage and gene mutation in mammalian cells. It was not found to be mutagenic in tests with bacteria.

The most significant adverse effects from prolonged exposure to benzene are haematotoxicity, genotoxicity and carcinogenicity. IARC (1987) has concluded that benzene is carcinogenic to humans (Group 1).

Human Health Criteria

Benzene is a genotoxic human carcinogen and there is no safe or acceptable concentration for it in drinking water. The NHMRC (2004) drinking water guideline value of 0.001mg/L is based on a recommendation made by the WHO that this concentration in drinking water would entail a maximum lifetime risk of one extra case of leukaemia per million people.

Reference Doses and Slope Factors values provided by the US EPA (2002) PRGs for benzene are:

- SFo = 5.5E-02 (mg/kg body wt-day) $^{-1}$
- RfDo = 3.0E-03 mg/kg body wt-day
- SFi = 2.9E-02 (mg/kg body wt-day) $^{-1}$
- RfDi = 1.7E-03 mg/kg body wt-day

12.3 Toluene

General

Toluene is an aromatic hydrocarbon. The NHMRC (2004) *"Australian Drinking Water Guidelines"* and the WHO (1986) *"INCHEM Environmental Health Criteria 52"* advise that toluene occurs naturally as a component of crude oil and is present in petrol. Toluene is produced in large quantities during petroleum refining and is a by-product in the manufacture of styrene and coke-oven preparations. It also occurs in natural gas and emissions from volcanoes, forest fires and cigarettes.

The general population is exposed to toluene mainly through inhalation of vapour in ambient air, cigarette smoking and to a minor extent, by ingestion of food or water contaminated with toluene.

Toxicology

In humans, toluene is readily absorbed from the gastrointestinal tract after ingestion and is distributed preferentially in adipose tissue, then the kidneys, liver and brain. It is rapidly metabolised by the liver to benzl alcohol, benzoic acid and to a lesser extent phenols.

Data on human health effects come mainly from inhalation studies. The predominant effects of acute exposure were impairment of the CNS and irritation of the mucous membranes, with fatigue and drowsiness being the most obvious symptoms.

Rats exposed to toluene vapour for 2 years exhibited decreased blood haeatocrit values at high toluene concentrations. No data are available on long-term oral toxicity. However, a 13-week gavage study using rats and mice reported increased liver weights at doses from 625 mg/kg body weight per day.

Toluene generally did not exhibit genotoxic activity in tests on bacteria, yeast cells and mammalian cells in vitro. IARC (www.monographs.iarc.fr) has concluded that toluene is not classifiable as to its carcinogenicity in humans (Group 3).

Human Health Criteria

The NHMRC (2004) guidelines advise that the no effect level for toluene, based on a 13-week oral study using rats, is 312 mg/kg body weight per day. The NHMRC (2004) drinking water guideline value is 0.8mg/L, which includes a safety factor of 1000 using the results of the animal study as a basis for human exposure. This health-based value exceeds the taste threshold of 0.025mg/L for toluene in water.

Reference Doses and Slope Factors values provided by the US EPA (2002) PRGs for toluene are:

- SFo = not specified
- RfDo = 2.0E-01 mg/kg body wt-day
- SFi = not specified
- RfDi = 1.1E-01 mg/kg body wt-day

12.4 Ethylbenzene

General

Ethylbenzene is an aromatic hydrocarbon. The NHMRC (2004) *"Australian Drinking Water Guidelines"* and the WHO (1996) *"INCHEM Environmental Health Criteria 186"* advise that ethylbenzene occurs naturally as a component of crude oil and is present in petrol in small quantities. It is also used commercially in paints, insecticides and is a constituent of coal tars, asphalt and naphtha. Ethylbenzene is a non-persistent chemical, being degraded primarily by photo-oxidation and biodegradation. Volatilization to the atmosphere is rapid. It is a colourless liquid at room temperature with a sweet gasoline-like odour. It is lighter than water and has a density of 0.866g/cm^3 at 25°C.

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Human exposure to ethylbenzene occurs mainly by inhalation; 40-60% of inhaled ethylbenzene is retained in the lung.

Toxicology

Ethylbenzene is readily absorbed from the human gastrointestinal tract. It can be stored in fat and is extensively metabolised, mainly to mandelic and phenylglyoxylic acids and excreted in the urine. It can cross the placenta. No data are available on the health effects in humans after oral exposure and inhalation data are limited to short-term studies.

A 6-month gavage study using rats reported enlargement of the liver and kidney at high doses. Liver effects were also observed in a number of inhalation studies. No long-term studies are available.

Studies on the mutagenic activity of ethylbenzene to bacteria, insects and mammalian cells have reported negative results. IARC (www.monographs.iarc.fr) has concluded that ethylbenzene is possibly carcinogenic to humans (Group 2B).

Human Health Criteria

Ethylbenzene has low acute and chronic toxicity for both animals and humans. It is toxic to the central nervous system and is an irritant of mucous membranes and the eyes. The WHO (1996) report that the threshold for these effects in humans after short single exposures was estimated to be about 430-860 mg/m3 (100-200ppm).

The NHMRC (2004) guidelines advise that the no effect level for ethylbenzene, based on a 6-month gavage study using rats, is 136mg/kg body weight per day. The NHMRC (2004) drinking water guideline value is 0.3mg/L, which includes a safety factor of 1000 using the results of the animal study as a basis for human exposure. This health-based value exceeds the taste threshold of 0.003mg/L for ethylbenzene in water.

Reference Doses and Slope Factors values provided by the US EPA (2002) PRGs for ethylbenzene are:

- SFo = 3.85E-03 (mg/kg body wt-day) $^{-1}$
- RfDo = 1.0E-01 mg/kg body wt-day
- SFi = 3.85E-03 (mg/kg body wt-day) $^{-1}$
- RfDi = 2.9E-01 mg/kg body wt-day

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12.5 Xylenes

General

Xylene is an aromatic hydrocarbon which exists in three isomeric forms: ortho, meta and para. The NHMRC (2004) *"Australian Drinking Water Guidelines"* and the WHO (1997) *"INCHEM Environmental Health Criteria 186"* advise that xylenes occur as a component of crude oil and are present in petrol, but in small quantities. It is also produced in the petroleum refining process and is used in the manufacture of insecticides, pharmaceuticals, detergents, paints, adhesives and other products. Xylenes are readily biodegraded in surface waters and they volatilise to air very quickly. It is a colourless liquid at room temperature with an aromatic odour. It is lighter than water and has a density of between 0.860 and 0.876g/cm^3 at 25°C.

The majority of xylene released into the environment enters the atmosphere directly. In the atmosphere the xylene isomers are readily degraded, primarily by photooxidation. Volatilisation to the atmosphere from water is rapid for all three isomers. In soil and water, the meta and para isomers are readily biodegraded under a wide range of aerobic and anaerobic conditions, but the ortho isomer is more persistent. The limited evidence available suggests that bioaccumulation of the xylene isomers by fish and invertebrates is low.

Toxicology

Xylenes are readily absorbed after inhalation and metabolised almost completely to methyl benzoic acid. More than 90% is biotransformed to methylhippuric acid, which is excreted in urine. Xylene does not accumulate significantly in the human body. It can cross the placenta. No data are available on human absorption after ingestion, or on health effects of oral exposure in humans.

Acute exposure to high concentrations of xylene can result in CNS effects and irritation in humans. However, there have been no long-term controlled human studies or epidemiological studies. The chronic toxicity appears to be relatively low in laboratory animals. There is suggestive evidence, however, that chronic CNS effects may occur in animals at moderate concentrations of xylene. A 2-year gavage study using rats and mice reported decreased growth at high doses but no xylene-related lesions.

There was no evidence of carcinogenicity in oral and skin administration studies using rats and mice, and xylenes were not mutagenic in tests using bacteria and mammalian cells. IARC (www.monographs.iarc.fr) has concluded that xylene is not classifiable as to carcinogenicity in humans (Group 3).

Human Health Criteria

The WHO (1997) report that the lowest LC_{50} for invertebrates was measured for o-xylene at 1mg/L amd 7.6mg/L for fish. For m- and p-xylenes, the LC_{50} in fish was measured at 7.9 and 1.7mg/L, respectively.

The NHMRC (2004) guidelines advise that the no effect level for xylene, based on a 2-year gavage study using rats, is 250mg/kg body weight per day. The NHMRC (2004) drinking water guideline value is 0.6mg/L, which includes a safety factor of 1000 using the results of the animal study as a basis for human exposure. This health-based value exceeds the taste threshold of 0.02mg/L for xylenes in water.

Reference Doses and Slope Factors values provided by the US EPA (2002) PRGs for xylenes are:

- SFo = not specified
- RfDo = 7.0E-01 mg/kg body wt-day
- SFi = not specified
- RfDi = 2.9E-02 mg/kg body wt-day

12.6 Petroleum Hydrocarbons

General

Turczynoxicz (1998) advises that total petroleum hydrocarbons (TPH) are a diverse range of chemicals derived from crude petroleum. Their numerous properties result in a ubiquitous distribution within our community and they are frequently encountered on contaminated sites. General classes of TPHs include liquefied gases, solvents, gasoline, kerosene, jet fuels, fuel oils, lubricating oils, asphalts and waxes. These substances are environmentally mobile and will result in contamination of soil, air and water. Their environmental fate and transport behaviour is a reflection of their molecular weight and bonding characteristics with high molecular weight substances being less mobile and more resistant to degradation.

Toxicology

The toxicology of some distillate mixtures such as diesel fuel, fuel oils and gasoline and chemicals such as benzene, 1,3-butadiene, toluene and xylenes has been extensively evaluated by regulatory agencies such as IARC, IPCS, US EPA and the US ATSDR. However, toxicological information on many constituents is limited due to commercial and historical factors. The Total Petroleum Hydrocarbon Working Group (1996), in examining toxicological information on 254 chemicals in the C3-C26 range identified approximately 65 compounds as possible surrogates for other total petroleum hydrocarbons and for which useful toxicological information was available.

In terms of acute exposure, low molecular weight petroleum distillates are poorly absorbed from the gastrointestinal tract and do not cause appreciable systemic toxicity by ingestion unless aspiration occurs, in which case primary effects include pulmonary damage and transient CNS depression or excitation.

Heavy fuel oils produce the most severe eye irritation while the middle distillates produce the most severe dermal irritation. Contact with diesel fuel can result in dermal blisters while paraffinic and naphthenic oils were the least reactive.

Inhalation exposure to volatile petroleum hydrocarbons such as low molecular weight aromatics and aliphatics, including petrol, may result in cardiac arrhythmais and CNS depression. Case reports of renal and haematological effects have also been recorded from acute high exposure.

Dermal effects from short-term exposure to solvents may include irritant and defatting effects, and exposure to lubricating oils, greases and waxes may result in skin disorders such as primary irritation, oil acne, hyperkeratosis and photosensitivity.

In terms of chronic exposures, toxicity endpoints are generally centred around concerns about the development of carcinomas and petroleum hydrocarbons are no exceptions. The IARC rankings of carcinogenic activity for some petroleum hydrocarbons, deemed as representing a significant hazard and for which data are available, include:

- Benzene - Group 1 (human carcinogen)
- Gasoline/petrol – Group 2B (possibly carcinogenic to humans)
- Jet fuel – Group 3 (not classifiable)
- Fuel oils – Group 2A (probably carcinogenic to humans)
- Residual fuel oils and marine diesel oil – Group 2B
- Light fuel oils and light diesel oils – Group 3
- Mineral-based crankcase oil – Group 3

Human Health Criteria

The WHO or Australian health authorities have not published health criteria that specify acceptable intakes for TPH mixtures. Recourse has therefore been made to the use of Reference Doses for TPH surrogate chemicals as proposed by Turczynowicz (1998). A summary of this data is provided in **Table 32**.

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- **Table 32 Toxicological Data for TPH Fraction-Specific Surrogates (1)**

TPH Range	TPH Surrogate	RfD Oral (mg/kg-day)	RfD Inhalation (mg/m^3)
Aromatics			
C5-C7	Benzene (2)	0.003	0.0017 (mg/kg-day)
>C7-C8	Toluene, ethylbenzene, styrene, xylenes	0.2	0.4
>C8-C16	Naphthalene, acenaphthene, biphenyl, fluorene, anthracene, fluoranthene, pyrene	0.04	0.2
>C16-C35	Pyrene	0.03	
Aliphatics			
C5-C8	n-hexane	5.0	18.4
>C8-C16	JP-8/ dearomatized petroleum stream	0.1	1.0
>C16-C35	Mineral oils	2.0	
>C35	Mineral oils	20.0	

Notes:
(1) Reference Turczynowicz (1998)
(2) US EPA (2002) PRGs

13 Risk Characterisation

This section of the report brings together the first three stages of the site-specific risk assessment as presented in Sections 11 and 12 and characterises the health and ecological risks and develops site-specific criteria where appropriate (Section 13). The assessment forms the fourth and final step in the site-specific risk assessment for ground contamination at the Former Gasworks site. The methodology that has been used was previously described in Section 2.4.

The analysis assesses the risks to each of the potential human and ecological receptors, these being on-site construction workers (Section 13.1), site workers (Section 13.2), nearby residents/surrounding community and off-site construction workers (Section 13.3) and the freshwater ecosystems in Alexandra Canal (Section 13.4). The analysis has also considered phytotoxicity risks to plants (Section 13.5) and aesthetic issues (Section 13.6). An assessment is then made on the need for remedial actions at the Former Gasworks site (Section 13.7).

13.1 Risks to On-site Construction Workers

The results of the data and exposure assessment presented in **Section 11.2** indicate that the main health risks to on-site construction/maintenance workers from ground contamination at the Former Gasworks site are associated with:

- Exposure to contaminated groundwater that is intercepted or extracted during the course of the redevelopment or as a result of future maintenance work. The contaminants of concern are benzene, toluene, ethylbenzene, total xylenes, TPH (C_{10}-C_{36}) and naphthalene; and
- Exposure to contaminated surface soils during the course of the redevelopment or as a result of future maintenance work. The contaminants of concern are total PAHs, BaP, TPH (C_{10}-C_{36}), benzene and total xylenes.

The human health risks associated with each of these exposure scenarios have been estimated using the estimates of intakes given in **Section 11.4.3** (intercepted/extracted groundwater) and **Section 11.4.5** (contaminated surface soils) together with the toxicological data provided in **Section 12.** The daily doses in mg/kg body weight per day have been converted into daily intake amounts in mg using a body weight of 70kg, as recommended in the NEPM (1999) Schedule B(4) guidelines.

The main exposure routes are considered to comprise:

- Ingestion of contaminants from surface soils;
- Dermal contact with contaminated soils; and
- Dermal contact with contaminated groundwater.

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As previously mentioned in **Section 11.2**, the inhalation of dust and vapours have not been included in this site-specific risk assessment since such exposures will depend heavily on work practices and it has been assumed that these health risks would best be managed as part of an occupational health and safety plan covering any earthworks conducted at the Former Gasworks site. The requirement for such safety procedures will need to be incorporated into the long-term SMP to be placed on the Former Gasworks site. This recommendation is included in **Section 14.2** of this report.

A summary of the estimated contaminant intakes to an on-site construction/maintenance worker for the contaminants of concern are summarised in **Table 33**.

- **Table 33 Daily Contaminant Intakes for On-site Construction / Maintenance Worker**

Substance	Daily Contaminant Intake (µg)			Total Daily Intake (µg)
	Ingestion of Surface Soil	Dermal Contact with Groundwater	Dermal Contact with Surface Soils	
Total PAHs	98.8	--	111	210
Benzo(a)pyrene	5.5	--	7.39	12.9
Naphthalene	--	448	--	448
TPH C_{10}-C_{36}	960	2124	1168	4252
Benzene	0.175	171	0.117	171
Toluene	--	7.31	--	7.3
Ethylbenzene	--	24.4	--	24.4
Total Xylenes	5.25	51.9	3.06	60.2

The results show that dermal contact with the highly contaminated groundwater and/or soils that occur in the tar tank/gasholder area would be the main exposure pathway for on-site construction/maintenance workers at the Former Gasworks site. The risk posed by the ingestion of surface soils is secondary. These results also indicate that the ingestion of contaminated dusts would also be a secondary exposure pathway.

Health Risks from PAHs

The health risk posed by PAHs has been assessed by expressing all forms of PAH exposure in terms of BaP, since most health data is available for this compound, as indicated in **Section 12.1**. The first step in the process has been to convert the total PAH contaminant intake into an equivalent BaP intake. This has been done by breaking the total PAH intake into individual PAH compounds using the breakdown of PAH compounds given in the statistical analysis of fill materials at the Former Gasworks site given in **Table C**. The toxicity equivalence factors given in

Table 30 were then applied to obtain an equivalent BaP concentration. The results of this analysis are presented in **Table 34**.

▪ Table 34 Conversion of Total PAH to Equivalent BaP Concentration

PAH Compound	Proportion of 95% UCL Total PAH Concentration	Toxicity Equivalence Factor	Equivalent BaP Proportion
Naphthalene	0.235	0.01	2.353E-03
Acenaphthylene	0.029	0.001	2.926E-05
Acenaphthene	0.010	0.001	1.003E-05
Fluorene	0.031	0.001	3.119E-05
Phenanthrene	0.128	0.001	1.276E-04
Anthracene	0.036	0.001	3.631E-05
Fluoranthene	0.105	0.01	1.051E-03
Pyrene	0.116	0.001	1.157E-04
Benzo(a)anthracene	0.077	0.1	7.680E-03
Chrysene	0.039	0.1	3.898E-03
Benzo(b,k)fluoranthene	0.080	0.1	8.004E-03
Benzo(a)pyrene	0.061	1	6.109E-02
Indeno(123-cd)pyrene	0.029	0.1	2.864E-03
Dibenz(ah)anthracene	0.005	4	1.921E-02
Benzo(ghi)perylene	0.019	0.1	1.924E-03
Total PAHs	1.000		1.084E-01

The results in **Table 34** predict that the level of total PAH contamination in the fill at the Former Gasworks site can be converted into an equivalent BaP by multiplying the total PAH concentration by a factor of 0.108. Such a factor could also be applied to contaminant intakes. Using this approach, a total PAH intake of 210 μg is equivalent to an intake of BaP 22.7 μg, which is some 4 times higher than if only the BaP intake of 5.5 μg was used.

The dermal intake of 448μg/day of naphthalene has also been converted into an equivalent BaP intake by applying the toxicity equivalence factor of 0.001, which gives an additional BaP intake of 0.448μg/day.

Combining the ingestion and dermal intakes for total PAHs, naphthalene and BaP gives a total equivalent BaP intake of 36μg per day for an on-site construction/maintenance worker at the Former Gasworks site. This daily intake of BaP is some 4 times greater than the guidance dose of 9.5μg per day recommended by Fitzgerald (1998), as previously discussed in **Section 12.1**. The hazard quotient for exposure to PAHs is greater than 1, which indicates an unacceptable risk to human health if no special work procedures and personal protective equipment (PPE) were used by construction/maintenance workers at the Former Gasworks site.

Health Risks from TPHs

The data provided in **Table 33** estimates that the total amount of TPH intake for a construction/ maintenance worker at the Former Gasworks site from both ingestion of contaminated soil and dermal contact with contaminated groundwater and soil is 4252 μg per day.

The health risks posed by this TPH intake has been assessed using a Reference Dose of 0.03mg/kg body weight per day, which is the recommended Reference Dose for >C_{16}-C_{35} aromatic TPHs (**Table 32**). The aromatic value was used rather than the aliphatic one because the speciated TPH data obtained by this investigation has found that the majority of TPHs in the samples tested were aromatic, as previously discussed in **Section 9.2.** This Reference Dose for a 70kg adult gives an acceptable daily intake for TPH C_{10}-C_{36} of 2.1 mg/day or 2,100 μg/day (**Section 12.6**).

The results of the risk assessment show that for an on-site construction /maintenance worker at the site, the daily intake of 4252 μg of TPH C_{10}-C_{36} is approximately twice the acceptable daily intake of 2,100 μg. The hazard quotient for exposure to TPH C_{10}-C_{36} is greater than 1, which indicates an unacceptable risk to human health if no special work procedures and PPE were used by construction/maintenance workers at the Former Gasworks site.

Health Risks from Benzene

The data provided in **Table 33** estimates that the total amount of benzene intake for a construction/ maintenance worker at the Former Gasworks site from both ingestion of contaminated soil and dermal contact with contaminated groundwater and soil is 171 μg per day.

The health risks posed by this benzene intake has been assessed using an oral (ingestion) Reference Dose of 0.003mg/kg body weight per day, as stated in **Section 12.2**. This Reference Dose for a 70kg adult gives an acceptable daily intake for benzene of 0.21mg/day or 210μg/day.

The results of the risk assessment show that for an on-site construction /maintenance worker at the site, the daily intake of 171 μg of benzene is slightly less than the acceptable daily intake of 210 μg. The hazard quotient for exposure to benzene is 0.81, which is less than 1 and indicates that potential exposure to benzene at the Former Gasworks site is within acceptable limits if benzene was the only contaminant at the site.

Health Risks from Toluene

The data provided in **Table 33** estimates that the total amount of toluene intake for a construction/ maintenance worker at the Former Gasworks site from dermal contact with contaminated groundwater is 7.3 μg per day, while no significant intake would occur from the ingestion or dermal contact with contaminated soil.

The health risks posed by this toluene intake has been assessed using an oral (ingestion) Reference Dose of 0.20mg/kg body weight per day, as stated in **Section 12.3**. This Reference Dose for a 70kg adult gives an acceptable daily intake for toluene of 14.0mg/day or 14,000μg/day.

The results of the risk assessment show that for an on-site construction /maintenance worker at the site, the daily intake of 7.3 μg of toluene is much less than the acceptable daily intake of 14,000 μg. The hazard quotient for exposure to toluene is 5.2E-04.

Health Risks from Ethylbenzene

The data provided in **Table 33** estimates that the total amount of ethylbenzene intake for a construction/ maintenance worker at the Former Gasworks site from dermal contact with contaminated groundwater is 24.4 μg per day, while no significant intake would occur from the ingestion or dermal contact with contaminated soil.

The health risks posed by this ethylbenzene intake has been assessed using an oral (ingestion) Reference Dose of 0.10mg/kg body weight per day, as stated in **Section 12.4**. This Reference Dose for a 70kg adult gives an acceptable daily intake for ethylbenzene of 7.0 mg/day or 7,000 μg/day.

The results of the risk assessment show that for an on-site construction /maintenance worker at the site, the daily intake of 24.4 μg of ethylbenzene much less than the acceptable daily intake of 7,000 μg. The hazard quotient for exposure to ethylbenzene is 1.0E-03.

Health Risks from Xylenes

The data provided in **Table 33** estimates that the total amount of xylene intake for a construction/ maintenance worker at the Former Gasworks site from both ingestion of contaminated soil and dermal contact with contaminated groundwater and soil is 60.2 μg per day.

The health risks posed by this xylene intake have been assessed using an oral (ingestion) Reference Dose of 0.7mg/kg body weight per day, as stated in **Section 12.5**. This Reference Dose for a 70kg adult gives an acceptable daily intake for xylenes of 49 mg/day or 49,000μg/day.

The results of the risk assessment show that for an on-site construction /maintenance worker at the site, the daily intake of 60.2 μg of xylenes is much less than the acceptable daily intake of 49,000μg. The hazard quotient for exposure to xylenes is 1.2E-03.

Total Health Risk to Construction/Maintenance Workers

The total risk to on-site construction/maintenance workers from ground contamination at the Former Gasworks site has been estimated by the summation of the hazard quotients for the main contaminants of concern. These contaminants and their individual hazard quotients are presented in **Table 35**.

- **Table 35 Hazard Quotients for On-site Construction Workers at Former Gasworks Site**

Substance	Total Daily Intake (µg/day)	Reference Dose (µg/day)	Hazard Quotient
Total PAHs (as equivalent BaP)	36	9.5	3.79
TPH C_{10}-C_{36}	4252	2,100	2.02
Benzene	171	210	0.81
Toluene	7.3	14,000	5.2E-04
Ethylbenzene	24.4	7,000	3.5E-03
Total Xylenes	60.2	49,000	1.2E-03
		TOTAL	**6.6**

The results indicate that on-site construction/maintenance workers at the Former Gasworks site have the potential to being exposed to a high risk of health impacts from ground contamination if working in an unremediated environment with no personal protective equipment (PPE) or special work procedures. The main health risks are posed by workers exposed to PAHs and petroleum hydrocarbon contamination, which occurs both in the shallow soils and groundwater.

In order to mitigate these risks, it will be necessary for work procedures to be adopted by on-site construction/maintenance workers at the Former Gasworks site that will minimise/avoid:

- Dermal contact with contaminated groundwater;
- Physical contact with the surface soils;
- Dust generation; and
- Require high levels of hygiene and decontamination.

A program of environmental monitoring should also be undertaken when any construction work or significant maintenance work is undertaken at the Former Gasworks site. Alternatively, consideration should be given to capping the contaminated soils with a clean-soil cover or pavement.

13.2 Risks to Long-Term Site Workers

The results of the data and exposure assessment presented in **Section 11.2** indicate that the health risks to long-term Site Workers from contamination at the Former Gasworks site are low for the exposure pathways involving:

- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated soils in the unsaturated zone above the shallow aquifer (**Section 11.3.3**);
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated groundwater in the shallow aquifer(**Section 11.3.3**); and
- Ingestion or have dermal contact with contaminated groundwater (**Section 11.2**).

The results of the data and exposure assessment (**Section 11.3.4**) indicate that the main health risks to long-term Site Workers from ground contamination at the Former Gasworks site are associated with exposure to contaminated surface soils. The contaminants of concern are total PAHs, BaP, TPH (C_{10}-C_{36}), benzene and total xylenes.

The human health risks associated with each of these exposure scenarios have been estimated using the estimates of contaminant intakes given in **Section 11.4.6** together with the toxicological data provided in **Section 12**. The daily doses in mg/kg body weight per day have been converted into daily intake amounts in mg using a body weight of 70kg, as recommended in the NEPM (1999) Schedule B(4) guidelines.

The main exposure routes are considered to comprise:

- Ingestion of contaminants in surface soils; and
- Dermal contact with contaminants in surface soils.

A summary of the estimated contaminant intakes to a long-term Site Worker for the contaminants of concern are summarised in **Table 36**.

Table 36 Daily Contaminant Intakes by Long-Term Site Workers

Substance	Daily Contaminant Intake (µg)		Total Daily Intake (µg)
	Ingestion of Surface Soil	Dermal Contact with Surface Soil	
Total PAHs	14.7	111	126
Benzo(a)pyrene	0.975	7.39	8.37
Naphthalene	--	--	--
TPH C_{10}-C_{36}	200	1168	1368
Benzene	0.020	0.117	0.137
Toluene	--	--	--
Ethylbenzene	--	--	--
Total Xylenes	0.525	3.06	3.59

The results show that dermal contact with the highly contaminated soils that occur in the tar tank/gasholder area would be the main exposure pathway for long-term Site Workers.

Health Risks from PAHs

The health risk posed by PAHs has been assessed by expressing all forms of PAH exposure in terms of BaP using the same approach as described in **Section 13.1**. The results in **Table 34** predict that the level of total PAH contamination in the fill at the Former Gasworks site can be converted into an equivalent BaP by multiplying the total PAH concentration by a factor of 0.108. Such a factor could also be applied to contaminant intakes. Using this approach, a total PAH intake of 126 µg is equivalent to a BaP intake of 13.6 µg, which is nearly double the concentration if only the BaP intake of 8.37 µg was used.

Combining the ingestion and dermal intakes for total PAHs and BaP gives a total equivalent BaP intake of 22.0 µg per day for a long-term Site Worker at the Former Gasworks site. This daily intake of BaP is 2.3 times the guidance dose of 9.5 µg per day recommended by Fitzgerald (1998), as previously discussed in **Section 12.1**. The hazard quotient for exposure to PAHs is greater than 1, which indicates an unacceptable risk to human health if no remedial works were to be undertaken at the Former Gasworks site.

Health Risks from TPHs

The data provided in **Table 36** estimate that the total amount of TPH intake for a long-term Site Worker at the Former Gasworks site from both ingestion and dermal contact with contaminated soil is 1,368µg per day. This level of TPH C_{10}-C_{36} intake is less than the acceptable daily intake of 2,100 µg. The hazard quotient for exposure to TPH C_{10}-C_{36} is 0.65, which is less than 1 and indicates that potential exposure to TPHs at the Former Gasworks site is within acceptable limits if C_{10}-C_{36} was the only contaminant at the site.

Health Risks from Benzene

The data provided in **Table 36** estimate that the total amount of benzene intake for a long –term Site Worker at the Former Gasworks site from both ingestion and dermal contact with contaminated soil is 0.137 µg per day. This level of benzene intake is much less than the acceptable daily intake of 210 µg, with the hazard quotient being 6.5E-04.

Health Risks from Xylenes

The data provided in **Table 36** estimate that the total amount of xylene intake for a long-term Site Worker at the Former Gasworks site from both ingestion and dermal contact with contaminated soil is 3.59 µg per day. This level of xylene intake is much less than the acceptable daily intake of 49,000 µg, with the hazard quotient being 7.3E-05.

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Total Health Risk to Long-Term Site Workers

The total risk to long-term Site Workers from ground contamination at the Former Gasworks site has been estimated by the summation of the hazard quotients for the main contaminants of concern. These contaminants and their individual hazard quotients are presented in **Table 37**.

- Table 37 Hazard Quotients for Long-Term Site Workers at Former Gasworks Site

Substance	Total Daily Intake (µg/day)	Reference Dose (µg/day)	Hazard Quotient
Total PAHs (as equivalent BaP)	22.0	9.5	2.3
TPH C_{10}-C_{36}	1368	2,100	0.65
Benzene	0.137	210	6.5E-04
Toluene	--	14,000	--
Ethylbenzene	--	7,000	--
Total Xylenes	3.59	49,000	7.3E-05
		TOTAL	**2.95**

The results indicate that long-term Site Workers at the Former Gasworks site could be exposed to an unacceptable health risk from ground contamination if working in an unremediated environment with no personal protective equipment (PPE) or special work procedures. The main health risks are posed by workers exposed to high concentration of PAHs and TPH C_{10}-C_{36} that have been detected in fill materials in the tar tank/gasholder area on the Former Gasworks site.

In order to mitigate these risks, it will be necessary for work procedures to be adopted by long-term Site Workers at the Former Gasworks site that will minimise/avoid:

- Physical contact with the surface soils;
- Dust generation; and
- Require high levels of hygiene and decontamination.

Alternatively, consideration should be given to capping the contaminated soils with a clean-soil cover or pavement.

13.3 Risks to Nearby Residents and Off-site Construction Workers

The exposure pathway assessment (**Section 11.2**) concluded that the feasible exposure pathways for nearby residents at properties surrounding the Former Gasworks site are:

- Ingestion and dermal contact with contaminated near-surface soils at the Former Gasworks site;

- Ingestion and dermal contact with contaminated groundwater;
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated soils in the unsaturated zone above the shallow aquifer; and
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated groundwater in the shallow aquifer.

The risk assessment concluded (**Section 11.2**) that nearby residents would face a low risk from ingestion and dermal contact with contaminated near-surface soils at the Former Gasworks site because:

- It is understood that RailCorp has removed contaminated soils from the properties adjacent to the western site boundary under a remediation program completed in 2005; and
- Access to the Former Gasworks site is restricted to authorised personnel, who would largely be on-site workers.

A long-term SMP will also need to be placed on the Former gasworks site in order to ensure that the risk to the surrounding residential community from on-site soil contamination remains low. Restrictions that would need to be part of an SMP include the erection and maintenance of security fencing and controlling site access. These recommendations are included in **Section 14.2** of this report.

The risk assessment concluded (**Sections 11.3.1 & 11.3.2**) that nearby residents would face a low risk from ingestion and dermal contact with contaminated groundwater because:

- It is unlikely that licensed groundwater extraction would occur at either the Former Gasworks site or a nearby off-site area;
- Contaminated groundwater at the Former Gasworks site flows in a south to south-easterly direction away from the adjacent residential properties to the west of the site. Monitoring programs also confirm that there is no evidence of groundwater contamination having migrated from the Former Gasworks site into adjacent residential properties or off railway-owned land to the south of the site; and
- There would be minimal leakage through a tanked basement wall or other type of underground structure if constructed below the water table. Calculations indicate that the amount of groundwater seepage that would occur through typical cracks in a tanked structure would correspond to 1 to 2% of the total amount of groundwater that currently flows through a residential property, which is considered to be negligible and not cause contaminated groundwater to migrate towards residential properties.

The risk assessment concluded (**Section 11.3.3**) that nearby residents would face a low risk from the inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by

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contaminated soils or groundwater at the Former Gasworks site. The results of computer modelling predicted that indoor air quality in basements on residential properties would be well below the US EPA PRGs by a factor of 10^2 to 10^7 times. Since the predicted indoor air concentrations are well below the occupational exposure standards, the risks posed by the volatilisation and vapour transport to residents on adjacent properties are considered to meet current regulatory requirements. The predicted impacts to outdoor air quality would be even lower.

However, the site-specific risk assessment (**Section 11.3.2**) did identify an exposure pathway involving construction workers at a residential property subjected to dermal exposure to groundwater when working on a deep excavation. This exposure scenario would arise through the digging of a deep excavation that needs to be temporarily dewatered during the construction period.

In this exposure scenario, the risk assessment has conservatively assumed that the deep excavations would remain open for a relatively long period of time sufficient to cause the temporary migration of contaminated groundwater from the Former Gasworks site onto the residential property. The estimated contaminant intakes to an on-site construction worker from dermal contact with groundwater have used the average groundwater concentrations measured at the Former Gasworks site in order to account for the attenuation that would occur if groundwater from the Former gasworks site was drawn towards a residential property. The daily contaminant intakes for such a construction worker in dermal contact with groundwater are presented in **Table 26B**. Using these daily intakes, the risks posed to an off-site construction worker are presented in **Table 38**.

- **Table 38 Hazard Quotients for Off-site Construction Worker**

Substance	Total Daily Intake (µg/day)	Reference Dose (µg/day)	Hazard Quotient
Total PAHs (as equivalent BaP)	0.0422	9.5	4.44E-03
TPH C_{10}-C_{36}	262	2,100	0.125
Benzene	17.2	210	0.0819
Toluene	0.862	14,000	6.16E-05
Ethylbenzene	3.36	7,000	4.80E-04
Total Xylenes	8.30	49,000	1.69E-04
		TOTAL	**0.212**

The results indicate that off-site construction workers should face a low risk from working in deep excavations at nearby residential sites and that no restrictions should be required to manage construction works at these properties.

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13.4 Risks to Freshwater Ecosystems

The results of the data and exposure assessment presented in **Section 11.2** indicate that the main health risks to the nearest freshwater aquatic receptor (Alexandra Canal) from ground contamination at the Former Gasworks site would be associated with the extraction and discharging of contaminated groundwater to the stormwater system that would in turn be discharged into the headwaters of Alexandra Canal.

The risk assessment concluded (**Sections 11.3.1 & 11.3.2**) that the freshwater aquatic ecosystem at the headwaters of Alexandra Canal would face a low risk from contaminated groundwater present at the Former Gasworks site because:

- Contaminated groundwater at the Former Gasworks site flows in a south to south-easterly direction away from the adjacent residential properties to the west of the site. Monitoring programs also confirm that there is no evidence of groundwater contamination having migrated from the Former Gasworks site into adjacent residential properties or off railway-owned land to the south of the site; and
- There would be minimal leakage through a tanked basement wall or other type of underground structure if constructed below the water table. Calculations indicate that the amount of groundwater seepage that would occur through typical cracks in a tanked structure would correspond to 1 to 2% of the total amount of groundwater that currently flows through a residential property, which is considered to be negligible and not cause contaminated groundwater to migrate towards residential properties.

This conclusion is dependent on the requirement for groundwater to be retained and managed on-site if it was to be intercepted during construction work at the Former Gasworks site. A long-term SMP will need to be placed on the Former Gasworks site in order to ensure that any intercepted groundwater is retained and managed on-site. These recommendations are included in **Section 14.2** of this report.

13.5 Phytotoxic Impacts to Future Landscaping at the Site

The Former Gasworks site is to continue to be used as a commercial/industrial site, although it is not known what site activities will occur or if any structures/ buildings will be established on the site. While the NSW EPA (1999) Site Auditor Guidelines consider that ecological receptors need not be considered at a commercial/industrial site, there may be a need as part of this development to include landscaped areas. This section of the report provides an assessment of the potential phytotoxic effects of contaminants due to ground contamination that exists at the site.

The statistical analysis of the fill layer that is presented in **Table C** shows that some of the 95% UCL average values marginally exceed the Ecological Investigation Levels (EILs) given in the NEPC (1999d) guidelines. These contaminants and their exceedances are:

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- Arsenic 95% UCL = 29mg/kg (EIL = 20mg/kg);
- Copper 95% UCL = 106mg/kg (EIL = 100mg/kg);
- Zinc 95% UCL = 267 mg/kg (EIL = 200mg/kg).

These exceedances indicate there is a minor risk that some heavy metal contaminants may affect the health of plants that are grown at the Former Gasworks site in the fill soils. To address these risks it is recommended that:

- Landscaping areas be formed in areas where there is a 1-2m thick layer of clean soil that is conditioned to be suitable for plant growth; and/or
- Native plants should be used at the site having a tolerance of elevated heavy metal concentrations.

These recommendations should be included in a long-term SMP that will need to be placed on the Former Gasworks site. This recommendation is included in **Section 14.2** of this report.

13.6 Aesthetic Assessment

As previously indicated in **Section 8.4**, the aesthetic criteria of most relevance to the Former Gasworks site in its present condition are considered to be:

- No malodorous materials exposed at ground surface;
- No malodorous gases emanating from the ground; and,
- No floating product to remain on groundwater or surface waters at the Site.

Inspections of the Former Gasworks site undertaken by SKM during the investigation found no physical evidence at the ground surface of:

- Visible signs of contamination;
- Visible signs of plant distress to vegetation;
- Odours; or
- Waste materials, although scrap metal from rail operations was observed at several locations across the site.

However, it is likely that some areas of the Site not examined by the investigation may contain localised areas of odorous or stained material.

Aesthetically unacceptable materials are known to occur below the ground surface. These materials include:

- Highly odorous soils and waste materials, particularly in the area of the former tar tanks, retorts and gasholders;

- Industrial waste in the form of ash, slag, coke;
- Demolition rubble; and
- Phase separated hydrocarbons present in the shallow and deep aquifers.

This study considers there is a low risk of aesthetic issues affecting the future use of the Former Gasworks site provided the site continues to remain commercial/industrial land and any site works are undertaken in a manner that properly manages the aesthetic impacts associated with subsurface materials at the site.

A long-term SMP will need to be placed on the Former Gasworks site in order to ensure that any future works are undertaken in a manner that properly manages the aesthetic impacts associated with subsurface materials at the site. This recommendation is included in **Section 14.2** of this report.

13.7 Need for Remedial Works

This site-specific health risk assessment has concluded that contamination at the Former Gasworks site would present a low health risk to nearby residents, off-site construction workers undertaking work at nearby residential properties and the freshwater aquatic ecosystem at the headwaters of Alexandra Canal.

However, the site-specific health risk assessment has concluded that contamination at the former Gasworks site would present an unacceptable health risk to long-term site workers and construction/maintenance workers undertaking work at the site. The main causes of the elevated health risks are from exposure to contaminated surface soils together with exposure to contaminated groundwater for the case of a construction/maintenance worker working in wet conditions at the site. These risks could be reduced to acceptable levels if a program of remedial works were carried out at the site. Alternatively, access to the Former Gasworks site should continue to be restricted.

The program of on-site remedial work should at a minimum involve the capping or removal of contaminants in the upper 0.5m of soil across the site. Consideration should also be given to the removal of ongoing sources of groundwater contamination such as in the suspected area of the former tar tanks and sludge in the gasholder base. A long-term SMP should also be prepared and used to manage activities at the site in order to ensure the risks posed by contamination are properly managed. The issues that the SMP should address include among other things:

- A prohibition on the extraction and reuse of groundwater at the Former Gasworks site and a prohibition on the construction of drained basements or deep pits that intersected the groundwater table (**Section 11.2**). These restrictions are required to ensure that the risk to long-term site workers from ingestion or dermal contact with contaminated groundwater remains low;

- The requirement for an occupational health and safety plan to be prepared and implemented for any earthworks conducted at the Former Gasworks site (**Section 11.2**). This requirement is needed in order to ensure on-site construction/maintenance workers and long-term site workers are not subjected to volatile soil gas vapours and dust levels that exceed OH&S standards;
- The erection and maintenance of security fencing and controlling site access to ensure that the risk to the surrounding residential community from on-site soil contamination remains low (**Sections 11.2 & 13.3**). This requirement may not be required if remedial works are conducted at the Former Gasworks site;
- Any groundwater intercepted by on-site construction works would need to be managed within the Former Gasworks site (**Sections 11.3.2, 13.1 & 13.4**). This requirement is needed to protect freshwater ecosystems in the headwaters of Alexandra Canal;
- Landscaping areas should only be formed in areas where there is a 1-2m thick layer of clean soil that is conditioned to be suitable for plant growth (**Section 13.5**);
- Native plants should be used at the site having a tolerance of elevated heavy metal concentrations (**Section 13.5**); and
- Any future works at the Former Gasworks site should be undertaken in a manner that properly manages the aesthetic impacts associated with subsurface materials at the site (**Section 13.6**).

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14 Conclusions and Recommendations

14.1 Conclusions

This site-specific risk assessment has identified the potential issues that should be addressed with respect to contamination at the Former Gasworks site. Ground contamination that is present at the neighbouring former stabling area has been addressed in a separate risk assessment prepared by SKM.

Soil Contamination

The site-specific risk assessment involved the assessment of soil contamination data provided by previous investigations together with some additional data that targeted data gaps. The study has found that the fill layer is mainly contaminated with high levels of PAHs and TPH C10-C36 distributed over much of the site. In the fill layer, hot-spots were found to be contaminated by benzene and xylenes in addition to PAHs and TPH C10-C36. Contamination in the fill layer was found to be highest in samples located near to the former tar tanks/gasholders, retorts/gas converter and the gas scrubbers.

The study found that the natural soils generally have lower levels of contamination compared to the fill layer and fewer hot-spots. Contamination in the natural soils was also found to be highest in samples located near to the former tar tanks/gasholders, retorts/gas convertor and the gas scrubbers.

Soil-Gas

The site-specific risk assessment involved the collection of field measurements of soil-gas vapour and computer analyses involving US EPA vapour transport models. Comparison of the results from the computer analysis and the field measurements showed that highly variable field results are to be expected given the highly variable volatile concentrations that have been measured in the shallow groundwater and unsaturated soils at the Former Gasworks site. The low soil gas levels measured in wells MW30-MW34 in March 2005 are consistent with the low groundwater concentrations that were measured in the last monitoring undertaken also in March 2005 and the low soil concentrations that have been measured in the plume area.

However, the computer analysis shows that much higher soil gas vapours may be present at the site than were measured by the investigation. This is because the results of the computer analyses show that much higher soil gas levels may occur if the higher volatile concentrations measured in the earlier groundwater monitoring rounds and/or higher soil concentrations measured in some shallow soil samples are more representative of site conditions. Due to this high degree of variability, there is potential for elevated levels of soil gas vapours to be emitted from the ground surface of the site and the exposure pathway from volatile soil vapours needed to be included in this risk assessment.

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The analysis also showed that the primary source of BTEX in the soil vapour at the volatile plume area is likely to be from the shallow groundwater, since no significant BTEX levels have been measured in the shallow soils. On the other hand, the analyses showed that the primary source of the six target PAHs in the soil vapour at the volatile plume area is likely to be from the unsaturated shallow soils, due to the relatively higher PAH concentrations in these soils compared to the shallow groundwater.

Groundwater Contamination

The site-specific risk assessment involved the collection of a third round of groundwater monitoring data, which was combined with the data obtained by previous investigations. The study has found that high levels of light-end petroleum hydrocarbons (TPH C_6-C_9 and BTEX) and light-end PAHs (naphthalene, acenaphthalene, fluorene, pyrene) are present in the groundwater at locations close to the former gasworks, in the vicinity of the former gasholders and location of possible tar tanks. Although high concentrations of low-end hydrocarbon contamination were recorded during previous investigations at the Former Gasworks site, minimal middle to high-end contamination was detected by the additional investigation conducted by SKM. Heavy metal contamination at the Former Gasworks site is widespread with concentrations elevated above ANZECC (2000) trigger values for 95% level of protection for freshwater aquatic ecosystems. The highest concentrations were recorded at locations near to the former gas production process areas.

Site Contamination Model

The main contaminants of concern for a site-specific risk assessment at the Former Gasworks site are PAH compounds (particularly naphthalene and benzo(a)pyrene), benzene, ethylbenzene, xylenes and the heavy metals cadmium, copper, lead, nickel and zinc. The environmental media of concern are the fill layer, the underlying natural soils, groundwater and soil gas.

The conceptual site contamination model identified the potential receptors of ground contamination from the Former Gasworks site to be:

- Future long-term commercial/industrial users of the Former gasworks site (RailCorp workers);
- Future maintenance / construction workers at the Former Gasworks site and surrounding areas;
- The community who live in residential land adjacent to the western boundary of the site, off-site construction workers and users of any groundwater extracted from wells down-gradient of the site; and
- Freshwater aquatic ecosystems in the headwaters of Alexandra Canal.

The main exposure pathways for future long-term site workers at the Former Gasworks site are considered to be:

- Ingestion and dermal contact with contaminated surface soils;

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- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated soils in the unsaturated zone above the shallow aquifer; and
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated groundwater in the shallow aquifer.

The main exposure pathways for construction workers at the Former Gasworks site are considered to be the same as those for long-term site workers plus the ingestion and dermal contact with contaminated groundwater. This additional exposure pathway has been included because of the potential for excavations to extend deeper than 1.5m and past the shallow aquifer water table. Construction workers at the site may also be subjected to volatile soil gas vapours and inhalation of dusts, particularly when excavating in highly contaminated areas such as near areas that contained tar pits, retorts and gasholders. However, the site-specific risk assessment did not include these exposure pathways since these health risks should be managed as part of an occupational health and safety plan covering any earthworks conducted at the Former Gasworks site.

The main exposure pathways for residents and off-site construction workers at properties surrounding the Former Gasworks site are considered to be:

- Ingestion and dermal contact with contaminated groundwater;
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated soils in the unsaturated zone above the shallow aquifer; and
- Inhalation of vapours emitted into the outdoor air and indoor air (within buildings) generated by contaminated groundwater in the shallow aquifer.

The main exposure pathways for the freshwater ecosystems in the headwaters of Alexandra Canal are considered to be the extraction and discharging of contaminated groundwater to the stormwater system that would be discharged into the headwaters of Alexandra Canal.

Health Risks to On-site Construction Maintenance Workers

The site-specific risk assessment found that there is potential for on-site construction/maintenance workers at the Former Gasworks site to be exposed to a high risk of health impacts from ground contamination if working in an unremediated environment with no personal protective equipment (PPE) or special work procedures. The hazard quotient was calculated to be 6.6, which exceeds the acceptance criteria of 1. The main health risks are posed by workers exposed to PAHs and petroleum hydrocarbon contamination, which occurs both in the shallow soils and groundwater.

In order to mitigate these risks, it will be necessary for work procedures to be adopted by on-site construction/maintenance workers at the Former Gasworks site that will minimise/avoid:

- Dermal contact with contaminated groundwater;
- Physical contact with the surface soils;

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- Dust generation; and
- Require high levels of hygiene and decontamination.

A program of environmental monitoring should also be undertaken when any construction work or significant maintenance work is undertaken at the Former Gasworks site. Alternatively, consideration should be given to capping the contaminated soils with a clean-soil cover or pavement.

Health Risks to Long-Term Site Workers

The site-specific risk assessment found that there is potential for long-term site workers at the Former Gasworks to be exposed to an unacceptable health risk from ground contamination if working in an unremediated environment with no personal protective equipment (PPE) or special work procedures. The hazard quotient was calculated to be 2.95, which exceeds the acceptance criteria of 1. The main health risks are posed by long-term site workers exposed to high concentration of PAHs and TPH C_{10}-C_{36} that have been detected in fill materials in the tar tank/gasholder area on the Former Gasworks site.

In order to mitigate these risks, it will be necessary for work procedures to be adopted by long-term Site Workers at the Former Gasworks site that will minimise/avoid:

- Physical contact with the surface soils;
- Dust generation; and
- Require high levels of hygiene and decontamination.

Alternatively, consideration should be given to capping the contaminated soils with a clean-soil cover or pavement.

Health Risks to Nearby Residents and Off-site Construction Workers

The site-specific risk assessment found that nearby residents would face a low risk from contamination present at the Former Gasworks site provided:

- Access to the Former Gasworks site is restricted to authorised personnel, who would largely be on-site workers; and
- Licensed groundwater extraction does not occur in the area;

The site-specific risk assessment found that off-site construction workers should face a low risk from working in deep excavations at nearby residential sites and that no restrictions should be required to manage construction works at these properties.

Phytotoxic Impacts to Future Landscaping at the Site

The investigation found there is a risk that some heavy metal contaminants may affect the health of plants that are grown at the Former Gasworks site in the fill soils. To address these risks it is recommended that:

- Landscaping areas be formed in areas where there is a 1-2m thick layer of clean soil that is conditioned to be suitable for plant growth; and/or
- Native plants be used at the site having a tolerance of elevated heavy metal concentrations.

These recommendations should be included in a long-term SMP that will need to be placed on the Former Gasworks site.

Aesthetic Assessment

This study considers there is a low risk of aesthetic issues affecting the future use of the Former Gasworks site provided the site continues to remain commercial/industrial land and any site works are undertaken in a manner that properly manages the aesthetic impacts associated with subsurface materials at the site. A long-term SMP will need to be placed on the Former Gasworks site in order to ensure that any future works are undertaken in a manner that properly manages the aesthetic impacts associated with subsurface materials at the site.

Need for Remedial Works

This site-specific health risk assessment has concluded that contamination at the Former Gasworks site would present an unacceptable health risk to long-term site workers and construction/ maintenance workers undertaking work at the site. The main causes of the elevated health risks are from exposure to contaminated surface soils together with exposure to contaminated groundwater for the case of a construction/maintenance worker working in wet conditions at the site. These risks could be reduced to acceptable levels if a program of remedial works were carried out at the site. Alternatively, access to the Former Gasworks site should continue to be restricted.

14.2 Recommendations

It is recommended that access to the Former Gasworks site should continue to be restricted if no redevelopment of the site is proposed in the near future. However, if the site is to be redeveloped and used for ongoing commercial/industrial land use, it is recommended that a program of on-site remedial work be undertaken.

The remedial work should at a minimum involve the capping or removal of contaminants in the upper 0.5m of soil across the site. Consideration should also be given to the removal of ongoing sources of groundwater contamination such as in the suspected area of the former tar tanks and sludge in the gasholder base. A long-term SMP should also be prepared and used to manage activities at the site in order to ensure the risks posed by contamination are properly managed. The issues that the SMP should address include among other things are:

- A prohibition on the extraction and reuse of groundwater at the Former Gasworks site and a prohibition on the construction of drained basements or deep pits that intersected the groundwater table. These restrictions are required to ensure that the risk to long-term site workers from ingestion or dermal contact with contaminated groundwater remains low;
- The requirement for an occupational health and safety plan to be prepared and implemented for any earthworks conducted at the Former Gasworks site. This requirement is needed in order to ensure on-site construction/maintenance workers and long-term site workers are not subjected to volatile soil gas vapours and dust levels that exceed OH&S standards;
- The erection and maintenance of security fencing and controlling site access to ensure that the risk to the surrounding residential community from on-site soil contamination remains low. This requirement may not be required if remedial works are conducted at the Former Gasworks site;
- Any groundwater intercepted by on-site construction works would need to be managed within the Former Gasworks site. This requirement is needed to protect freshwater ecosystems in the headwaters of Alexandra Canal;
- Landscaping areas should only be formed in areas where there is a 1-2m thick layer of clean soil that is conditioned to be suitable for plant growth;
- Native plants should be used at the site having a tolerance of elevated heavy metal concentrations; and
- Any future works at the Former Gasworks site should be undertaken in a manner that properly manages the aesthetic impacts associated with subsurface materials at the site.

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