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SA EPA South Eastern Edwardstown Assessment Area

SA Environment Protection Authority

12-Oct-2017

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# Stage 4 Detailed Site Investigation

## South Eastern Edwardstown Assessment Area

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South Eastern Edwardstown Assessment Area

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# Quality Information

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Reviewed by Mark Chapman

Revision History

| Rev | Revision Date | Details | Authorised | |
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| DRAFT | 7-Apr-2017 | Draft Report | Mark McFarlane Senior Environmental Scientist |  |
| FINAL | 04-May-2017 | Final Report | Mark McFarlane Senior Environmental Scientist |  |
| FINAL | 15-Jun-2017 | Final Report- Updated Table 4 in Appendix B | Mark McFarlane Senior Environmental Scientist |  |
| FINAL | 12-Oct-2017 | Amended text and figures to reflect corrected survey data for well MW24 | Mark McFarlane Senior Environmental Scientist |  |

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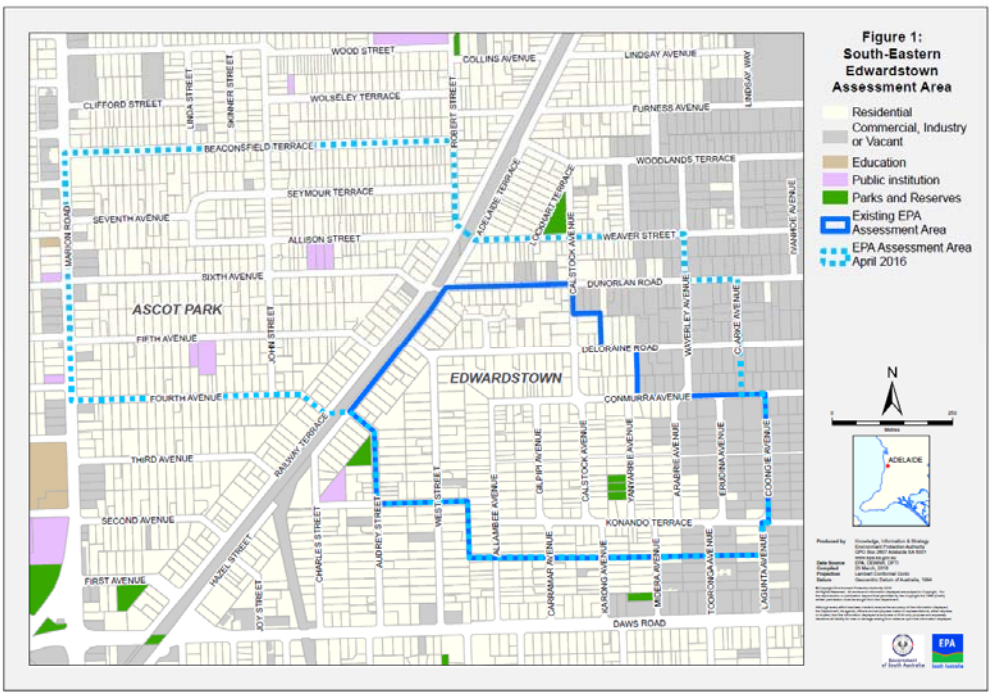
# Executive Summary

## Background

AECOM Australia Pty Ltd (AECOM) was commissioned by the South Australian Environment Protection Authority (EPA) to conduct Stage 4 Environmental Assessment works in the EPA's South Eastern Edwardstown (SEE) Assessment Area. The location of the Assessment Area is shown on the EPA figure reproduced below.




The Stage 4 investigations follow from the EPA's recent completion of a Stage 3 environmental assessment program within the SEE area, also conducted by AECOM.

Earlier stages of assessment work directed or commissioned by the EPA identified several sources of chlorinated hydrocarbon contamination:

- Two Focus Sites comprising commercial/industrial properties currently or previously used for electroplating activities, located on Erudina and Arabrie Avenues, Edwardstown, have been substantially characterised; and
- A separate source of chlorinated hydrocarbon contamination has been identified north of Conmurra Avenue, with impacts extending west.

The Stage 3 works conducted by AECOM between May 2016 and June 2016 focused mainly on an extended Assessment Area to the north-west as shown in the figure above, with 19 additional groundwater wells and 20 additional soil vapour bores installed as part of the works. The investigations resulted in better characterisation of the volatile halogenated aliphatic (VHA) impacts in both soil vapour and groundwater, and a refined assessment of potential source locations. However, based on the results of these additional investigations, it was apparent that soil vapour and groundwater VHA plumes are not yet fully delineated.

## Objectives and Scope

The objectives of the proposed Stage 4 DSI works were to:

- Delineate the VHA impacts in groundwater for the purpose of establishing a Groundwater Prohibition Area;

- Delineate the nature and extent of the soil vapour contamination in the Assessment Area;
- Determine and identify properties (sensitive land use) where the potential for vapour intrusion exists, using existing and new seasonal data; and
- Update the Human Health/Vapour Intrusion Risk Assessment (HH/VIRA) based on the new data set.

The Stage 4 DSI conducted by AECOM between January and March 2017 within the Assessment Area included:

- Expansion of the existing groundwater well monitoring network by a further 10 new wells;
- Conduct of a groundwater monitoring event encompassing 43 new and existing wells, with analysis targeting selected VHAs;
- Installation of 14 new soil vapour wells, and vapour sampling of a total of 74 new and existing soil vapour wells, with samples analysed for selected VHAs;
- Collection and analysis of soil samples for moisture content analysis and physical parameters to refine vapour intrusion modelling parameters; and
- Crawl space vapour sampling at five (5) residential properties.

## Findings

The groundwater investigations are assessed to have delineated the down-gradient extent of VHA impacts in the shallow aquifer to concentrations less than the adopted drinking water guideline (20 µg/L), other than to the south although TCE concentrations exceed laboratory limits of reporting in samples collected from most perimeter wells.

The source and up-gradient extent of the VHA plume in the northern portion of the Assessment Area is yet to be determined. Groundwater concentrations were generally consistent with those identified in the Stage 3 investigations.

While some VHA soil vapour concentrations were reported for Assessment Area perimeter bores, based on a comparison of vapour results to groundwater concentrations, it is considered that elevated soil vapour concentrations associated with the groundwater plumes are encompassed by the Assessment Area, other than to the east where the source and thus extent are unknown. Maximum measured soil vapour concentrations were consistent with those reported for the Stage 3 investigation.

Crawlspace vapour sampling was not indicative of VHA concentrations representing risk to human health for the selected residential properties along Arabrie Avenue, with all results less than guidelines.

Groundwater impacts and associated soil vapour impacts attributable to the Focus Sites are evidently present; however, it is apparent that a significant proportion of the VHA impacts across the Assessment Area are related to a separate source (or sources) potentially located within or adjacent the north-eastern portion of the Assessment Area. A cursory review of historical records indicates a number of sites within or immediately east of the Assessment Area with the potential to represent historical sources of VHA.

As for the Stage 3 investigation, soil geotechnical properties including soil bulk density, moisture content and particle density were measured to enable an assessment of the air-filled porosity as a key vapour modelling parameter. The results obtained again showed generally high water saturation (average > 90%) in the vadose zone soils, although a greater range of air-filled porosity than previously assessed, and this data was incorporated into updated vapour transport modelling to form the quantitative basis of the vapour intrusion risk assessment.

## Vapour Intrusion Risk Assessment

As a result of the notably higher air-filled porosity input value used, indoor air vapour concentrations modelled for the Stage 4 investigation from measured soil vapour concentrations based on field-measured parameters were an order of magnitude higher than estimated for the Stage 3 investigation; however, the modelling resulted in no predicted exceedances of the 2 µg/$m^3$ indoor air guideline for trichloroethene (TCE), the primary contaminant of concern.

Assessment of the potential for vapour intrusion into outdoor, shallow (1.5 m deep) excavations that might be entered (e.g. by workers maintaining underground services) found concentrations would be more than two orders of magnitude below commercial industrial guidelines and not considered to represent an unacceptable vapour inhalation risk.

It is noted that the vapour modelling is highly sensitive to the assumed soil moisture. A sensitivity analysis indicated that under severe and prolonged drying conditions, further investigation of potential vapour intrusion risk in residential areas overlying the central areas of the northern plume might be warranted, although it is highlighted that even the calculated indoor air concentrations would generally be within the EPA/SA Health Investigation levels, which are not considered to pose any immediate health concerns.

Consistent with the earlier risk assessment, the shallow depth to water and measured soil vapour concentrations mean that VHA impacts across a substantial portion of the investigation area might pose an unacceptable vapour intrusion risk were there to be basements present.

## Groundwater Fate and Transport Modelling

Saturated zone solute transport modelling has been undertaken using the US EPA model BIOCHLOR, which uses the Domenico analytical solute transport model to simulate one-dimensional advection, three-dimensional dispersion, linear adsorption and biotransformation (via dechlorination) as a sequential first-order decay process. The model was set up using site data, where available, and model calibration assessed by qualitatively comparing simulated groundwater TCE concentrations (as the primary COPC), along the plume centre-line with observed concentrations from the February 2017 data set.

Due to the limitations in the available data relating to potential source sites, particularly in the north of the Assessment Area, the 1D-model conservatively assumed ongoing plume migration based on a continuing source, with source concentrations inferred from observed well concentrations in the inferred down-gradient plume centreline.

Based on this preliminary modelling the following were predicted:

- In order to match the observed decline in concentration from the several hundred micrograms per litre in the middle and up-gradient areas of the plume to relatively low concentrations at the down-gradient extent of the investigation area, it was necessary to assume that the *plume is still expanding*. However, it is noted that the relatively large distances between groundwater wells in the Assessment Area and inferred source zone may mean that the current well network does not intersect the highest concentrations and this may affect modelling calibration and predictions.
- Concentrations in the vicinity of MW29 (near the current down-gradient extent of the Assessment Area) are predicted to rise from currently around 10 µg/L (2017) to greater than the drinking water guideline (20 µg/L) by 2020. It is noted that wells providing plume delineation have only been sampled once with a maximum of three data points available for wells within the Assessment Area monitoring network over an 18 month period.
- TCE would not be expected to have reached Bowaka Street, Park Holme (approximately 275 m west of the current extent of the Assessment Area) at the current time, however impacts are predicted to slowly migrate further west and approach the drinking water guideline at this distance in approximately 30 years' time.

## Data Gaps

While the Stage 4 investigations have progressed the understanding of the nature and extent of VHA impacts to the subsurface across the Assessment Area, the potential risks posed, and their likely fate and transport, there remain a number of data gaps pertinent to an appropriate level of understanding of these issues, inclusive of the data gaps identified in relation to the site conceptual model as noted previously:

- There is limited information as to the identity of potential source sites other than the Focus Sites. AECOM is not aware of any detailed study of historical site activities across the eastern portion of the Assessment Area or the area further to the east. While the existence of a number of former commercial/industrial operations that could represent historical sources of VHA impacts was identified by AECOM, a detailed review was outside the scope of this assessment.
- While not considered material to the broad understanding of groundwater flow beneath the site, the inferred groundwater contours exclude one well at which groundwater levels had evidently not stabilised. A refined assessment of standing water levels would be possible once sufficient time for stabilisation to have occurred.
- VHA impacts in groundwater remain undelineated (to below the adopted criteria) to the south of the current Assessment Area, both in the eastern portion and notably at MW31 (off Railway Terrace, installed with the aim of delineating groundwater impacts south-west of MW27). Groundwater impacts are also not delineated up-gradient (east) of the northern plume area, where it is apparent that further source(s) exist.
- TCE impacts have not been delineated to below laboratory limits of reporting in any direction, apart from the north-east.
- It has not yet been established whether there is a link between the groundwater impacts reported for MW21 and the impacts in the vicinity of the Focus Sites to the east, or indeed the up-gradient materially impacted well MW07. The apparent disconnect is due largely to the reported low TCE concentrations for wells MW8 and MW10. Further groundwater investigation up-gradient of MW21, inclusive of at least a further well between MW08 and MW10, should assist with understanding of the origin of the impacts at MW21.
- Other than sampling of one existing private well in Stage 3 (which identified VHA impact), there has been no investigation of potential VHA impacts to the deeper (Q2) aquifer. Interactions between the unconfined aquifer and deeper water bearing zones which may have been intersected for productive or drainage purposes historically or currently, have not been considered in this assessment.
- Soil vapour impacts are largely delineated within the Assessment Area, other than to the east (up-gradient) where further investigation would be required to identify the sources and delineate impacts, and to the north at the western extent of the plume, where further temporal data may provide additional understanding of the nature and origin of the observed impacts.
- Apparent increases in soil vapour in a number of vapour bores off Arabrie Avenue (H1 to H10) are based on sampling in 2015 and 2017 only. Further temporal data is required to assess trends in these and other vapour bores.
- The vapour intrusion risk assessment has identified the potential for greater indoor air concentrations, potentially exceeding SA EPA TCE Investigation criteria and into the Intervention range, in the event soils are subject to substantial drying. An ongoing assessment of soil conditions in areas of higher groundwater impact would be warranted, potentially inclusive of assessment of the soil moisture regime beneath concrete floor slabs (or equivalent sealed surfaces) in this area.

- The one-dimensional groundwater modelling undertaken indicated that the extent of the VHA plume is unlikely to currently be stable, with future concentrations in excess of drinking water guidelines predicted to extend beyond the current Assessment Area. It is noted that due to the absence of information regarding sources, the limited temporal data and relatively large distances between groundwater wells, particularly in the down-gradient, western area, uncertainties relating to the plume fate and transport are large and *limited confidence is placed in the predictions of the groundwater modelling*. Additional well installation targeting potential up-gradient sources, down-gradient extent beyond the current Assessment Area and infilling at key locations within the current Assessment Area and additional temporal data would aid in refining the model and improving confidence in model predictions.

# Acronyms

| | |
|---|---|
| 1,1-DCE | 1,1-Dichloroethene |
| 1,2-DCE | 1,2-Dichloroethene |
| ANZECC | Australia and New Zealand Environment and Conservation Council |
| ASC NEPM | National Environment Protection (Assessment of Site Contamination) Measure |
| ASTM | American Society for Testing and Materials |
| $CH_4$ | Methane |
| cis-1,2-DCE | cis-1,2-Dichloroethene |
| COC | Chain of Custody |
| COPC | Chemical of Potential Concern |
| $CO_2$ | Carbon Dioxide |
| CRC CARE | Cooperative Research Centre for Contamination Assessment and Remediation of the Environment |
| CSM | Conceptual Site Model |
| CSMoS | Center for Subsurface Modelling Support |
| DCE | Dichloroethene (total of three isomers) |
| DEWNR | Department of Environment, Water and Natural Resources |
| DSI | Detailed Site Investigation |
| DNAPL | Dense Non-Aqueous Phase Liquid |
| DO | Dissolved Oxygen |
| EC | Electrical Conductivity |
| EPA | Environment Protection Authority |
| EPP | Environment Protection Policy |
| GME | Groundwater Monitoring Event |
| HH/VIRA | Human Health/Vapour Intrusion Risk Assessment |
| HI | Hazard Index |
| HIL | Health Investigation Level |
| HSL | Health Screening Level |
| HQ | Hazard Quotient |
| HSEP | Health Safety and Environment Plan |
| HSL | Health Screening Level |
| ITRC | Interstate Technology and Regulatory Council |
| J&E | Johnson and Ettinger Vapour Model |
| LNAPL | Light Non-Aqueous Phase Liquid |
| LOR | Laboratory Limit of Reporting |
| m bgl | Metres Below Ground Level |
| m AHD | Metres Above Australian Height Datum |
| NAPL | Non-Aqueous Phase Liquid |
| NEPC | National Environmental Protection Council |
| NEPM | National Environmental Protection Measure |
| NHMRC | National Health and Medical Research Council. |
| OECD | Organisation for Economic Co-operation and Development |
| $O_2$ | Oxygen |
| PCE | Tetrachloroethene (also known as Perchloroethene or Perchloroethylene) |
| PID | Photo Ionisation Detector |

| | |
|---|---|
| ppm | Parts Per Million |
| QAQC | Quality Assurance/Quality Control |
| Redox | Reduction Potential |
| RfC | Reference Concentration |
| RfQ | Request for Quote |
| SEE | South Eastern Edwardstown |
| SWL | Standing Water Level |
| TCA | Trichloroethane |
| TCE | Trichloroethene (also known as Trichloroethylene) |
| TDS | Total Dissolved Solids |
| TPH | Total Petroleum Hydrocarbons |
| trans-1,2-DCE | trans-1,2- Dichloroethene |
| USCS | Unified Soil Classification System |
| US EPA | United States Environmental Protection Agency |
| VC | Vinyl Chloride |
| VHA | Volatile Halogenated Aliphatic |
| VME | Vapour Monitoring Event |
| VOC | Volatile Organic compound |
| WHO | World Health Organisation |

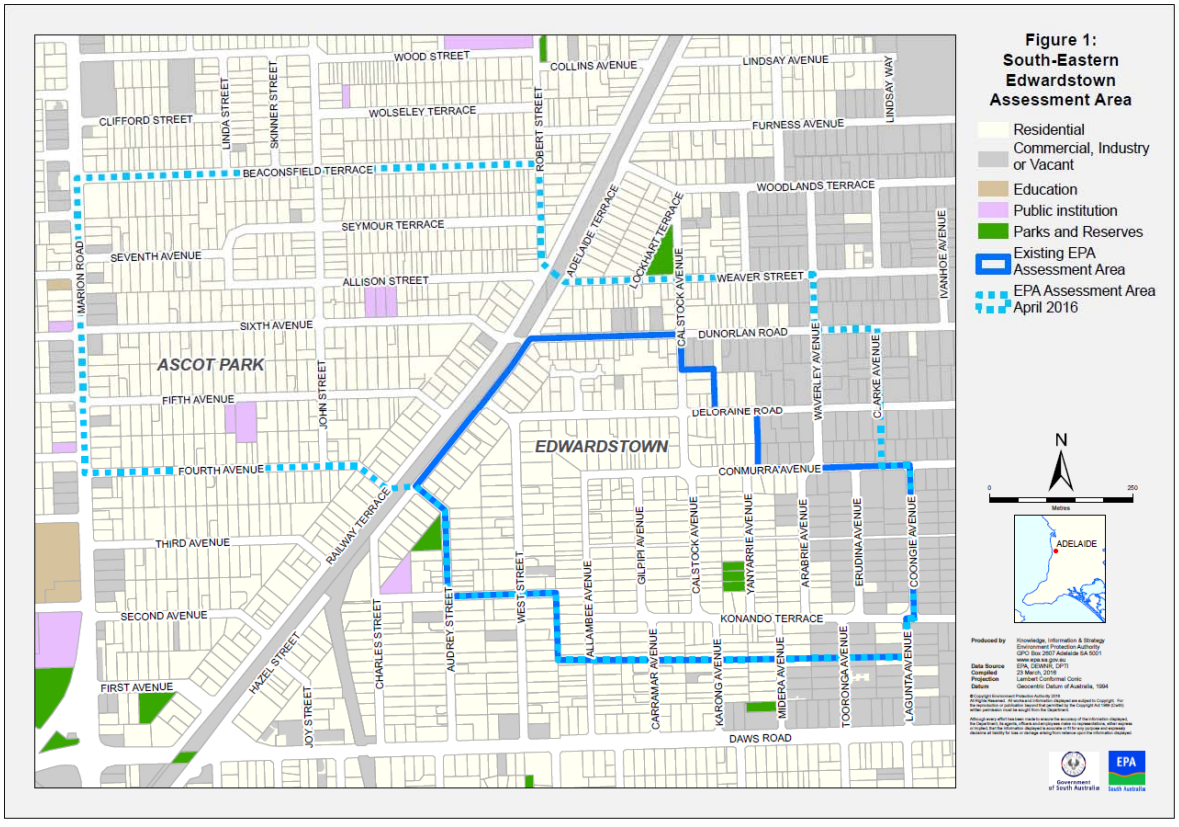
# 1.0 Introduction

## 1.1 Background

AECOM Australia Pty Ltd (AECOM) was commissioned by the South Australian Environment Protection Authority (EPA) to conduct Stage 4 Environmental Assessment works in the EPA's South Eastern Edwardstown (SEE) Assessment Area. AECOM's commission, in December 2016, was on the basis of AECOM's proposal dated 14 November 2016 in response to a Request for Quote (RFQ) issued by the EPA on 1 November 2016, reference 05/22616.

The location of the Assessment Area is shown on the EPA figure reproduced below.

**Figure 1-1 Assessment Area**

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- Two Focus Sites comprising commercial/industrial properties currently or previously used for electroplating activities, located on Erudina and Arabrie Avenues, Edwardstown, have been substantially characterised; and
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The Stage 3 works conducted by AECOM between May 2016 and June 2016 focused mainly on an extended Assessment Area to the north-west as shown in the figure above, with 19 additional groundwater wells and 20 additional soil vapour bores installed as part of the works. The investigations resulted in better characterisation of the volatile halogenated aliphatic (VHA) impacts in both soil vapour and groundwater, and a refined assessment of potential source locations. However,

based on the results of these additional investigations, it was apparent that soil vapour and groundwater VHA plumes are not yet fully delineated.

## 1.2 Objectives

The EPA's stated objectives for the Stage 4 assessment works were to:

- Delineate the VHA in groundwater for the purpose of establishing a Groundwater Prohibition Area;
- Delineate the nature and extent of the soil vapour contamination in the Assessment Area;
- Determine and identify properties (sensitive land use) where the potential for vapour intrusion exists, using existing and new seasonal data; and
- Update the Human Health/Vapour Intrusion Risk Assessment (HH/VIRA) based on the new data set.

## 1.3 Scope of Works

The scope of works proposed as part of the Stage 4 investigations addressed the tasks detailed in the EPA request for tender and included the following key elements:

- Preparatory works including planning, permitting and stakeholder engagement;
- Install 10 additional groundwater wells within the broadened Assessment Area;
- Install 14 additional soil vapour bores to delineated the lateral extent of the soil vapour contamination;
- Collect 10 geotechnical cores (from new groundwater and soil vapour installations) for geotechnical analysis;
- A groundwater monitoring event (GME) of the newly installed (10) and existing available (33) groundwater wells;
- A vapour monitoring event (VME) of existing (70) and newly installed (14) soil vapour bores;
- Crawl space vapour sampling at five (5) residential properties;
- Review and update of the previously developed conceptual site model (CSM), and fate and transport modelling of VHAs in groundwater and soil vapour;
- Review and update the HH/VIRA to refine the characterisation of potential risks to affected residential properties from vapour intrusion; and
- Preparation of this detailed site investigation (DSI) report.

### 1.3.1 Modifications to Scope

The following modifications to the scope proposed are noted:

- The existing soil vapour bores to be monitored were agreed with the EPA prior to commencement of works, resulting in a proposed total of 84 bores (70 existing and 14 new)
- While initially 18 bores (9 nested pairs) were proposed to be sampled in the Arabrie Road residential area, this was reduced to 10 bores in total in this area at the direction of the EPA during the works program, with generally the shallow bore only of the nested pairs sampled
- Two soil vapour bores proposed for sampling (VP08 and VP38) were found to be unsuitable for sampling (as detailed in **Section 3.7**) and were omitted from the sampling and analytical program
- As a result of the above, in total, 74 soil vapour bores were sampled, as detailed in **Section 3.7**
- Carbon tube back-ups were not collected as proposed.

# 2.0 Background Information

## 2.1 Site Setting

The location of the Assessment Area is shown on the attached Site Locality Plan (**Figure 1, Appendix A**). **Figure 1** also presents details of generalised land use, topography and watercourses within a 1 km radius of the site, along with identified registered groundwater bores (DEWNR, 2016b).

### 2.1.1 Site Location

The defined Assessment Area is located in south-eastern Edwardstown, South Australia. The Assessment Area comprises land in the vicinity of a historical industrial area and consists of a number of industrial and residential properties. The assessment area is approximately 860,000 $m^2$ in size.

For the purpose of this DSI, the Assessment Area (as delineated in **Figure 1**) has been defined by the following roadways:

- North: portions of Beaconsfield Terrace, Robert Street, Weaver Street, Waverley Avenue and Dunorlan Road.
- South: portions of Fourth Avenue, Audrey Street, Albert Street, and a line that transects the residential area (to the south of Konando Terrace) from just west of Allambie Avenue to Lagunta Avenue.
- East: portions of Clark Avenue, a line that intersects the industrial area (from Clark Avenue to Conmurra Avenue), Conmurra Avenue, Coongie Avenue and Lagunta Avenue.
- West: Marion Road.

### 2.1.2 Zoning Information

The majority of the Assessment Area lies within the residential zone shown on Zone Map Mar/6 of the Marion Council Development Plan (DPTI, 2016), consolidated 28 April 2016. To the west of South Road, between Coongie Avenue and Calstock Avenue, the land is zoned industrial.

### 2.1.3 Topography

Based on the Department of Environment, Water and Natural Resources (DEWNR) (DEWNR, 2016a) Nature Maps website, the Assessment Area is generally flat with a gradual fall to the west, from approximately 30 metres Australian Height datum (m AHD) at South Road to 20 m AHD near Marion Road, 1.6 km further west.

### 2.1.4 Surface Water

The nearest surface water bodies are the Sturt River and Gulf St Vincent located approximately 1 km and 4 km west of the site, respectively.

## 2.2 Regional Geology and Hydrogeology

### 2.2.1 Geology

The 1:50,000 geological map of Adelaide shows the surface geology in the Edwardstown area is the Pooraka Formation (unconsolidated red-brown poorly-sorted clayey sand and gravel, with an average thickness of 4 m) (SADME, 1980). Published information suggests that in the Edwardstown area the Pooraka Formation is underlain by approximately 5 m of grey clays including the Keswick Clay, which is primarily clay but may include bands of silty or sandy clay, and which overlies the Hindmarsh Clay (primarily comprising red-brown to orange clay but also containing some sand and gravel horizons). These deposits are of Quaternary age, with Tertiary strata beneath (sands, sandstones, limestones and clays) (Sheard and Bowman, 1996). The strata are almost flat-lying. The depth to the top of the Tertiary in the vicinity of the former Hills' site is estimated to be approximately 35 to 40 m[1].

[1] Based on interpolation from Figure 21c of DWLBC Report 2004/47

### 2.2.2 Hydrogeology

According to Gerges (2006) there are up to six aquifer units within the Quaternary deposits in the Adelaide metropolitan area. These are referred to in sequence from Q1 (water table aquifer) to Q6 (deepest), although only Q1 to Q3 are likely to be present beneath the Edwardstown area. There are also a further three deeper aquifers (T1 to T3) in the underlying Tertiary deposits. Based on maps presented in the Gerges report, the salinities of groundwater in the Quaternary aquifers and in the underlying first Tertiary aquifer (T1) in this area are likely to be in the following ranges:

- Q1: 1,000 to 1,500 mg/L total dissolved solids (TDS)
- Q2: 2,500 to 3,500 mg/L TDS
- Q3: 1,000 to 1,500 mg/L TDS
- T1: 800 to 1,000 mg/L TDS

The regional groundwater flow is expected to flow towards the west, driven by recharge in the Adelaide hills to the east and discharge at the coast to the west.

### 2.2.3 Registered Bore Search

#### Surrounding Area

As part of the Stage 3 investigation, a search for registered groundwater bores located within and around the Assessment Area defined by the EPA (as indicated in **Figures 1** and **2**) was undertaken by reviewing the DEWNR WaterConnect online groundwater database on 23 June 2016 (DEWNR, 2016b).

The records, including the use and operational status of the 369 registered bores listed on the database, are in **Appendix C**. A summary of the search results for bores located within a 2 km radius of the site is provided below in **Table 2-1** and **Table 2-2**.

**Table 2-1 Registered Bore Use and Status**

| Listed Bore Use | Number of Bores | % of Total |
|---|---|---|
| Domestic | 68 | 18 |
| Drainage | 17 | 5 |
| Environmental | 3 | 1 |
| Industrial | 6 | 2 |
| Investigation | 90 | 24 |
| Irrigation | 5 | 1 |
| Monitoring | 2 | 1 |
| Observation | 16 | 4 |
| Recreational | 1 | 0 |
| Aquifer Storage and Recovery/Irrigation | 1 | 0 |
| Environmental/Recreational | 3 | 1 |
| Irrigation/Observation | 1 | 0 |
| Unknown(MAR)/ Monitoring | 1 | 0 |
| Unknown | 155 | 42 |
| **Total** | **369** | |

| Listed Bore Status | Number of Bores |
|---|---|
| Abandoned | 9 |
| Backfilled | 44 |
| Not In Use | 1 |
| Operational | 44 |
| Rehabilitated | 2 |
| Unknown | 269 |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| **Total** | **369** |

**Table 2-2 Registered Bore Details**

| Detail | Minimum | Maximum | Number of Datum |
|---|---|---|---|
| Drilled Depths (metres below ground level (m bgl)) | 1.83 | 304.8 | 361 |
| Standing Water Levels (SWLs) (m bgl) | 0 | 37.68 | 277 |
| Total Dissolved Solids (mg/L) | 67 | 15249 | 224 |
| pH | 6.1 | 9 | 125 |
| Yield (L/s) | 0.01 | 40 | 154 |
| Groundwater Formation Details | Hindmarsh Clay, (Quaternary aquifer) (2 wells) | | |

An updated search by AECOM conducted in March 2017 confirmed that additional wells within the Assessment Area are limited to the groundwater monitoring wells installed by AECOM as part of the Stage 3 works.

The reported depths of these 369 bores range from approximately 2 to 300 m. The varying water level and drill depths noted in **Table 2-2** indicate that the registered bores intersect both Quaternary formation and Tertiary aquifers in this area. The reported depths can be classified into four depth ranges as follows:

- Less than 10 m deep (therefore likely to be screened in the water table aquifer): 158 wells with an average reported salinity of approximately 2,600 mg/L TDS.
- Between 10 and 30 m deep (likely to be screened in one or more Quaternary aquifers): 130 wells with an average reported salinity of approximately 3000 mg/L TDS.
- Approximately 40 m deep (may intersect the Q3 and/or T1 aquifers): 6 wells with an average reported salinity of approximately 1900 mg/L TDS.
- More than 40 m deep (likely to be screened in the T1 aquifer): 75 wells with an average reported salinity of approximately 1,400 mg/L TDS.

Some of the Q1 wells are potentially in use for domestic purposes (‘backyard’ irrigation bores). Some of the deeper bores (screened in the Q3 and/or T1 aquifers) are also potentially in use for irrigation purposes, including bores at Edwardstown Oval (bore reference 6628-25759) and at Forbes Primary School (bore reference 6628-8112).

The recorded salinity levels of the shallow groundwater in the area (average 2,600 mg/L TDS) support the use of groundwater for domestic, irrigation, stock watering and industrial purposes (SA EPA, 2009 and SA EPP (WQ), 2015). For comparison, the average salinity encountered by AECOM during sampling of the monitoring wells during the Stage 4 investigation was approximately 3,000 mg/L.

It should be noted that the purposes of all bores within the bore search area are not documented; and further, it is possible that other unknown, unregistered bores are present in the vicinity of the site.

**Wells Within and Adjacent to the Assessment Area**

The majority of registered wells within the Assessment Area are investigation wells associated with previous phases of environmental investigations, including:

- Three wells (6628-25605 to 6628-25607) installed on EPA Focus Site 1 in 2009
- Three wells (6628-25608 to 6628-25610) installed on EPA Focus Site 2 in 2007

- Nineteen wells (6628-28449 to 6628-28467) installed across the Assessment Area by AECOM in May 2016

It is apparent that the seven wells installed by Greencap in April 2015 are not identified in the WaterConnect search.

Five registered extraction wells are noted to be present in the south-western portion of the Assessment Area, including:

- two industrial bores, listed as operational, drilled to 49 m and 57 m in 1983 and 1987, respectively, located within EPA Focus Site 1
- one industrial bore drilled to 48 m in 1984, located within EPA Focus Site 2
- two bores listed as used for domestic purposes, drilled to 7.5 m and 13.5 m, located on properties fronting Arabrie Avenue to the north and west of the Focus Sites

Only three further registered wells are located within the eastern portion of the Assessment Area (east of the rail line); two of unrecorded use (6628-13478 (10.9 m) and 6628-27174 (9 m)) and one noted as used for domestic purposes (6628-17843 (17 m). It is noted that bore 6628-27174, drilled to 20 m but apparently constructed to 9 m, and located adjacent the rail corridor near the southern boundary of the Assessment Area, has been included in the groundwater monitoring program as MW27 since the Stage 3 investigation.

A number of registered wells are recorded within the portion of the Assessment Area to the west of the rail line, including:

- Four shallow water wells (5.18 to 8.5 m), purpose unrecorded, drilled between 1940 and 1967 (6628-7957 to 6628-7960);
- Two water wells of unknown purpose (6628-12533 and 6628-13206), the former drilled in 1983 to 30 m depth;
- Three wells recorded as being for domestic purposes (6628-12803 (18 m), 6628-16959 (16.5 m) and 6628-20918 (29 m)), drilled between 1984 and 2000, with the former recorded as operational;
- One well recoded as being for drainage purposes, drilled to 16 m in 1988 (6628-14258); and
- One well recorded as operational and used for irrigation purposes, drilled to 8.2 m in 1988 (6628-14285).

The following registered wells were noted in close proximity to the Assessment Area:

- A number of investigation wells drilled in 2007 and 2015 are present south-east of the Assessment Area, indicative of off-site environmental site assessments in this area.
- A bore noted as operational and for domestic purposes, drilled to 67 m depth in 1934, is also recorded for this area; however, the bore appears to be associated with a commercial/industrial premises such that domestic use is unlikely.
- Two drainage bores are registered to the south of the eastern portion of the Assessment Area.
- Potential use of the shallow groundwater within 150 m to the north and west of the Assessment Area is apparent, with registered wells to the north including four of unknown use and one operational domestic well, while three domestic wells are recorded to the west.
- Local irrigation use of the deeper aquifer is also apparent, with four wells located south-west and north-west of the Assessment Area drilled to depths of 40 to 60 m recorded as for irrigation use.

## 2.3 Previous Investigations

A detailed review of the investigations within the Assessment Area prior to 2016 is presented as Appendix A of the Fyfe Earth Partners (Fyfe) (2016) report. A summary of key information is presented below, together with a summary of key findings of AECOM's Stage 3 assessment.

### 2.3.1 Prior Investigations – AEC Environmental – 4-6 Erudina Avenue, Edwardstown

In June 2009, AEC Environmental (AEC) conducted a preliminary groundwater investigation at the site of an operational metal plating facility at 4-6 Erudina Avenue, Edwardstown, comprising the installation and sampling of three on-site groundwater monitoring wells to assess the presence of a range of potential chemical impacts to the uppermost groundwater beneath the site.

Groundwater was measured to stand at depths of between 2.3 m and 2.8 m bgl, and a groundwater flow direction to the west was inferred.

Groundwater concentrations of metals (chromium and selenium), total petroleum hydrocarbons (TPH), chlorinated solvents (dichloroethene (DCE) and trichloroethene (TCE)) and cyanide were reported above adopted investigation levels, on the basis of which it was concluded that former metals plating activities at the site had resulted in groundwater impacts.

In March 2014, AEC completed a groundwater monitoring event comprising gauging and sampling of the three wells previously installed.

Groundwater elevations were slightly lower than measured in 2009; the inferred groundwater flow direction was consistent.

A range of metals exceeded the adopted investigation levels; reported zinc concentrations were noted to be significantly higher than reported in 2009. Concentrations of chlorinated hydrocarbons (DCE and TCE) and cyanide were again reported above investigation levels; 2014 concentrations were generally consistent with 2009 results.

### 2.3.2 Prior Investigations – AEC Environmental – 15-17 Arabrie Avenue, Edwardstown

In November 2007, AEC conducted a preliminary groundwater investigation at the Arabrie Avenue site, which is understood to have at that time been used for electroplating. The investigation comprised the installation and sampling of three on-site groundwater monitoring wells to assess the presence of a range of potential chemical impacts to uppermost groundwater beneath the site.

Groundwater concentrations of metals (chromium and nickel), TPH, chlorinated solvents (tetrachloroethene (PCE) and TCE) were reported above adopted investigation levels.

In May 2014, following cessation of electroplating activities (understood to have ceased in 2008), AEC completed a groundwater monitoring event comprising gauging and sampling of the three wells previously installed.

A range of metals, nitrate and ammonia, and PCE and TCE exceeded the adopted investigation levels. These reports have not been sighted by AECOM, however were summarised in Greencap (April 2015)

### 2.3.3 EPA Stage 1 Investigations – Greencap – April 2015

Greencap (incorporating AEC) was commissioned by the EPA to conduct an investigation of soil, groundwater and soil vapour impacts within a designated Assessment Area encompassing and extending down-gradient from the above two identified sites (Focus Sites).

The April 2015 investigations included:

- Investigation of soils within the Focus Sites through the drilling and sampling of a total of 16 soil bores;
- Installation of seven additional groundwater monitoring wells within the Assessment Area, and groundwater monitoring of the entire well network;
- Assessment of the extent of soil vapour impacts through the installation of nine single soil vapour sampling points (VP01 – VP09) and three clustered installations (VP10 – VP12) within the Focus Sites and the adjacent residential area; and
- Measurement of ambient outdoor air concentrations.

The investigations identified the presence of chlorinated hydrocarbon impacts to groundwater and soil vapour broadly across the Assessment Area; notably, the investigation did not delineate the extent of groundwater or soil vapour impacts.

### 2.3.4 EPA Stage 2 Investigations – Fyfe – November-December 2015

The EPA commissioned Fyfe to undertake a Stage 2 Investigation of the Assessment Area, which was completed during November and December 2015. The investigation comprised a number of elements:

- Conduct of a passive soil vapour survey utilising 44 Waterloo$^{TM}$ Membrane Samplers deployed on a grid pattern across the Assessment Area;
- Installation of nine pairs of clustered soil vapour bores (1.0/1.7 m) within or adjacent residential properties along Arabrie Avenue, including collection of soil samples for physical testing and determination of moisture content;
- Installation of 20 soil vapour wells (VP13 – VP32) to 1.5 m depth across the Assessment Area;
- Soil vapour sampling from existing and new soil vapour wells;
- Crawl space sampling beneath six residences along Arabrie Avenue;
- Indoor air sampling of buildings within the Focus Sites and a residence on Arabrie Avenue;
- Outdoor ambient air monitoring and vapour survey of subsurface utility access points; and
- A door-knock/survey of residences across a portion of the Assessment Area.

The results of the passive soil vapour survey were used in selection of the soil vapour well installation locations, which included wells VP11, VP18, VP29 and VP30 located immediately at or in the vicinity of the highest recorded TCE and PCE concentrations from the passive soil survey.

Of the 29 permanent soil vapour bores, 28 recorded measurable VHA concentrations including TCE, PCE, 1,2-DCE and 1,1-DCE. Graphical plots of soil vapour results indicated that in addition to soil vapour concentrations apparently related to groundwater impacts emanating from the Focus Sites and extending in a north-westerly direction, an apparent additional source of VHA impact was present north of Conmurra Avenue (contributing to elevated vapour concentrations in VP17, VP18 and VP28-VP32). Further, elevated results for VP08 potentially indicated the presence of an additional source area. The north-western extent of soil vapour impacts was not determined by the investigation.

Soil vapour concentrations reported for the deeper installations (1.7 m) of each of the nine paired soil vapour wells located on or adjacent the Arabrie Avenue residential properties were significantly lower than concentrations reported for nearby soil vapour bores installed to 1.5 m in the road verge as part of the broad installation of vapour wells across the Assessment Area. The reason for these lower concentrations was unknown, although variation in soil properties was suggested.

Detectable concentrations of VHAs were reported for indoor sampling in both residential and commercial buildings (one selected residential property on Arabrie Avenue and the commercial buildings in Focus Sites 1 and 2).

Based on vapour intrusion modelling, Fyfe assessed that impacts to some 25 residential properties warranted further investigation, but that the predicted indoor air concentrations did not represent immediate health effects. For a larger number of properties, current concentrations were assessed to be safe, but warranting validation.

It was noted that the lateral (and vertical) extent of groundwater impacts had not been determined, and that future lateral groundwater migration could also result in further off-site soil vapour impacts. Recommendations were presented in relation to risk mitigation for occupation of buildings within the Focus Sites.

### 2.3.5 EPA Stage 3 Investigations – AECOM – May-June 2016

The EPA commissioned AECOM to undertake a Stage 3 Investigation of the Assessment Area, which was completed during May and June 2016. The investigation comprised a number of elements:

- expansion of the existing groundwater well monitoring network by a further 20 wells (drilling and construction of 19 new wells and incorporation of one identified existing well);
- conduct of a groundwater monitoring event encompassing 33 new and existing wells, with analysis targeting selected VHAs;

- conduct of slug tests at eight groundwater well locations to improve the characterisation of the subsurface environment;
- installation of 20 new soil vapour wells, and vapour sampling of a total of 49 new and existing soil vapour wells, with samples analysed for selected VHAs;
- collection and analysis of soil samples for moisture content analysis and physical parameters to refine vapour intrusion modelling parameters;
- collection of ambient air samples at a few locations distributed across the Assessment Area; and
- Sampling of one well located within a private residential allotment and analysis of the groundwater sample for selected VHAs.

Other than the sampling of the private residential well, work was limited to sampling locations within the Focus Sites or on public land.

The soil vapour investigations provided a refined characterisation of the VHA soil vapour impacts across the Assessment Area; it was apparent from Stage 3 investigation results that soil vapour impacts from the Focus Sites, and an additional plume associated with a northern source (yet to be identified) are largely delineated to the north and south within the Assessment Area.

The up-gradient (eastern) extent of the groundwater plume, while not expected to extend a significant distance, had not been established. To the west, the groundwater plume apparently extended beyond the soil vapour monitoring network, which itself did not extend fully across the Assessment Area.

TCE impacts were noted to be the most widespread of the VHA impacts to shallow groundwater beneath the site. While the highest concentrations were reported for locations well within the Assessment Area, the extent of TCE impacts remained undelineated. Notably, data gaps with respect to plume delineation existed north of MW19 and south/south-west of MW21 and MW27. The down-gradient extent of the plume had also not been delineated.

Despite the fact that the highest measured soil vapour concentration (36,000 µg/$m^3$ TCE) exceeded that previously measured by the earlier investigations, vapour modelling from measured soil vapour concentrations resulted in no predicted exceedances of the 2 µg/$m^3$ indoor air guideline for TCE, the primary contaminant of concern, which was attributed to the high relative soil moisture measured.

It was noted that the vapour modelling is highly sensitive to the assumed soil moisture, and the lower indoor risks estimated in the assessment compared to the earlier report by Fyfe related principally to the measured and adopted soil porosity and moisture data.

Consistent with the earlier risk assessment, the shallow depth to water and measured soil vapour concentrations meant that VHA impacts across a substantial portion of the investigation area were considered to potentially pose an unacceptable vapour intrusion risk in the event of the presence of basements.

It is noted that survey data initially procured for well MW24 as part of the AECOM Stage 3 Investigation was subsequently identified to be erroneous, and this well was resurveyed following completion of the Stage 4 investigations. The corrected data is presented in this Stage 4 report, and incorporated into a revised final version of the Stage 3 investigation report (AECOM, 2017) also.

# 3.0 Stage 4 Intrusive Investigations

## 3.1 Overview and Chronology of Works

The scope and timing of field investigations is summarised in **Table 3-1** below:

**Table 3-1 Overview of Stage 4 Field Works**

| Investigation Element | Works Conducted | Date of Works |
|---|---|---|
| Groundwater and Soil Investigations | Underground service clearance for new groundwater monitoring wells and soil bores | 9 and 17 January 2017 |
| | Installation of 10 new groundwater monitoring wells (MW28-MW37) | 16 – 19 January 2017 |
| | Collection of soil sample from adjacent previous investigation locations VP08, MW07, MW21, MW22 | 19 January 2017 |
| | Development of 10 new groundwater monitoring wells (MW28-MW37) | 21 – 24 January 2017 |
| | Gauging of 33 existing (GW1-GW3, GWA-GWC, MW01-MW27) and 10 new (MW28-MW37) groundwater monitoring wells | 31 January 2017 |
| | Sampling of 33 existing and 10 new groundwater monitoring wells (GW1-GW3, GWA-GWC, MW01-MW37) | 2 – 13 February 2017 |
| | Collection and disposal of drums of waste soil and purge water | 3 April 2017 |
| | Survey of location and elevation of 10 new groundwater monitoring wells (MW28-MW37) | 13 February 2017 |
| | Resurvey of location and elevation for groundwater monitoring well MW24 | 30 September 2017 |
| Soil Vapour and Crawl Space Investigations | Underground service clearance for new soil vapour wells | 9 January 2017 |
| | Installation of 14 new soil vapour monitoring wells (VP53-VP66) | 10 – 11 January 2017 |
| | Soil vapour sampling including 14 new soil vapour bores (VP53-VP66), 50 existing soil vapour bores (VP01-VP07, VP09-VP37, VP39-VP52), and 10 residential soil vapour bores | 17 January – 10 February 2017 |
| | 15 crawl space monitoring locations (CS1-CS15) from five residential properties. | 30 January, 1 February and 6 February 2017 |
| | Collection and disposal of drums of waste soil from drilling | 3 April 2017 |
| | Survey of location of 14 new soil vapour monitoring wells (VP53-VP66) | 13 February 2017 |

## 3.2 Preparatory Works

### 3.2.1 Stakeholder Engagement

Prior to commencement of works, AECOM liaised with Council for permission for groundwater well and soil vapour well installations on behalf of the EPA. An “Authorisation to Make an Alteration to a Public Road” was completed by AECOM and approved by the City of Marion on 21 December 2016.

### 3.2.2 Well Permits

South Australian legislation requires a well permit to be issued for the installation of each individual groundwater monitoring well. Ten well permits were obtained from DEWNR in advance of the intrusive works, and are presented in **Appendix D**.

### 3.2.3 Health Safety and Environment Plan

A site-specific health safety and environment plan (HSEP) was developed for the site to manage risks to the investigation team, subcontractors, site personnel and the broader population, as well as risks to the environment, that might arise from the performance of AECOM’s site assessment works.

## 3.3 Service Location and Selection of Investigation Locations

Approximate investigation locations were as denoted by the EPA in information accompanying the request for tender, or otherwise agreed with the EPA, but final locations were determined on site taking into account site observations and site constraints.

Sure Search Locations was engaged to mark out identifiable underground and aboveground services at all investigation locations using Dial Before You Dig plans and radio frequency detection.

All underground service location works were undertaken on 9 and 17 January 2017, prior to commencement of intrusive investigation works at each location.

## 3.4 Groundwater Well Installation

Ten new groundwater wells were installed as part of this investigation. The new wells, denoted MW28 to MW37, included four on the down-gradient (north-westerly) perimeter of the assessment area, two on the southern perimeter (south/southwest of wells MW21 and MW27), one on the northern perimeter (north of MW19) and three within the Assessment Area.

The new groundwater well locations are shown on **Figure 2** and **Figure 3**.

### 3.4.1 Drilling and Logging

Groundwater wells were drilled and constructed by WB Drilling using a 4WD-mounted drill rig in the full-time presence of an AECOM field investigator.

At each groundwater well location, following drilling of a nominal 0.6 m to 0.8 m depth (until natural soil confirmed) using a hand auger to mitigate risk to underground services, a continuous core of soil was retrieved using Geoprobe tooling, utilising disposable plastic liners to facilitate recovery of good quality core. Cores were logged by an experienced AECOM field scientist with reference to the Unified Soil Classification System (USCS). Soil descriptions for the lithology encountered at each location during drilling are presented in the bore logs in **Appendix E**. Core photographs are also presented in **Appendix E**.

Soil sampling in the course of the investigation was primarily conducted in the course of the soil vapour well installations; however, at one location during groundwater well installation, an undisturbed core sample was obtained using a 50 mm diameter thin walled sampling tube (U50) to enable geotechnical property testing. The sample was retrieved from well MW32 at a depth of 0.7-1.0 m.

Core samples from the surface and changes in lithology and/or regular depth intervals within each soil bore were screened for volatile organic compounds (VOCs) using a photo ionisation detector (PID) that was calibrated to a known concentration of isobutylene calibration gas. Calibration certificates are provided in **Appendix F**. PID readings are presented on the borehole logs in **Appendix E**.

Groundwater wells were subsequently reamed to approximately 125 mm diameter using solid stem augers to enable construction of groundwater wells.

### 3.4.2 Decontamination and Disposal

Drilling equipment which had contact with soils was decontaminated between groundwater wells with either high-pressure potable water (large equipment) or by hand washing with Decon 90 solution and potable water rinse.

Soil cuttings were contained at a designated collection site in labelled 200 L drums and disposed of by an independent waste disposal contractor to a waste disposal facility (Adelaide Resource Recovery) in accordance with SA regulations. The waste disposal certificates are presented in **Appendix G**.

### 3.4.3 Groundwater Well Installation

Groundwater monitoring wells MW28 – MW37 were drilled to depths of 5 and 6 m bgl. All groundwater wells were constructed by WB Drilling using 50 mm diameter, Class 18 uPVC threaded screen and blank casing. The wells were completed with sand to approximately 0.5 m above the screen and sealed with bentonite to the surface. Gatic covers were installed flush with the surrounding surface. Construction details for the groundwater monitoring wells are presented in **Appendix E**.

Following installation (with the exception of MW31, as discussed below), each well was developed using a combination of surging and water removal to flush fines from the sand filter pack and lessen the impact of smearing of clays in the bore during auger drilling. Typically, the wells were initially surged using a surge block (operated via Waterra HDPE tubing), followed by removal of a minimum of three bore volumes of water using dedicated disposable bailers. Where wells bailed dry, or residual turbidity was evident, additional surging and/or bailing was conducted with the aim of improving the well's connectivity to the aquifer and lessening sample turbidity.

Ex-situ measurements of groundwater pH, dissolved oxygen (DO), reduction potential (redox), temperature, and electrical conductivity (EC) were taken following the removal of each bore volume, using a water quality meter. Calibration certificates are provided in **Appendix F**.

Well development methods employed and field observations are recorded on the field record sheets included in **Appendix H**.

It is noted that although soil core moisture suggested the presence of water at a depth of 2.7 m bgl during drilling on 18 January, well MW31, which was screened to 5 m depth, was dry when gauged on 22 January and 24 January, and no development was conducted.

## 3.5 Groundwater Well Gauging and Sampling

### 3.5.1 Groundwater Well Gauging

A water level gauging round of all groundwater monitoring wells within the Assessment Area (10 new wells and 33 existing wells) was conducted on 31 January 2017.

At each accessible well, the depth to groundwater was measured from the top of casing using an oil/water interface probe. Well gauging results are provided in **Table 1** (**Appendix B**).

### 3.5.2 Groundwater Well Sampling

The 10 new and 33 existing groundwater wells were sampled using the low-flow technique (with one exception, MW31, which was sampled by grab sampling with a disposable bailer due to the limited water column) in general accordance with Schedule B2 of the Assessment of Site Contamination National Environment Protection Measure (NEPM) (1999). Wells were sampled between 2 and 13 February 2017.

Sampling was carried out by pumping each monitoring well at a low flow rate using a pneumatic bladder pump with its intake placed within the screened section of the monitoring well. The low-flow micro-purge pump was set at a consistent depth above the base of the well with the aim of collection of representative samples. Each well was purged prior to sampling, and the standing water level in each well was monitored at regular intervals during the purging process to allow the pumping rate to be adjusted with the aim of achieving a stable water level with minimal drawdown, thereby minimising

both introduction of air to the groundwater and mobilisation of particulate matter from the water table formation.

Field parameters of temperature, pH, EC, DO and redox and visual and olfactory evidence of the presence of chlorinated hydrocarbon compounds (where present) were recorded during sampling (other than for MW31, for which no parameters were recorded due to insufficient water). These records are summarised in **Table 2** (**Appendix B**). Copies of the groundwater purge and sampling sheets are provided in **Appendix H**.

### 3.5.3 Sample Handling and Laboratory Analysis

Groundwater samples were placed in laboratory-supplied bottles and held in chilled conditions pending and during transport to the laboratories under chain-of-custody (COC) protocols.

Samples were analysed for a selected VHAs (inclusive of PCE, TCE, DCE and VC) using an “ultra-trace” method to provide an enhanced limit of reporting. Each sample was also analysed for salinity, major cations and anions and degradation parameters (ethane, ethene, methane and carbon dioxide).

Quality assurance/quality control (QA/QC) samples (duplicate, triplicate, field blank, rinsate blank and trip blank) were collected and analysed in accordance with the NEPM.

The COC documents and laboratory certificates of groundwater analysis are provided in **Appendix I**.

### 3.5.4 Decontamination and Waste Water Disposal

To reduce the potential for cross-contamination between bores during gauging and sampling, the interface probe was rinsed with Decon90 and fresh water prior to the commencement of field work and between sampling locations. During low-flow sampling, a new disposable bladder unit and dedicated air and water hose were used at each monitoring well, and the pump was decontaminated with Decon90 prior to installation at each monitoring well.

Waste groundwater was collected into a sealed labelled drum which was disposed of by an independent waste disposal contractor to a waste disposal facility in accordance with SA regulations. A waste disposal certificate is provided in **Appendix G**.

## 3.6 Soil Vapour Bore Installation

### 3.6.1 Rationale

Twelve soil vapour bores denoted VP53-VP62, VP64 and VP65 were installed by A&S Drilling on 10 and 11 January 2017 with VP63 and VP66 installed by WB Drilling on 17 January 2017 in the full time presence of an AECOM field scientist. Each of the vapour bores was installed to a depth of 1.5 m bgl.

The new vapour bores were installed at locations as directed by the EPA; the majority provided a further extension of the vapour network to the north-west of the Focus Sites; with the Assessment Area extending in a north-westerly direction from the Focus Sites (to the north-west of the rail corridor), with four bores providing a greater investigation density within the existing bore network east of the rail corridor. The locations of the new vapour bores along with the existing vapour bore network are shown on **Figure 2** and **Figure 4** (**Appendix A**).

### 3.6.2 Drilling and Logging

Following service clearance, the vapour bores were hand augered to a minimum of 0.7 m bgl to provide a further level of protection to potential underground services. The bores were then advanced to their final depth using either a hand auger or mechanically drilled with push tubes using a 4WD-mounted rig operated by A&S Drilling.

The soil profile encountered during drilling was photographed and logged using visual-tactile methods in accordance with AS1726 (1993). Borehole logs are presented in **Appendix J**; core photographs are also included in **Appendix J**.

### 3.6.3 Soil Sampling

At five locations during soil vapour well installation (in addition to the single noted sample collected during groundwater well installation), undisturbed core samples were obtained using 50 mm diameter

thin walled sampling tubes (U50s) to enable geotechnical property testing. The samples were retrieved from the following locations and depths:

- bore VP55 at a depth of 0.8-1.2 m
- bore VP57 at a depth of 0.8-1.2 m
- bore VP61 at a depth of 0.7-1.1 m
- bore VP63 at a depth of 0.7-1.2 m
- bore VP66 at a depth of 0.7-1.1 m

An additional four locations were targeted to investigate discrepancies between historical concentrations of soil vapour and groundwater. In particular, locations that have reported low soil vapour concentrations relative to high groundwater concentrations. Samples were retrieved from the following locations and depths:

- adjacent vapour bore VP08 at a depth of 0.8-1.2 m
- adjacent vapour bore VP09 and groundwater monitoring well MW07 at a depth of 0.7-1.2 m
- adjacent vapour bore VP15 and groundwater monitoring well MW21 at a depth of 0.8-1.3 m
- adjacent vapour bore VP49 and groundwater monitoring well MW22 at a depth of 0.7-1.0 m

Following service clearance, soil bores were hand augered to a minimum of 0.7 m bgl to provide a further level of protection to potential underground services. The bores were then advanced to the target depth for soil sampling with push tubes using a 4WD-mounted rig operated by WB Drilling, and then samples collected using undisturbed (U50) sampling tubes prior to backfill of the bores.

The samples were sent to the Coffey geotechnical laboratory for analysis for the determination and calculation of bulk density, moisture content, dry density, void ratio, degree of saturation, air and water-filled porosity and specific gravity.

The COC and laboratory certificate of soil analysis is provided in **Appendix K**.

### 3.6.4 Decontamination and Waste Soil Disposal

Drilling equipment which had contact with soils was decontaminated between soil vapour bores with either high-pressure potable water (large equipment) or by hand washing with Decon 90 solution and potable water rinse.

Soil cuttings were contained on-site in labelled 200 L drums and disposed of by an independent waste disposal contractor to a waste disposal facility in accordance with SA regulations. The waste disposal certificates are presented in **Appendix G**.

### 3.6.5 Soil Vapour Bore Installation

The vapour bores were constructed by setting a piece of ¼" OD Teflon tubing with a stainless steel screen of approximately 200 mm length at the base of the hole, packing with sand to approximately 100 mm above the screen and isolating from the surface using a bentonite seal and cement/bentonite grout to the surface. Each bore was finished at the surface with a concreted flush Gatic cover protecting the upper end of the tubing, which was terminated with a Swagelok fitting. Soil vapour bore construction and lithological logs (including photographs and PID readings), are provided in **Appendix J**.

## 3.7 Soil Vapour Bore Sampling

Existing vapour bores VP01-VP07, VP09-VP37, VP39-VP52 (the shallow bore only at nested installations VP10, VP11 and VP12), shallow (1.0 m) bores at nested Arabrie residential installations H1, H3-H4 and H6-H10 and the deeper (1.7 m) bore at locations H5 and H9 (refer **Section 3.8** below), and the fourteen new vapour bores (denoted VP53-VP66) were sampled between 17 January and 10 February 2017. Bores VP08 and VP09 were proposed for sampling, but were found to be unsuitable; insufficient vapour could be extracted from VP08 resulting in draw-up of water into the sampling tube, while VP38 was found to be inundated with water and was not sampled.

The following works were undertaken:

- Each bore was screened in the field using a PID and a landfill gas meter for measuring carbon dioxide ($CO_2$), methane ($CH_4$) and oxygen ($O_2$). Field screening was conducted for sufficient time to allow for purging of the well.
- Leak testing of bores and sample trains using a combination of vacuum and helium was undertaken:
  - Vacuum line test. With all Teflon lines securely fitted using Swagelok nuts and ferrules, and the valves to the well and to the canister closed, a hand pump was used to evacuate the lines, producing a vacuum of at least -20 inHg. Upon cessation of pumping, the vacuum was monitored for one minute. If unacceptable leaks were detected, fittings were checked, tightened, or replaced and the vacuum test repeated.
  - Helium gas leak test. The sampling train was passed through a bucket, which was placed over the well, ensuring an adequate seal with the ground to prevent substantial leakage of the tracer gas. The shroud was filled with the helium tracer gas and the concentration of helium in the sampling train recorded using a helium detector for 5 minutes. The concentration of helium within the shroud was then recorded. If the concentration in the sampling train was greater than 10% of the shroud concentration then fittings were checked, tightened, or replaced, then re-tested.
  - Isopropanol leak test. Consistent with the methodology outlined in Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) TR23, an isopropanol soaked cloth was placed under a hood housing the well head, canister and sampling train. The sample canisters were then laboratory analysed additionally for isopropanol to check for leakage into the sampling train.
- Samples were collected into laboratory-certified, evacuated (summa) canisters, equipped with 1-hour flow regulators. Canister valves were closed while the canisters remained under partial vacuum, to enable checking for leaks following transport to the laboratories. Soil vapour purge records are provided in **Appendix L**.
- Samples were sent under standard AECOM COC protocols to Eurofins (Air Toxics) in the USA for laboratory analysis of VHA compounds of concern including TCE and related breakdown products. Blind field duplicate samples from VP29, VP30, VP32 and VP44 were sent to Eurofins (Air Toxics) in the USA and to EnviroLab in Australia. The COC and laboratory certificate of analysis is provided in **Appendix M**.

## 3.8 Crawl Space Vapour Sampling

Crawl space vapour sampling locations (and corresponding soil vapour bore locations) in Arabrie Avenue residential properties are summarised in **Table 3-2** below:

**Table 3-2 Arabrie Avenue Residential Property Sampling Program**

| Residential Property | Crawl Space Sampling | | Soil Vapour Bores | |
|---|---|---|---|---|
| | Sample ID | Location | Sample ID | Location |
| 1 | CS7 | Front bedroom | H1-VP1 | Front yard |
| | CS8 | Lounge room | | |
| | CS9 | Kitchen | | |
| 2 | | | H6-VP1 | Front yard |
| 3 | CS13 | Lounge room | H3-VP1 | Front yard |
| | CS14 | Front bedroom | H7-VP1 | North side of house |
| | CS15 | Kitchen | | |

| Residential Property | Crawl Space Sampling | | Soil Vapour Bores | |
|---|---|---|---|---|
| | Sample ID | Location | Sample ID | Location |
| 4 | | | H9-VP1 | Footpath |
| | | | H9-VP2 | Footpath |
| 5 | CS1 | Front bedroom | H4-VP1 | Front yard |
| | CS2 | Lounge room | H8-VP1 | Rear yard |
| | CS3 | Kitchen | | |
| 6 | CS4 | Kitchen | H5-VP2 | North side of house |
| | CS5 | Back bedroom | | |
| | CS6 | Lounge room | | |
| 7 | CS10 | Front bedroom | H10-VP1 | Front yard |
| | CS11 | Kitchen | | |
| | CS12 | Lounge room | | |

*As instructed by the EPA, only the shallow (1.0m) soil vapour bore at each residential property was sampled.

**The shallow soil vapour bore (H5-VP1) at residential property six was unable to be accessed. The deeper soil vapour bore (H5-VP2) was sampled instead.

***Both soil vapour bores H9-VP1 and H9-VP2 located within the footpath adjacent to residential property 4 were sampled.

The following methodology was applied to each of the crawl space sampling locations:

- At each location a ¼" OD Teflon tube was passed through the existing penetration to enable sampling using a summa canister.
- A vacuum shut-in test was conducted to check the integrity of the sampling line/canister fittings to ensure the sampler was drawing from the crawl space, and not leaking at the canister head.
- The crawl space samples were collected using summa canisters with 24 hour regulators. Canister valves were closed while the canisters remained under partial vacuum, to enable checking for leaks during transport to the laboratories.
- Samples were sent to Eurofins (Air Toxics) in the USA under AECOM's standard COC protocols for laboratory analysis of VHA compounds of concern including TCE and related breakdown products. A blind field duplicate sample from CS11 (labelled QC07) was also sent to Eurofins (Air Toxics) in the USA.

## 3.9 Groundwater Well and Soil Vapour Bore Survey

New groundwater monitoring wells MW28 to MW37, and new soil vapour monitoring wells VP53 to VP66 were surveyed by a subcontracted surveyor (Link Up) on 13 February 2017.

Existing groundwater monitoring well MW24 was surveyed by Link Up on 30 September 2017 after it was identified that the survey data procured as part of the Stage 3 investigation was erroneous.

Survey results are provided in **Appendix N**. Well construction details and survey information are summarised in the **Table 3** (Groundwater Wells) and **Table 4** (Soil Vapour Bores) included in **Appendix B**.

# 4.0 Quality Assurance and Data Validation

This section presents the findings of QA/QC assessments undertaken with respect to both the groundwater and soil vapour monitoring works undertaken. **Section 4.1** presents a review of groundwater monitoring well construction and development, with relevant observations in relation to groundwater sampling discussed in **Section 4.2**. The soil vapour monitoring field procedures incorporate checks on vapour well and sampling chain integrity, the results of which are discussed in **Section 4.3**. Analytical results for QA/QC samples for soil vapour and groundwater samples, including field and laboratory duplicates, are discussed in **Section 4.4**.

## 4.1 Groundwater Well Installation and Development

A summary of groundwater monitoring well installation and development is presented in **Table 4-1** below.

**Table 4-1 Groundwater Well Installation and Development Summary**

| Well ID | Depth Drilled | Screen Interval | Purge Amount | Turbidity | Comment |
|---|---|---|---|---|---|
| MW28 | 5 m | 2 – 5 m | 9 x BV | High to Low | Field parameters stable |
| MW29 | 6 m | 1.5 – 6 m | 6 x BV | Med to Low | Well bailed dry. Field parameters not stabilised |
| MW30 | 6 m | 1.5 – 6 m | 4 x BV | Med | Well bailed dry. Field parameters relatively stable but not within criteria |
| MW31 | 6 m | 2 – 5 m | n/a | n/a | Well dry and not developed |
| MW32 | 6 m | 1.5 – 6 m | 7 x BV | High to Med | Field parameters stable |
| MW33 | 6 m | 2 – 5 m | 3 x BV | Medium high | Well bailed dry. Field parameters not stabilised |
| MW34 | 6 m | 2 – 5 m | 8 x BV | High to Med | Field parameters stable |
| MW35 | 6 m | 2 – 5 m | 9 x BV | High to Low | Field parameters stable |
| MW36 | 5 m | 2 – 5 m | 9 x BV | High to Low | Field parameters stable |
| MW37 | 5 m | 2 – 5 m | 11 x BV | High to Med | Field parameters stable |

## 4.2 Groundwater Sampling

For the majority of wells, sufficient inflow was observed to permit sampling using low-flow techniques.

Relatively poor well recharge was noted in wells MW10, MW14 and MW22-MW24 consistent with observations during the Stage 3 assessment. Additionally, slow recharge was observed in existing well MW26 and new wells MW29, MW30 and MW33, resulting in failure to achieve steady state drawdown conditions in these wells during low flow sampling. As noted previously, a grab sample was collected for MW31 using a disposable bailer.

In general, well construction and development (as detailed in **Section 4.1** above) and stabilisation of field parameters during sampling was considered appropriate for the acquired samples to be submitted for analysis. The results for the above wells (MW10, MW14, MW22-MW24, MW26, MW29, MW30 and MW33) should be considered in the context of the low inflow to these wells, and the use of grab sampling for MW31 must also be noted in interpretation of results.

## 4.3 Vapour Bore Integrity

A review of helium leak test results and isopropanol leak test results is presented in **Appendix O**, and concludes that vapour well integrity was adequate. Comprehensive details of vapour sampling integrity checks are presented in **Table 5** (**Appendix B**) attached.

## 4.4 Analytical Data Validation

COC details and laboratory certificates are provided in **Appendix I** (groundwater samples), **Appendix K** (soil samples) and **Appendix M** (soil vapour and crawl space samples). A summary of the laboratory batches is provided in **Table 4-2** below.

**Table 4-2 Sampling and Laboratory Analysis Summary**

| Lab Certificate Batch ID | Laboratory | Sample Date | Sample Type | Sample Technique |
|---|---|---|---|---|
| 161511<br>192037<br><br>EM1701635 | Envirolab (primary)<br><br><br>ALS (secondary) | 2 – 13 February 2017 | Groundwater (New and Existing Wells) | Low Flow (1 grab sample) |
| 754-ADEL00058AA | Coffey | 10 – 19 January 2017 | Soil – Physical | U50 Tubes |
| 1702090A<br>1702090B<br>1702090C<br>1702090D<br>1702090E<br>1702272A<br>1702272B<br>1702094A<br>1702094B<br><br>161827 | Eurofins Air Toxics (primary)<br><br><br><br><br><br><br><br><br>Envirolab (secondary) | 17 January – 10 February 2017 | Soil Vapour and Crawl space Vapour | Summa Canisters |

The data validation guidelines adopted by AECOM provide a consistent approach for the evaluation of analytical data. These guidelines are based upon data validation guidance published in the NEPM (NEPC, 1999). The process involves the checking of analytical procedure compliance and an assessment of the accuracy and precision of analytical data from a range of QA/QC measures, generated from both the sampling and analytical programs.

Specific elements that have been checked and assessed by this project are:

- preservation and storage of samples upon collection and during transport to the laboratory
- sample holding times
- use of appropriate analytical and field sampling procedures
- required limits of reporting (LOR)
- frequency of conducting quality control measurements
- rinsate, field and trip blank and laboratory blank results
- field duplicate and triplicate and laboratory duplicate results
- matrix spike and surrogate spike results;
- laboratory control spike and laboratory control spike duplicate results
- continuing calibration verifications
- leak testing (soil vapour)
- canister pressure (soil vapour)
- the occurrence of apparently unusual or anomalous results, e.g., laboratory results that appear to be inconsistent with field observations or measurements.

Validation summary reports and tables of field duplicates are provided in the data validation summary in **Appendix P**, while laboratory duplicates and matrix spike/matrix spike duplicates are provided with the laboratory certificates.

From this information an assessment of the quality of the analytical data is such that it can be used as a basis for interpretation with reference to the comments included in **Appendix P**.

### 4.4.1 Soil Vapour Sampling – Canister Pressure

Comments in relation to reliability of soil vapour measurements on the basis of recorded canister pressure are presented in **Appendix P**. Laboratory receiving pressures for canister samples were within acceptable ranges, with the following notes and exceptions:

- Upon collection of 24-hour summa canisters CS6 and CS12, no residual vacuum remained in these canisters due to faster flow rates. While this precluded subsequent assessment of leakage during transit back to the laboratory, it is noted that the reported concentrations in these samples were consistent with the two remaining samples collected beneath the same residential properties.
- Due to slow flow, at a number of sampling locations, sampling was halted with residual vacuums higher than the target (nominally 5 ”Hg), resulting in an increased limit of reporting for these samples. This did not materially affect interpretation of the data, the limit of reporting remained below the adopted criteria for each of these bores other than for VP21, for which the TCE LOR (21 µg/$m^3$) marginally exceeded the adopted criterion (20 µg/$m^3$).
- Several other samples reported potentially material (>=20%) vacuum reductions (relative to collected volumes) during transit, as listed in **Table 4-3**.

  Reported analyte concentrations in these samples would be anticipated to be biased low by approximately these percentages. A review of vapour analytical results (total VOCs) against 2015 and 2016 data, as presented in **Appendix O**, is summarised in **Table 4-3**.

**Table 4-3 Review of Implications of Potentially Material Vacuum Reductions**

| Sample | Measured Vacuum Reduction (%) | Comment |
|---|---|---|
| VP21 | 27% | Result is relatively consistent with historical data; there is a potential that without loss of vacuum the 2017 result would have been indicative of an increase, but this is a relatively minor concentration and such a change would not materially affect the interpretation of the data. |
| QC03 (VP30) | 63% | Notably, while results for VP30 are lower than for the 2016 sampling, the intra-lab duplicate pair for this sample, which was not affected by loss of vacuum, was in close agreement. The inter-laboratory duplicate reported comparable but lower values, indicating the apparent loss of vacuum need not be considered to have detrimentally affected the results. |
| VP36 | 28% | Results for 2016 and 2017 were both below limits of reporting; even low bias by 28% would not substantially affect the interpretation of the data. |
| H04-VP01 | 21% | Results for 2017 show a substantial increase relative to 2015 results; however, allowing for a 21% low bias would not substantially affect the interpretation of the data. |

# 5.0 Results and Discussion

## 5.1 Soil Physical Properties

Soil physical property testing results from U50 tubes collected from soil vapour wells VP55, VP57, VP61, VP63 and VP66, groundwater monitoring well MW32 and targeted locations VP08, MW07 (VP09), MW21 (VP15) and MW22 (VP49) are presented in **Table 6** (**Appendix B**) and summarised in **Table 5-1** below, which also presents a summary of the data from the Stage 3 (May 2016) investigations.

**Table 5-1 Summary of Geotechnical Soil Laboratory Results**

| Sample ID | Soil Classification and Description | Soil Moisture (%) | Particle Specific Gravity (t/m$^3$) | Bulk Density (t/m$^3$) | Dry Density (t/m$^3$) | Total Porosity | Water Filled Porosity | Air Filled Porosity | % Saturation |
|---|---|---|---|---|---|---|---|---|---|
| Range for Stage 3 (May 2016) | Sandy CLAY to Silty CLAY | 15.3 to 19.9 | 2.68 to 2.70 | 2.09 to 2.15 | 1.74 to 1.86 | 31.0 to 35.3 | 28.6 to 34.7 | 0.29 to 2.44 | |
| VP08_0.8-1.2 | Sandy CLAY | 19.9 | 2.66 | 2.05 | 1.71 | 35.80 | 33.99 | 1.81 | 94.9% |
| VP55_0.8-1.2 | Sandy CLAY | 21.9 | 2.69 | 2.06 | 1.69 | 37.15 | 37.02 | 0.12 | 99.7% |
| VP57_0.8-1.2 | CLAY | 23.1 | 2.67 | 2.03 | 1.65 | 38.17 | 38.14 | 0.04 | 99.9% |
| VP61_0.7-1.1 | CLAY | 19.3 | 2.70 | 2.10 | 1.76 | 34.81 | 33.91 | 0.91 | 97.4% |
| VP63_0.7-1.2 | Sandy CLAY | 26.7 | 2.70 | 1.97 | 1.56 | 42.33 | 41.57 | 0.77 | 98.2% |
| VP66_0.7-1.1 | Sandy CLAY | 17.0 | 2.71 | 2.06 | 1.76 | 34.96 | 29.97 | 4.99 | 85.7% |
| MW07_0.7-1.2 | Sandy CLAY | 15.6 | 2.68 | 2.18 | 1.89 | 29.48 | 29.43 | 0.05 | 99.8% |
| MW21_0.8-1.3 | Sandy CLAY | 22.3 | 2.70 | 2.06 | 1.69 | 37.57 | 37.53 | 0.04 | 99.9% |
| MW22_0.7-1.0 | Sandy CLAY | 18.2 | 2.69 | 2.12 | 1.79 | 33.34 | 32.66 | 0.67 | 98.0% |
| MW32_0.7-1.2 | CLAY | 19.9 | 2.67 | 1.94 | 1.62 | 39.23 | 32.24 | 7.00 | 82.2% |

While the soil moisture contents are similar to or marginally greater than those reported for May 2016 (potentially reflecting the unseasonably wet conditions in Adelaide), the ranges of water-filled and air-filled porosities are higher than previously reported.

It is noted that the very low air-filled porosity values for samples from adjacent MW07 and MW21 are consistent with the observation of soil vapour concentrations for both Stage 3 (Table 15, AECOM (2017) and Stage 4 (**Table 15**) vastly lower than the theoretical values derived from adjacent groundwater concentrations.

## 5.2 Groundwater Field Results

### 5.2.1 Groundwater Gauging

Description of the site-specific hydrogeology is based on observations of the shallow groundwater made during the site groundwater monitoring and sampling. Findings and observations with respect to the site-specific hydrogeology are summarised in **Table 5-2** below. It is noted that no investigation of any deeper water bearing layers was included in the Stage 4 DSI.

**Table 5-2 Hydrogeological Summary – Shallow Groundwater**

| Aspect | Results |
|---|---|
| Depth to Groundwater | SWLs for the shallow groundwater beneath the Assessment Area varied from approximately 2.083 m bgl (MW29, located at the western boundary of the Assessment Area) to 3.21 m bgl (MW18, located on the southern boundary of the western portion). |
| Depth to Groundwater (continued) | While a reading of 4.880 m bgl was recorded for MW31, it is apparent that this does not represent a stabilised groundwater elevation consistent with the other wells, and is this omitted from assessment of groundwater contours.<br>A summary of SWLs for this and previous AECOM investigations is presented in **Table 1** (**Appendix B**).<br>It is apparent that recorded groundwater elevations were generally comparable to those measured in May and June 2016. The majority of wells east of Railway Terrace reported SWLs typically within 0.3 m greater or less than June 2016 elevations, and within 0.3 m greater than May 2016 elevations, while most of the wells across the western portion of the Assessment Area reported slightly larger increases in elevation, most notably with increases of approximately 1 m compared to May 2016 elevations for wells MW18 and MW23 at the western perimeter of the 2016 well network. |
| Groundwater Inferred Flow Direction | Groundwater elevations calculated for monitoring wells across the site are tabulated in **Table 1** and varied between 15.593 m AHD (MW28, the most westerly well along the northern boundary of the Assessment Area) and 25.426 mAHD (GW1, the most south-easterly well, located within the southern Focus Site).<br>Inferred groundwater piezometric contours are presented graphically on **Figure 5**, and indicate groundwater flow in a west-north-westerly direction across the site.<br>Inferred contours for the Stage 3 investigation based on data from June 2016 indicated predominantly west north-westerly flow in the eastern portion of the Assessment Area, tending westerly in the western portion. The noted greater relative increases in elevation in wells in the western portion of the site, and notably in wells MW18 and MW23, have resulted in a more consistent west-north-westerly flow direction across the entire Assessment Area.<br>While it is possible that these wells had not fully equilibrated prior to gauging in 2016, and that the 2017 contours are thus a better representation of groundwater flow beneath the site, it is noted also that May 2016 salinity values for MW18 (especially) and MW23 were relatively low in comparison to the majority of other wells across the site, and were further decreased further in February 2017, suggesting that local recharge (surface water or leaking services) could also be responsible for the relatively greater change in elevation. Further temporal data would be required to assess whether this is a seasonal effect. |
| Groundwater Hydraulic Gradient | An average hydraulic gradient calculated for the shallow water bearing layer from the inferred groundwater contours (**Figure 5**) is approximately 0.008. There is a slight reduction in the hydraulic gradient evident in the north-western most extent of the monitoring network to approximately 0.005. |
| NAPL Presence | No non-aqueous phase liquid (NAPL) was detected during the gauging of the wells. |

### 5.2.2 Groundwater Field Parameters

Field parameters measured during groundwater sampling are presented in **Table 2** (**Appendix B**) and summarised in **Table 5-3** below.

**Table 5-3 Groundwater Field Parameters and Observations**

| Parameter | Results and Comments |
|---|---|
| pH | Groundwater pH values ranged from approximately 6.9 to 8.2, indicative of generally neutral conditions. The pH values recorded at development were generally marginally higher than those recorded at the time of sampling; this is potentially indicative of variation in the calibration of the field equipment. Within each event, however, stability of the pH readings contributed to AECOM's assessment of the representativeness of samples collected, and the pH accuracy is considered sufficient for these purposes. The range of pH results is consistent with those observed for the Stage 3 investigations. |
| Redox | Redox potential ranged from 65 to 255 mV indicating slightly to moderately oxidising conditions. These redox potentials would not generally be suggestive of conditions suitably reducing to enable material reductive dechlorination of PCE or TCE. |
| DO | Higher DO readings were obtained for the new wells during development than during sampling, consistent with agitation of the water column. However, DO readings still ranged between 0.37 and 3.73 mg/L during low flow sampling, likely indicative of varying degrees of aeration during sampling. The high results were noted to be not limited to those wells for which stabilisation of groundwater levels during sampling was not achieved. |
| EC and Calculated TDS | EC values ranged from 1639 µS/cm to 9372 µS/cm, a very similar range to that reported from the Stage 3 investigation. These values correspond to TDS values of the order of 980 mg/L to 5600 mg/L. The highest salinity values were reported for MW10, MW14, MW22, MW27 and MW30, located in the central and north-western area; while the lowest were reported for MW18 (in the south-west) and MW19, MW24 and MW25 (in the north-east). A graphical plot of salinity values (as TDS) across the site based on field data is presented as **Figure 11**, and illustrates the distribution of zones of high and low salinity. |
| Temperature | Recorded water temperatures ranged from 19.1 to 29.5 degrees Celsius. |
| Odour | No odour was noted for any of the groundwater samples. |

## 5.3 Groundwater Laboratory Results

Groundwater analytical laboratory reports and COC documentation are presented in **Appendix I**. Tabulated summary results and graphical presentations for the targeted contaminants of potential concern are presented as follows:

Figure 6: Groundwater Analytical Results – February 2017

Figure 7: TCE Concentrations in Groundwater – February 2017 (µg/L)

Figure 8: PCE Concentrations in Groundwater – February 2017 (µg/L)

Figure 9: 1,1-DCE Concentrations in Groundwater – February 2017 (µg/L)

Figure 10: 1,2-DCE Concentrations in Groundwater – February 2017 (µg/L)

Figure 11: Total Dissolved Solids in Groundwater – February 2017 (mg/L)

Table 7: Groundwater Analytical Results – Regulatory (EPP 2003) Criteria

Table 8: Groundwater Analytical Results – regulatory (EPP 2015) and Risk Based Criteria

Table 9: Historical Groundwater Analytical Results

### 5.3.1 Screening Criteria

The groundwater screening criteria adopted for this investigation were devised in consideration of:

- Regulatory water quality criteria, being the most stringent of the SA EPA (2003) Environmental Protection (Water Quality) Policy (EPP) criteria for each of the protected environmental values
- Regulatory water quality criteria, with reference to the SA EPA (2015) EPP
- Risk-based criteria selected in consideration of realistic potential beneficial uses of groundwater in the vicinity of the site, sourced from other Australian and international publications
- The World Health Organisation (WHO) Guidelines for Drinking-water Quality (referred to for TCE only, in the absence of other applicable criteria).

The selection of groundwater assessment criteria is detailed in **Appendix Q**.

The adopted assessment criteria are presented on **Tables 7** and **8** (**Appendix B**).

### 5.3.2 Groundwater Analytical Results

**Table 5-4** provides a summary of groundwater analytical results for halogenated aliphatics.

**Table 5-4 Summary of Groundwater Analytical Results for Monitoring Wells - VHAs**

| VCH | Units | Adopted Guideline Value (µg/L) | Min Result | Max Result | Wells Exceeding EPP Guidelines | Wells Exceeding NEPM/WHO* Guidelines |
|---|---|---|---|---|---|---|
| 1,1-DCE | µg/L | 30 | <LOR | 31 | MW12 | MW12 |
| 1,1-DCE | µg/L | | <LOR | 1.3 | MW22 | - |
| 1,2-DCE | µg/L | 60 | <LOR | 55 | - | - |
| 1,2-DCE | µg/L | 3 | <LOR | 1.5 | - | - |
| TCE | µg/L | 20 | <LOR | 560 | (No TCE guideline) | GW02, GWA, GWB, MW01, MW02, MW04, MW05, MW06, MW07, MW10, MW11, MW12, MW13, MW15, MW19, MW20, MW21, MW22, MW26, MW27, MW31, MW34, MW36, MW37 |
| PCE | µg/L | 40 | <LOR | 140 | GWA, MW12, MW13, MW15, MW19, MW20 | GWA, MW12, MW13, MW15, MW19, MW20 |
| Vinyl chloride (VC) | µg/L | 0.3 | <LOR | 2.3 | MW05, MW07, MW20 | MW05, MW07, MW20 |

** In the absence of a NEPM Investigation Level for TCE, the WHO Drinking Water Guideline of 20 µg/L is adopted*

Final VHA degradation parameters methane, ethane and ethene were reported below the LOR in all groundwater monitoring wells sampled.

### 5.3.3 Extent and Magnitude of Groundwater Impact

The results of groundwater analyses are presented in numerical form on **Figure 6** attached; inferred contour plots for TCE, PCE, 1,1-DCE and 1,2-DCE are presented on **Figures 7**, **8**, **9** and **10** (**Appendix A**).

As shown on **Figure 7** the overall envelope of VHA impacts to shallow groundwater spans virtually the full extent of the groundwater monitoring network and thus almost the entirety of the Assessment Area. As such, the VHA plume has not been delineated to concentrations less than laboratory LOR in any direction, with the exception of the three northern-most wells in the eastern portion of the Assessment Area (MW24, MW25 and MW35).

While the majority of perimeter wells reported TCE concentrations above LOR, all perimeter wells except MW11 (36 µg/L) near the southern boundary of the eastern portion of the Assessment Area, MW31 (80 µg/L) on the southern boundary of the Assessment Area adjacent Railway Terrace and MW37 (560 µg/L), approximately 200 m west of the eastern boundary, reported TCE concentrations less than the WHO drinking water guideline of 20 µg/L. On this basis, the overall VHA impacts to shallow groundwater are considered practicably delineated to less than the drinking water guidelines, other than to the south and up-hydraulic gradient to the east.

TCE impacts in shallow groundwater are widespread across the Assessment Area. The relatively sparse distribution of groundwater monitoring wells (generally separated spatially by 100 – 200 m across most of the Assessment Area) allows for various interpretations of the data and at this point precludes definitive attribution of observed impacts to specific sources.

Elevated TCE concentrations are present in shallow groundwater beneath both Focus Sites; however, the relatively low concentrations reported for wells located immediately down-hydraulic gradient (wells MW01 (46 µg/L) and MW06 (32 µg/L) for the southern Focus Site (FS1), and wells MW04 (29 µg/L) and MW05 (52 µg/L) for the northern Focus Site (FS2)) do not provide definitive evidence to link these Focus Site groundwater impacts to the elevated concentrations present to the north-west.

Despite the presence of low concentrations in MW04 and MW05 (consistent with the Stage 3 investigation), the TCE concentration in MW07 (310 µg/L) located less than 250 m directly down-hydraulic gradient (**Figure 5**) of the northern Focus Site is again of similar magnitude to those in shallow groundwater at the Focus Site. It remains likely that these impacts are related, noting that the VHA impacts in these wells appear of consistent composition, comprising primarily TCE with negligible PCE. The ongoing observation of low VHA concentrations at MW10 (40 µg/L) located further down-gradient, and the presence of elevated concentrations at MW21 (270 µg/L) to the south-west, contribute to uncertainty as to the extent of impacts originating from the Focus Sites and the possible presence of other sources in this area.

The newly installed well MW34 appears to have demonstrated a link between VHA impacts observed in MW12/MW19 and in down-gradient wells MW20, MW22 and MW15 that was apparent from the Stage 3 investigation results. Reported VHA concentrations for the two additional wells (MW36 and MW37) installed to investigate the area up-gradient of MW12 are indicative of this plume extending in an east-south-easterly direction, inconsistent with the source being related to either of the Focus Sites. The assessment of the relationship between impacts in wells MW37, MW36, MW12, MW34, MW20, MW13 and possibly MW15 is further supported by the consistent presence of PCE across this band of wells (refer **Figure 8**), indicative that this plume, at least in part, originates from a different source or sources than the Focus Sites, beneath and down-gradient of which there are notably lower concentrations of PCE.

**Figure 9**, showing 1,1-DCE impacts, provides further support for a common source of impacts observed at wells MW37, MW36, MW12 and MW20, with 1,1-DCE impacts limited to well MW37 and down-gradient wells, and delineated within the Assessment Area. 1,2-DCE impacts (**Figure 10**), by comparison, are consistent with impacts arising from the Focus Sites, but are potentially indicative of impacts from the Focus Sites and other sources to the north contributing to a co-mingled down-gradient plume.

Consistent with the findings of the Stage 3 investigation, there appears to be a disconnect between TCE impacts in well MW21 (270 µg/L) in the southern portion of the Assessment Area and the up-gradient materially impacted well MW07 (310 µg/L). Relatively low TCE concentrations for wells MW8 (19 µg/L) and MW10 (40 µg/L), located between MW07 and MW21, contribute to the appearance of a disconnect between elevated concentrations in MW21 and those to the east and north-east. It is noted that well MW10 exhibited poor yield (both in 2016 and 2017) and has materially higher salinity than surrounding wells, and it is possible that limited connection to the aquifer has an influence on groundwater concentrations at this location.

Reference to **Figure 8** shows that PCE impacts are identified in the immediate vicinity of the northern Focus Site (FS2), but are present at greater concentrations at MW12 (120 µg/L) located in the northern portion of the Assessment Area west of Calstock Avenue, and notably, in well MW37 (140 µg/L) located north of Conmurra Avenue and unlikely to be hydraulically down-gradient. Impacts in wells MW13 (57 µg/L), MW19 (59 µg/L), MW20 (66 µg/L), MW34 (58 µg/L) and MW36 (78 µg/L) also exceed the NEPM (2013) Drinking Water criterion of 50 µg/L. The observed impacts are expected to be associated with a source area within or beyond the eastern portion of the Assessment Area.

The PCE impacts appear to be delineated (to concentrations below investigation levels) within the Assessment Area.

### 5.3.4 Temporal trends in Groundwater VHA Concentrations

Temporal groundwater data is available for the 13 wells installed as part of previous investigations on and in the vicinity of the Focus Sites and the 20 wells installed by AECOM in 2016.

Review of the current and historical VHA concentration data (presented in **Table 9** (**Appendix B**)) indicates generally good consistency between data sets, with no clear overall increasing or decreasing trend evident. The majority of TCE concentrations were steady or slightly decreased in 2017, with minor increases evident in three wells exhibiting relatively low concentrations (MW04 (29 µg/L), MW05 (52 µg/L) and MW10 (40 µg/L)); these increases are not considered material with respect to interpretation of the extent of impacts or assessment of risk.

Rather, the high degree of consistency between the 2016 and 2017 results is considered indicative of the reliability of the groundwater data for use in evaluation of human health risk.

## 5.4 Soil Vapour Field Screening

Both prior to and following soil vapour sampling from each of the new and existing soil vapour wells, AECOM screened for VOCs using a PID connected to the sampling train. The recorded PID measurements are shown in **Table 10** (**Appendix B**), together with measurements of $CH_4$, $O_2$ and $CO_2$. The PID was equipped with a 10.6 eV lamp, which is suitable for detection of VHAs TCE, PCE, 1,1- and 1,2-DCE and VC.

There was observed to be generally reasonable agreement between pre- and post-sampling PID readings.

## 5.5 Soil Vapour Analytical Results

### 5.5.1 Screening Criteria

The NEPM includes soil vapour health investigation levels (HILs) for some VHAs, including TCE, and has adopted the US EPA Reference Concentration (RfC) for TCE (but not, however the US EPA PCE update). While these NEPM criteria are for soil vapour, rather than indoor air, they are based on a review of international ambient air guidelines (or equivalent inhalation-based toxicity data). The NEPM then converted these to soil vapour criteria by multiplying by a soil vapour to indoor air attenuation factor of 10. Residential HILs have been referenced for this assessment.

It is noted that the NEPM does not include a screening criterion for *trans*-1,2-DCE, however the ASC NEPM introduction to *cis*-1,2-DCE includes the following assessment of the trans-isomer toxicity:

"*cis-1,2-DCE is considered to be more toxic than trans-1,2-DCE and hence the HILs derived for the cis-isomer are adequately protective of exposures associated with the trans-isomer*".

There are no NEPM soil vapour guidelines for 1,1-DCE, however the US EPA provide an ambient air guideline for residential exposure for 1,1-DCE of 210 µg/m$^3$. Based on application of a conservative, 10-fold soil vapour to indoor air attenuation factor (consistent with the NEPM interim HIL derivation), a soil vapour screening level of 2100 µg/m$^3$ can be derived for 1,1-DCE; similar to the PCE soil vapour HIL in the NEPM.

### 5.5.2 Analytical Data

Laboratory certificates for the analysis of VHAs from summa canister samples are attached as **Appendix M**. Tabulated summary results and graphical presentations of selected VHAs are presented as follows:

Figures 12A and 12B: Soil Vapour Bore Results, Jan – Feb 2017

Figure 13: Soil Vapour TCE Concentrations (1.5 m bgl) – Jan – Feb 2017

Figure 14: Soil Vapour PCE Concentrations (1.5 m bgl) – Jan – Feb 2017

Table 11: Soil Vapour Analytical Results

Table 12: Historical Soil Vapour Analytical Results

**Table 5-5** below presents a summary of the results for VHAs for sampling conducted in January/February 2017.

**Table 5-5 Summary of Soil Vapour Analytical Results - VHAs**

| VCH | Units | Min Result | Max Result | Criteria Value | Wells Exceeding Guidelines |
|---|---|---|---|---|---|
| 1,1-DCE | µg/m$^3$ | < LOR | 3,300 | 2100** | VP29 |
| cis-1,2-DCE | µg/m$^3$ | < LOR | 41,000 | 80 | VP10 1.0, VP11 1.0, VP29 |
| trans-1,2-DCE | µg/m$^3$ | < LOR | 11,000 | None | - |
| PCE | µg/m$^3$ | < LOR | 1,200,000 | 2000 | VP11 1.0, VP12 1.0, VP18, VP29, VP63 |
| TCE | µg/m$^3$ | < LOR | 6,500,000 | 20 | H03 VP01, H04 VP01, H06 VP01, H08 VP01, H09 VP01, VP01-VP14, VP17-VP18, VP22-VP25, VP28-VP33, VP39, VP41, VP43-VP44, VP47-VP53, VP60, VP63-VP64, VP66 |
| VC | µg/m$^3$ | < LOR | < LOR* | 30 | None* |

* It is noted that for four samples (VP10 1.0, VP11 1.0, VP12 1.0 and QC06 (VP29)) the VC LOR was increased above the NEPM criteria value of 30 µg/m$^3$.

** 1,1-DCE guideline adapted from US EPA Regional Screening Level (refer **Section 5.5.1**).

### 5.5.3 Comparison of Analytical Data to Field Screening Results

A comparison of AECOM's reported total VOC concentrations to the post-sampling PID readings is shown in **Appendix O**. Comparison of PID data to the laboratory measured total VOC concentrations, while generally illustrative of a reasonable correlation and providing confidence in the laboratory data, is not indicative of a sufficiently reliable and accurate correlation for PID screening of soil vapour wells alone to be used as an qualitative assessment of soil vapour in the monitoring well network.

### 5.5.4 Spatial Distribution

**Figure 13** shows the distribution of TCE in soil vapour across the network of soil vapour bores sampled by AECOM in 2017 (it is noted that the soil vapour well network does not extend as broadly as the groundwater monitoring well network), with **Figure 14** showing PCE in soil vapour.

Elevated VHA concentrations in soil vapour are present extending across the Assessment Area from an apparent source zone or zones at the eastern end. The overall VHA vapour plume appears to be delineated to the north and south within the Assessment Area, although the two northern perimeter vapour bores along Beaconsfield Terrace west of Railway Terrace reported low TCE concentrations (and in VP54, an elevated PCE concentration), despite the row of bores to the south along Seymour

Terrace reporting concentrations <LOR; the Beaconsfield Terrace bore results may be unrelated to the main TCE and PCE vapour plume. The VCH vapour plume has not been delineated to the west, with the central westernmost bore (VP60, located approximately 300 m east of the Assessment Area perimeter) reporting low concentrations of TCE and PCE. The up-gradient extent of the plume has not been determined.

The 2017 soil vapour analytical results are presented in **Table 11** (**Appendix B**). The following additional observations are made:

- TCE and PCE impacts in soil vapour are present at the Focus Sites and down-hydraulic gradient. Elevated vapour concentrations at VP09 and VP14 appear likely to be related to groundwater impacts arising from the Focus Sites. TCE vapour impacts observed at down-gradient location VP28 appear to be consistent with a concentration gradient from VP09, although this is less evident for PCE; further, it is noted that corresponding groundwater well MW10 reported a relatively low groundwater TCE concentration, as discussed below.
- Very high TCE and PCE impacts are reported for vapour well VP29 west of Calstock Avenue. Soil vapour TCE impacts extend to the east of VP29 (MW12 location), with elevated concentrations at VP18, VP41 and VP66. Despite the presence of lower concentrations at interim locations VP64 and VP65, it would appear these impacts are related to a source area to the east.
- Elevated TCE (and to some extent, PCE) soil vapour impacts at soil vapour well VP25 indicate some up-gradient spread of vapour impacts from the Focus Sites; up-gradient groundwater wells within the Focus Sites indicate low groundwater TCE and PCE concentrations.

### 5.5.5 Comparison of 2017 Analytical Data to Historical Soil Vapour Data

To provide further confidence in the soil vapour data, results for the soil vapour wells installed prior to this investigation were compared to soil vapour data reported by AECOM in 2016 and by Fyfe for the 2015 investigation.

The comparison is tabulated in **Appendix O**; it is apparent that despite general consistency in terms of the presence of low, moderate or high levels of impact, there remains considerable variability between the 2016 and 2017 results at some locations. There is no indication of a systematic error (such as consistent under- or over-reporting for either event), consistent with previous comparison of the AECOM (2016) and Fyfe (2015) data sets.

The historical soil vapour analytical results are presented in **Table 12** (**Appendix B**). Notable trends or variation apparent from comparison of the historical data sets include:

- TCE (and PCE) concentrations at VP04 (approximately 30 m north-west of the northern Focus Site) in December 2015 were over an order of magnitude higher than for May 2015, but were reported in May 2016 at close to May 2015 levels. Results for February 2017 were increased to close to December 2015.
- TCE and PCE concentrations at VP05 (approximately 50 m down-gradient of the northern Focus Site) were consistent in May 2016 and February 2017, having reduced by almost an order of magnitude from those reported for May 2015.
- TCE concentrations in VP08 (over 150 m west of the southern Focus Site) have consistently increased over 3 events to May 2016, but remained of approximately the same order of magnitude, such that no definite trend was established. Bore VP08 could not be sampled in February 2017.
- Apparent increasing concentrations across 3 events in VP14, hydraulically down-gradient of and approximately 200 to 250 m from the Focus Sites.
- Apparent decreasing concentrations across 3 events in VP28, also down-gradient of the Focus Sites but on the southern fringe of an apparent northern vapour plume (refer **Section 5.5.5**).
- Apparent consistency between 2016 and 2017 TCE and PCE results for VP29 following a significant increase from 2015; this location reported the highest TCE vapour result for the northern vapour plume.

- TCE and PCE concentrations were higher in May 2016 than December 2015 (by a factor of approximately 2 or more) in VP30, VP31 and VP32, located between 150 m and 250 m down-gradient of VP29. Results for February 2017 were generally closer to December 2015 levels; the most recent data does not support an increasing trend in these bores.
- Apparent increases between 2016 and 2017 for VP48 (120 to 710 µg/$m^3$) and VP52 (520 to 3700 µg/$m^3$); these locations are in the western portion of the northern plume, and represent the most down-gradient locations for which temporal data is available. It should be noted that as discussed in **Section 5.6.1**, groundwater data does not provide any indication of plume expansion in the western portion of the Assessment Area.
- It is noted that VHA concentrations (notably TCE and PCE) were up to one to two orders of magnitude higher in 2017 than in 2015 for bores H03_VP01, H04_VP01, H06_VP01, H08_VP01 and H09_VP01, none of which were sampled in 2016. Fyfe (2016) noted that vapour concentrations in these wells were appreciably less than in wells VP01 to VP03 drilled in the nearby road verges; with the observed increases, it is apparent now that results are of the same approximate magnitude (noting that direct comparison is precluded by the different depth of screening).

Given the magnitude of variability generally observed, further temporal data would be required for confidence in any of these apparent trends.

## 5.6 Critical Review of Soil Vapour and Groundwater Data

### 5.6.1 Comparison of Vapour and Groundwater Data

**Spatial distribution**

The overall distribution of TCE and PCE concentrations in soil vapour is generally consistent with groundwater impacts representing the source of the observed vapour, and sources at both the Focus Sites and another location (or locations) to the north.

Several inconsistencies have been noted, such as:

- the highest vapour concentration at VP10 (southern Focus Site 1) and VP11 and VP12 (northern Focus Site 2) are not accompanied by correspondingly high groundwater concentrations, indicative of the residual presence of soil impacts contributing to these elevated vapour results;
- low vapour concentrations are reported for VP15, despite its location near MW21 at which high concentrations were reported for groundwater; and
- vapour impacts continue to be observed at VP25, up-gradient of the Focus Sites.

In the absence of further data, these inconsistencies cannot be definitively explained. Possible explanations include preferential pathways for vapour transport in the subsurface, limited connectivity of wells to the aquifer, soil VHA impacts, and additional sources. Further spatial and temporal data will enable an assessment of these inconsistencies, which are noted to not affect the broader interpretation of the magnitude and extent of impact across the Assessment Area.

While there are individual discrepancies apparent from comparison of groundwater and soil vapour, as noted above, comparison of the distribution of vapour and groundwater impacts (**Figure 13** and **Figure 7**, respectively) suggests a reasonable overall correlation.

**Comparison of Soil Vapour Data to Theoretical Values Based on Groundwater Concentrations**

**Table 15** (**Appendix B**) presents a comparison, for each paired vapour well and groundwater well, of measured soil vapour concentrations to the theoretical maximum soil vapour concentration based on application of Henry's Law Constant, for cis-1,2-DCE, TCE and PCE.

It is observed that for the majority of locations, the recorded soil vapour concentrations were significantly lower than the theoretical maximum values (typically below approximately 4% of the theoretical value, and in almost all cases below 9%). These findings are consistent with observations from the Stage 3 investigation.

Exceptions to this were noted at three locations only:

- At VP29/MW12, the recorded cis-1,2-DCE concentration was 11.2% of the theoretical maximum (9% for 2016), and the TCE and PCE concentrations in soil vapour were 16.2% (18.7% in 2016) and 16.1% (17% in 2016), respectively, of the theoretical maxima based on measured groundwater concentrations.
- At VP54/MW33, a PCE vapour concentration of 430 µg/$m^3$ was reported despite PCE reporting less than LOR in groundwater; based on the LOR of 1 µg/L, this represents 59% of the theoretical maximum vapour concentration.
- At VP27/MW09, cis-1,2-DCE was reported at 13.8% of the theoretical maximum.

With the noted exception of PCE at VP54/MW33, and consistent with the Stage 3 findings, the soil vapour results are considered to be low in comparison to theoretical maximum values, even taking into account that vapour measurements were conducted typically 1.0 to 1.5 m above the groundwater level. This phenomenon (lower vapour than the theoretical maximum) is consistent with literature observations. Shen *et al* (2012) concluded that under certain conditions of rainfall and infiltration, a *clean water lens* may form on top of contaminated groundwater. As the diffusion coefficients for solutes such as these VOCs in groundwater is approximately 4 orders of magnitude lower than their relative diffusion coefficients in air, this clean water lens can act to greatly slow the diffusion of vapour from the groundwater source.

As such, standard groundwater sampling techniques that may effectively integrate sample concentrations across several metres of thickness of well screen may greatly over-estimate the potential vapour concentrations generated from the relatively less contaminated lens located at the groundwater-vadose zone interface.

The US EPA (2012a) also acknowledges this effect in the 2012 *Conceptual Model Scenarios of the Vapor Intrusion Pathway*, with Section 6.4.2 noting:

*In locations where there is significant infiltration through the unsaturated zone, a layer of clean groundwater may build up on top of the contaminated groundwater plume and act as a barrier to VOC volatilization from the groundwater to soil gas and may decrease the soil vapor concentration distribution in the subsurface. This process has been referred to as clean water lens (Fitzpatrick and Fitzgerald, 1996) and diving plumes (Griesemer, 2001). Also, if the soil is coarse grained and there is high downwards drainage of the infiltrating water through the soil, the water may flush the contaminant from the soil gas as it infiltrates down the subsurface, which may also decrease the soil vapor concentration (Mendoza and McAlary, 1990).*

At VP54/MW33, it is noted that only one set of data exists. Well MW33 exhibited slow recharge, and again it is possible that this well is isolated from the surrounding groundwater; however, this well is not expected to be in an area of elevated groundwater impact. It is possible that the reported PCE in soil vapour is attributable to a local soil source.

**Comparison of Trends in Groundwater and Vapour**

As noted in **Section 5.3.4**, review of the current and historical VHA concentration data for groundwater did not indicate any clear overall increasing or decreasing trend. The majority of TCE concentrations were steady or slightly decreased in 2017, with minor increases evident in three wells exhibiting relatively low concentrations (MW04, MW05 and MW10), which correspond to soil vapour bores VP05, VP06 and VP28. By contrast, vapour concentrations in VP05, VP06 and VP28 appear to show a declining or steady trend.

No co-located wells are available to provide groundwater data adjacent the western area soil vapour bores VP48 and VP52 which appear to show an increasing trend; however, groundwater results for nearby wells MW15, MW16, MW22 and MW23 do not show any evidence of increasing concentrations which might indicate expansion of the plume.

## 5.7 Crawl Space Sampling

### 5.7.1 Screening Criteria

There are no Australian guidelines for crawl space vapour. Crawl space data is utilised in refinement of the conceptual model of attenuation from soil vapour to crawl space to indoor air concentrations, and in assessment of temporal trends through comparison to historical data.

The US EPA (2012b) provides empirical estimates of attenuation factors for chlorinated solvent vapour intrusion into residential properties. The document concluded that little attenuation generally occurs between the crawl space and indoor with a median attenuation factor of 0.4 and a 95 percentile attenuation of 0.9. The document does however note that these results may alternatively reflect air exchange between indoor and crawl space leads to approximate equilibrium between the two locations.

Based on the 95 percentile findings, of essentially no reduction in concentration between crawl space and indoor air, relevant indoor air screening criteria have been adopted for comparison of crawl space data.

### 5.7.2 Analytical Data

The laboratory results for VHAs for the crawl space sampling are provided in **Table 13** (**Appendix B**), while comparison to historical results is presented in **Table 14**. The laboratory certificate for the crawl space samples is attached in **Appendix M**.

TCE was reported above the LOR in only one sample (CS13 – 0.92 µg/m$^3$), below the adopted indoor air guideline of 2 µg/m$^3$. All other analytes were reported below the limits of reporting and adopted guidelines.

Previously, in sampling by Fyfe in December 2015, all residential crawl space samples analysed using summa canisters reported VHA concentrations below LOR. The highest reported concentration using Radiello samplers was 3.5 µg/m$^3$ for sample CSR-8, with the remainder ranging from <0.02 to 0.26 µg/m$^3$.

## 5.8 Potential Sources

The Focus Sites, at which industrial electroplating activities have historically been conducted, have previously been identified as probable source sites for VHA impacts to groundwater (and thus soil vapour) within the Assessment Area.

Based on the results of the investigations to date – specifically, the spatial distribution of impacts and the presence of PCE and 1,1,DCE at concentrations considered inconsistent with the Focus Sites being the source – at least one further source is considered present. With the additional groundwater data from wells MW36 and MW37 indicative of elevated VHA impacts in groundwater at these locations, it is inferred that one or more source sites are present within or beyond the eastern portion of the Assessment Area, north of the Focus Sites.

While a detailed review of current, recent and historical land use within and to the east of the Assessment Area was outside the scope of this investigation, AECOM has completed a cursory inspection of the on-line Sands and McDougall business directories. This review confirmed the presence, in the mid-1960s to early 1970s, of a number of businesses that based on the probable site activities could have been sources of VHA impact to soil and groundwater. Notable commercial/industrial businesses historically located within or just to the west of the Assessment Area, north of Conmurra Avenue and south of Dunorlan Road, included the following:

- Electroplaters (north of Deloraine Road)
- Sheet metal workers
- Bitumen pavement manufacturer
- Engineering workshop
- Spray painter

- Industrial chemicals

While the relatively coarse investigation grid to date and the absence of groundwater wells and limited presence of soil vapour bores up-gradient of MW37 preclude a more definitive location of the source, the historical presence of the above businesses (and potentially more) is considered consistent with the possibility of further sources as interpreted from the groundwater and soil vapour data.

# 6.0 Updated Conceptual Site Model

A Conceptual Site Model was developed by Fyfe on the basis of their 2015 investigation and previous site data, and updated by AECOM in 2016 on the basis of the results of the Stage 3 assessment. This CSM has been further refined on the basis of the findings of the Stage 4 assessment, and is presented in the following sections.

## 6.1 Site Characterisation

### 6.1.1 Assessment Area

The Assessment Area, as defined by the EPA and shown on the plan in **Section 1.1**, is approximately 85.6 hectares, extending from Coongie Avenue and Clarke Avenue in the east to Marion Road in the west, and from just south of Konando Terrace (and from Fourth Avenue west of the railway) to Weaver Street and Beaconsfield Terrace in the north.

### 6.1.2 History of Land Use

The two Focus Sites are known to have been used for electroplating activities and have been identified as sources of VHAs to groundwater. Search of on-line archives (Sands and McDougall business directories[2]) indicated that in the early 1970s, the current Focus Site at 15-17 Arabrie Avenue included the business Australian Heat Treatment P/L (Electro Plating Division) at No 17. While Australian Heat Treatment was listed at 19 Arabrie Avenue as far back as 1957, the business is only noted at No 17 from 1967 onwards. In the absence of a more detailed site history assessment, it is thus assumed that potentially contaminating activities (at Focus Site 2, at least) may have been occurring since at least as far back as 1967.

The mixed residential and commercial/industrial land use across the broader Assessment Area presents the potential for additional sources of impact, noting that industrial land uses are currently and appear to have been historically concentrated at the eastern end of the Assessment Area (and beyond to the east).

### 6.1.3 Previous Investigations

Investigations previously conducted by AEC/Greencap, Fyfe and AECOM are summarised in **Section 2.3**.

## 6.2 Assessment Area Setting

### 6.2.1 Local Geology

The natural soil profile across the site is generally consistent with the Quaternary Hindmarsh Clay formation, comprising predominantly silt and clay (medium to high plasticity) with a lesser component of sand and, at most, minor gravel.

### 6.2.2 Assessment Area Geology

Borehole logs for the groundwater wells provide an indication of soil conditions broadly across the Assessment Area to a depth of 5 to 6 m.

Fill was observed generally to depths of 0.3 m to 0.6 m, comprising variably clayey sand, sandy clay and gravelly sand. At one location (MW24), fill was encountered to a depth of 0.9 m, and was assessed to include trench backfill sands.

Natural soils comprised generally silty clay of medium to high plasticity, commonly with increasing (but generally minor) sand content at depth. A minority of wells including MW18 and MW32, on the southern boundary of the Assessment Area, and wells MW34, MW35, MW36 and MW37, in the eastern portion of the Assessment Area, were noted to encounter a clayey sand layer at depth. The thickness of this more permeable layer was between 0.5 and >2 m and typically occurred toward the base of the shallow wells.

[2] http://guides.slsa.sa.gov.au/c.php?g=410329&p=2794474

The driller's log for a private well in the western portion of the Assessment Area, which was sampled as part of the Stage 3 investigation, indicates clay to 18 m depth, clay and sand from 18 m to 20 m, and a sand layer (producing water) from 20 m to 24 m. From 24 m to 26 m the log shows sand and clay, with grey clay again encountered from 26 m to 29 m.

### 6.2.3 Regional Hydrogeology

The site, lying between the Eden-Burnside Fault to the south-east and the Para Fault to the north-west, is expected to be underlain by two to four Quaternary aquifers and three to four Tertiary aquifers.

The uppermost Quaternary aquifer is encountered at depths of between approximately 2.4 m and 3.2 m, with groundwater flow in a west-north-westerly direction. Groundwater elevations within the Q1 aquifer beneath the Assessment Area range between 16 and 25 m AHD (see **Figure 5**).

The Central Adelaide Plains Prescribed Wells Area observation network does not incorporate any Q1 aquifers in the vicinity of the site however regional groundwater flow in the unconfined regional aquifer is anticipated to be towards the north-west (Gerges, 2006), consistent with local interpretations of flow.

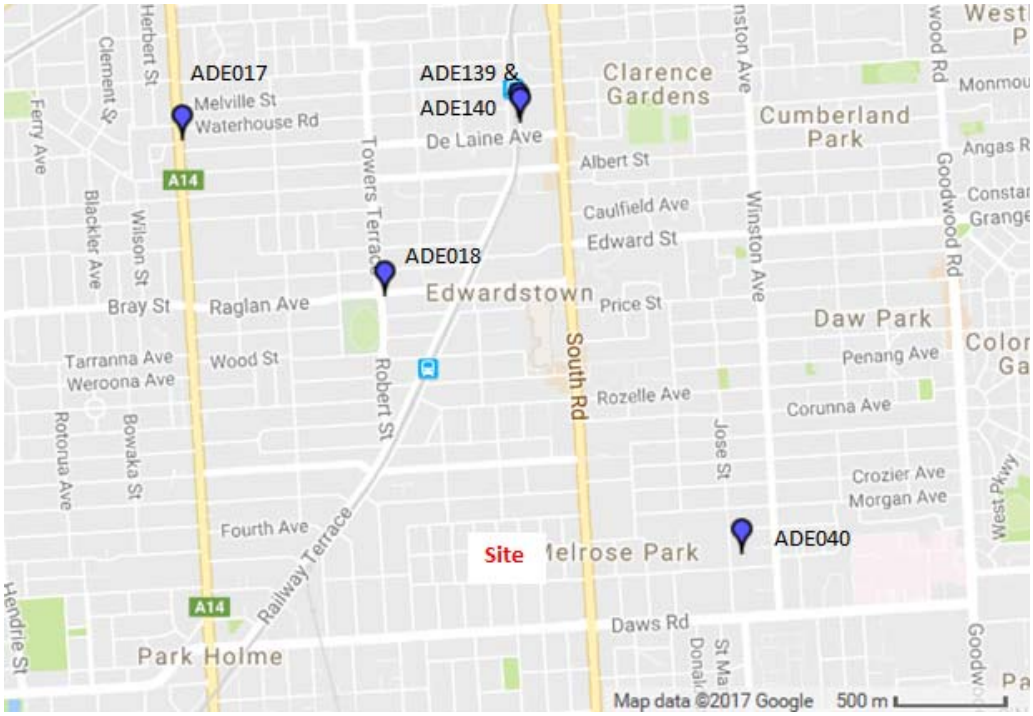
**Figure 6-1** below shows the location of the regional network monitoring wells within relatively close proximity to the site.

The closest regional observation network well monitored by DEWNR is ADE040 (6628-7974) located approximately 1 km east of the Focus Site. Drilled to 73 m bgl it monitors the uppermost Tertiary aquifer (T1a). A detailed hydrostratigraphic log is provided for this well and identifies 44 m of Hindmarsh Clay overlying the Hallett Cove Sandstone (T1a) however it has not been gauged since 1988 and all previous gauging events were conducted during pumping and hence were identified on the Water Connect database as anomalous (DEWNR, 2016b).

Other T1 observation network wells ADE017 (6628-8105) and ADE018 (6628-8115) are located to the northwest of the site are of similar depths (76 and 61 m bgl respectively). These regularly monitored wells report groundwater elevation ranges between 1 and 10 m AHD, which is typical of a confined aquifer subject to seasonal effects (pumping or recharge).

ADE139 (6628-12255) has a depth of 148 m and is constructed within the T2 aquifer, whilst the nearby ADE140 (6628-12256) is constructed within the T3 aquifer (drilled to 256 m). Both were last gauged in March 2000 with groundwater elevations of 24.94 m AHD and 22.76 m AHD respectively. Historically the T3 groundwater elevations were 2 to 6 m higher than the nearby T2 aquifer.

**Figure 6-1 Nearest DEWNR Regional Observation Network Monitoring Wells (from Water Connect)**



The groundwater level in the Q1 aquifer is approximately 15 to 20 m above the piezometric level in the T1, implying a high degree of hydraulic separation between the two, with a downward vertical hydraulic gradient from the Q1 to the T1. It should also be noted that the Q2 and Q3 aquifer units are likely to be present between the Q1 and the T1 aquifers and where they have lower heads, would intercept water seeping vertically down from the Q1. If they have higher heads, this would reverse the local vertical head gradient, further reducing the potential for vertical migration from the Q1.

Gerges (2006) identifies that there is very little head difference between the Q1 and Q2 aquifers based on limited information and he suggests that this is either due to effective hydraulic connectivity between the two aquifers or inadequate isolation of the aquifers during well construction.

During the available combined observation period (1983 to 2000) the piezometric level in the T1 aquifer was lower than in the underlying T2 aquifer, with the T3 piezometric level generally being higher still. This indicates an upward hydraulic gradient from the T3 aquifer towards the T1.

For the portion of the ADE observation network reviewed, the salinity was between 1,000 and 2,000 mg/L TDS and yields >10 L/s in the T1 wells, with the T2 well reporting much higher salinity (9,600 mg/L) and moderate yield (3 L/s). The deeper adjacent T3 well reported low salinity (198 mg/L) and low yield (0.2 L/s). On this basis it is likely that in the vicinity of the site the T1 aquifer would be used for industrial scale abstractive purposes over other deeper Tertiary aquifers.

It is noted however that domestic and irrigation wells identified in the groundwater bore search (see **Section 2.2.3**) identified shallower operational wells. It is possible that deeper permeable horizons within the Hindmarsh Clay provide better yields at suitable salinities.

The interaction of the deeper Hindmarsh Clay sub-aquifers and the uppermost unconfined Q1 aquifer is unknown as is the thickness of the more permeable layer(s) which were identified generally at the base of the investigation monitoring wells.

### 6.2.4 Assessment Area Hydrogeology

The above information is generally consistent with AECOM's observations, although in 2017 groundwater was observed at depths ranging from 2.0 to 3.2 m bgl, and TDS values ranged from approximately 980 mg/L to 5,600 mg/L.

Investigation wells were typically drilled to 5 or 6 m bgl with a 3 m screen across silty clay. Interpreted groundwater contours based on standing water level data are presented in **Figure 5** and indicate groundwater flow in the uppermost water bearing zone predominantly west-north-westerly across the Assessment Area.

Based on the January 2017 interpolated contours, the hydraulic gradient is estimated at 0.008 between the 25 and 17 m AHD contour lines which are reasonably equally distanced. A slightly lower gradient of 0.005 is observed between the 16 and 17 m AHD contours at the north-west extent of the monitoring network.

Hydraulic conductivities (K) were estimated from slug tests conducted in the previous Stage 3 program (AECOM, 2017). The estimated hydraulic conductivities reported were low, ranging from 0.05 m/d up to 0.5 m/d (geometric mean of 0.1 m/d). Given the smooth and reasonably low hydraulic gradient and the extent of dissolved TCE impact in shallow groundwater, it was implied that hydraulic conductivities must be greater to account for the contaminant plume length currently observed.

It is likely that preferential flow occurs along the sandier horizons within the wells and on this assumption the slug test raw data was re-analysed to consider a 1 m aquifer thickness as implied by the lithological logs. Re-interpretation of the raw data and review of the lithological logs is presented in **Appendix R**. **Table 6-1** shows the original estimates and revised estimates of hydraulic conductivity along with yield observations during well development, salinity information and contaminant concentrations.

The table shows that for the wells selected for aquifer testing, there appears to be no direct correlation between aquifer permeability (yield and estimated hydraulic conductivity) and salinity; nor does there appear to be a correlation between salinity and the magnitude of TCE impact.

**Table 6-1 Revised hydraulic conductivity estimates compared with other well information**

| Well | Original K (m/d) | Revised K (m/d) | Development Notes on Yield | TDS (mg/L)* | Total VCH (ug/L) 2017 | TCE (ug/L) 2017 |
|---|---|---|---|---|---|---|
| MW15 | 0.47 | 2.10 | 36L in 25min | 3722 | 394.5 | 300 |
| MW16 | 0.10 | 0.48 | 28L in 20min | 2400 | 1.3 | 1 |
| MW20 | 0.33 | 0.73 | 24L in 20min | 2823 | 525.3 | 330 |
| MW22 | 0.05 | 0.23 | purged dry at 11.5L | 3534 | 287 | 250 |
| MW23 | 0.06 | 0.31 | purged dry at 3.5L | 3551 | <1 | <0.1 |
| MW24 | 0.06 | 0.23 | purged dry at 4L | 1086 | <1 | <1 |
| MW25 | 0.11 | 0.94 | 21L in 15 min | 1846 | 0.2 | <1 |
| MW26 | 0.05 | 0.33 | 15L in 15 min | 2527 | 71.9 | 47 |

* Average of groundwater development and subsequent sampling in 2016 with TDS (mg/L) estimated from field measured EC (mS/cm * 600)

The revised hydraulic conductivity range is between 0.2 and 2.1 m/d, with a geometric mean of 0.5 m/d. The reinterpretation of the data reflects field observations of well yield during development and is consistent with literature ranges for silty sands and fine sands (0.86 m/d to 0.0086 m/d, Fetter, 2001).

Based on an estimated hydraulic gradient of 0.008, a revised hydraulic conductivity geometric mean of 0.5 m/d and a nominal effective porosity of 0.3, an estimated seepage velocity of approximately 5 m/yr is calculated.

It is also noted that the construction details and log for a private well in the western portion of the Assessment Area sampled in 2016 indicate that the well targeted a deeper sandier zone from approximately 18-26 m bgl. The well details are considered indicative of a second water bearing layer (Q2) at a depth of approximately 10 m below the unconfined regional aquifer (Q1) assessed by the monitoring wells installed to date as part of the site assessment. This deeper layer has not been investigated as part of AECOM's Stage 4 investigation.

### 6.2.5 Hydrology

No surface water bodies are identified within or in the immediate vicinity of the Assessment Area.

## 6.3 Nature of Chemical Impacts

### 6.3.1 Chemicals of Potential Concern

The Stage 4 DSI was limited to consideration of selected VHA impacts to groundwater and soil vapour broadly across the Assessment Area. As such, while the presence of other contaminants in groundwater associated with former electroplating activities at the sites has been identified, for the purpose of this report, the chemicals of potential concern (COPC) comprise volatile chlorinated hydrocarbons, and specifically, the following chlorinated ethenes which have been identified in groundwater and/or soil vapour at concentrations exceeding screening criteria:

- PCE
- TCE
- cis- and trans- 1,2-DCE
- 1,1-DCE

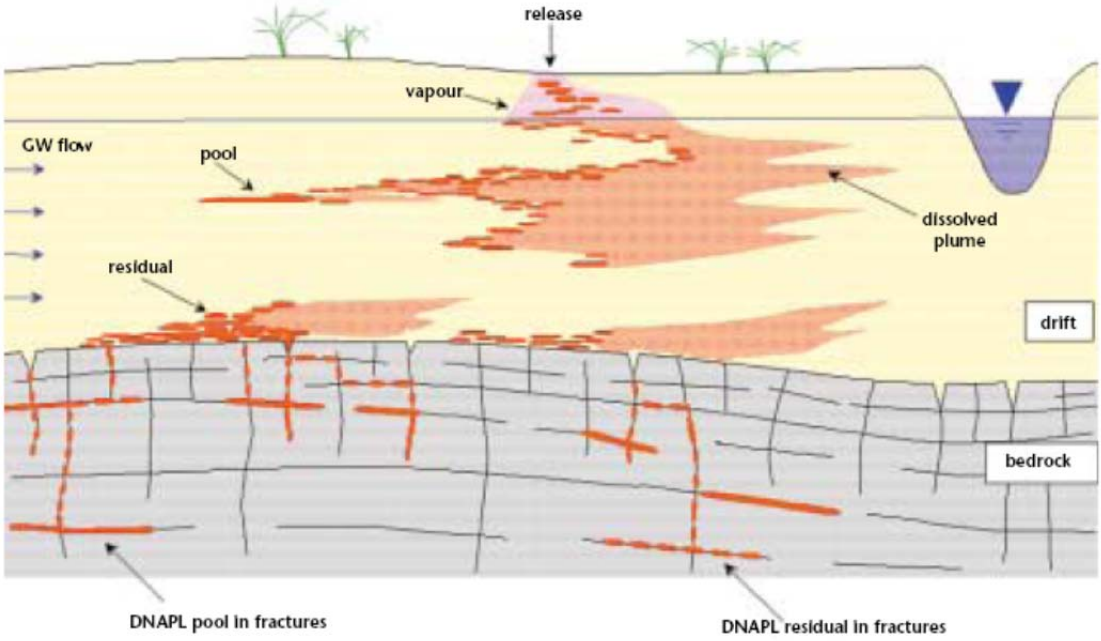
As discussed below, VC is thus also considered a COPC.

### 6.3.2 Generalised Conceptual Behaviour of Chlorinated Ethenes

**Chlorinated Ethenes in Groundwater**

PCE, TCE, DCE (3 isomers) and VC are volatile, dense, non-aqueous phase liquids (DNAPL). If released into groundwater as DNAPL they tend to sink until they reach a low permeability layer that they cannot penetrate or until the NAPL mass is reduced (by leaving a 'trail' of residual NAPL along the path), such that there is insufficient mass for continued movement of the liquid. However, as the NAPL migrates downward it may also migrate laterally, spreading out in response to localised heterogeneities in the aquifer permeability, as illustrated in **Figure 6-2** below.

**Figure 6-2 Schematic Illustration of DNAPL Distribution in Unconsolidated Deposits (UK Environment Agency, 2003)**



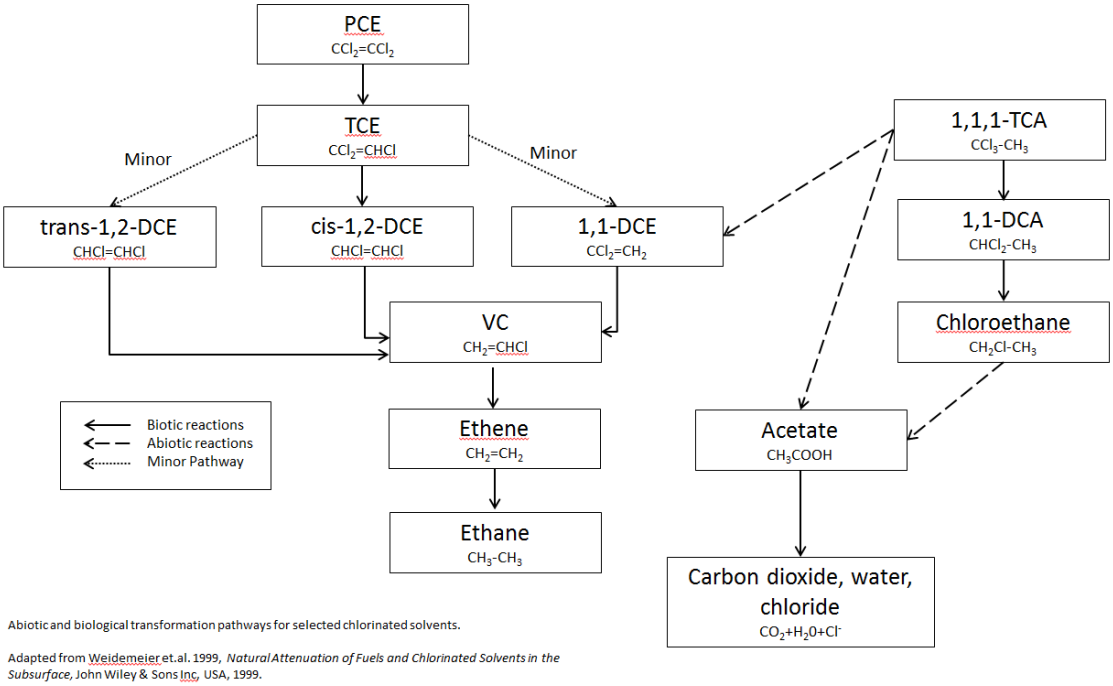

DNAPL may be mobile or present only as residual DNAPL in disconnected pore spaces, or as smearing on soil particles. When DNAPL is in contact with groundwater the contaminants gradually dissolve into the water, creating a dissolved phase 'plume' that can then migrate down-gradient with the groundwater as well as, to a lesser extent, diffuse (driven by concentration gradients) in all directions.

A 'rule of thumb' for assessing whether residual DNAPL may be present near a groundwater monitoring well, based on observed concentrations in the groundwater, is that dissolved concentrations above approximately 1% of the aqueous pure-phase solubility may be indicative of the local presence of DNAPL (US EPA,1992). On this basis, PCE concentrations above approximately 2 mg/L could indicate the presence of DNAPL, while this is approximately 10 mg/L for TCE and 35 mg/L for DCE. In the case of the Assessment Area, all measured dissolved phase concentrations are below these levels. Greencap (2015) indicated range of reported TCE results for monitoring wells including those on the Focus Sites of 0.006 to 0.52 mg/L, subsequent results for these two Focus Sites are consistent with this Greencap data. As such, there is no evidence of the presence of DNAPL.

It is noted that it does appear from the results of sampling of the private well as part of the Stage 3 investigation, however, that there is a possibility that deeper groundwater may be impacted.

The more highly chlorinated ethenes (PCE, TCE) are relatively biodegradation resistant (stable) in aerobic (oxygenated) environments. However, under anaerobic (reducing) conditions PCE and TCE can degrade into less-chlorinated ethenes by a process of successive dechlorination, producing daughter products as shown in **Figure 6-3**.

**Figure 6-3 Abiotic and Biological Transformation Pathways**




Abiotic and biological transformation pathways for selected chlorinated solvents.

Adapted from Weidemeier et.al. 1999, *Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface*, John Wiley & Sons Inc, USA, 1999.

Therefore, when PCE or TCE are identified as chemicals of concern in environmental investigations, their chlorinated daughter products (DCE and VC) are also of potential concern. Commonly PCE and or TCE are likely to be the principal source chemicals where the chlorinated ethenes have originated from use as degreasing solvents. DCE and VC may then be generated via this reductive dechlorination process. Although there are three forms (isomers) of DCE (1,1-DCE, cis-1,2-DCE and trans-1,2-DCE), the main one to be formed from degradation of TCE is typically cis-1,2-DCE.

It is noted that 1,1 DCE may also be formed via abiotic (non-biological) processes from trichloroethane (TCA), so its presence (e.g. in the absence of cis-1,2-DCE) may indicate the historic use of TCA as an alternative solvent to TCE or PCE.

### Chlorinated Ethenes in Vapour

US EPA (2012a) and Interstate Technology and Regulatory Council (ITRC) (2007) provide recent technical guidance summarising expected behaviour of volatile COPC for the *vapour intrusion pathway*. For VHAs such as PCE, TCE and cis-1,2-DCE, the following summarises the expected generalised behaviour and aids in supporting the adopted investigation approach and consequent assessment.

- Chemicals volatilise from impacted soil and/or groundwater and diffuse towards regions of lower chemical concentration (*Diffusion*).
- Soil gas can be drawn into a building due to a number of factors, including barometric pressure changes, wind load, thermal currents, or depressurization from building exhaust fans (*Advection*).
- The rate of movement of vapours into buildings is a difficult value to quantify and depends on the geology, chemical properties, building design, operation and condition, and the pressure differential.
- Advective transport is likely to be most significant in the region very close to a basement or a foundation, and soil gas velocities decrease rapidly with increasing distance from the structure. The reach of the building “zone of influence” on soil gas flow is usually less than a few feet, vertically and horizontally.

  It is noted that advection may not have a *net* effect on chronic exposure (i.e. long term), as

buildings may also be over-pressurised (as opposed to under-pressurised), thereby reducing the potential for vapour intrusion part of the time. The UK Environment Agency (2009) does not recommend generic inclusion of advective flow in its CLEA model due to absence of evidence of a sustained driving force for advective flow.

- PCE, TCE and cis-1,2-DCE vapours are unlikely to biodegrade to any significant degree while migrating through the vadose zone. The same is not true for VC which can be susceptible to aerobic, vadose zone biodegradation, in a similar manner to that routinely observed for petroleum hydrocarbons.
- Soil vapour concentrations can be higher beneath sealed surfaces (such as roads, building slabs) compared to similar depths beneath open surfaces due to build-up beneath the slab.
- All else being equal, soil vapour concentrations are proportional to source concentrations and soil vapour concentrations will be higher closer to the source.
- In general, temporal variability in soil vapour concentrations (at 4 feet/ 1.2 m depth) is relatively minor, having been found to vary by up to only a factor of 2, and seasonal variations in cold (snow) climates are less than a factor of 5. Effects would be expected to be greater closer to the ground surface (ITRC, 2007).
- Infiltration from rainfall can potentially affect soil vapour concentrations by displacing soil gas, dissolving VOCs and restricting vertical migration. Generally, such soil moisture is unlikely to penetrate to any great depth and samples collected at depths greater than about 3 feet/ 0.9 m (or beneath surface cover) are unlikely to be significantly affected. Due to relatively low measured soil vapour concentrations across the investigation area in comparison to groundwater concentrations, and given the relatively permeable nature of shallow soils, it is considered possible that surface infiltration has resulted in formation of a ‘clean water lens’ at the surface of the groundwater, lessening the resultant soil vapour concentrations in comparison to those that might be present otherwise.

## 6.4 Extent and Magnitude of VHA Contamination

### 6.4.1 Extent and Magnitude of Groundwater Impact

The results of groundwater analyses are presented in numerical form on **Figure 6** attached; inferred contour plots for TCE, PCE, 1,1-DCE and 1,2-DCE are presented on **Figures 7**, **8**, **9** and **10** (**Appendix A**).

TCE impacts in shallow groundwater in excess of the adopted assessment criteria (WHO (2011) Drinking Water guideline of 20 µg/L) extend broadly across much of the Assessment Area, and may also extend across the southern and eastern Assessment Area boundaries. PCE impacts above adopted criteria (NEPM (1999) Drinking Water guideline of 50 µg/L) are significantly less extensive.

The key observation with respect to spatial distribution of VHA impacts is that there is considered to be an additional plume of VHA groundwater impact arising from an as yet unidentified source likely located north of the Focus Sites. This conclusion is based on:

- the observed contaminant plume geometry
- interpolated groundwater flow directions and
- the presence of elevated PCE and 1,1-DCE in wells MW36/37, MW12 and MW20 (and surrounding wells to a lesser degree), considered uncharacteristic of impacts at the Focus Sites,

In the southern area, it is noted that a link between elevated groundwater TCE impacts at MW21 and the hydraulically up-gradient Focus Sites has not yet been established.

The limited number of groundwater wells constrains delineation of the individual plumes.

Previous results for a private well sampled in the Stage 3 investigation suggest the likelihood that deeper groundwater beneath the Assessment Area may also be solvent impacted, although the apparent well construction at this location appears to connect the two aquifers. No assessment of the deeper Q2 Aquifer has been undertaken in the Stage 4 DSI.

### 6.4.2 Extent and Magnitude of Soil Vapour Impacts

Elevated VHA concentrations in soil vapour are present broadly across the Assessment Area.

The overall VHA vapour plume appears to be delineated to the north and south within the Assessment Area, although the two northern perimeter vapour bores reported low TCE and/or PCE concentrations, with TCE marginally exceeding screening criteria in VP53. The VHA vapour plume has not been delineated to the west, with bore VP60 reporting low concentrations of TCE and PCE. The up-gradient extent of the overall plume has not been determined.

It is assessed that soil vapour impacts in fact comprise several plumes associated with VHA-impacted groundwater arising from distinct sources, including the Focus Sites and at least one further source site to the north.

The highest VHA soil vapour concentrations were reported at the Focus Sites, but their relative magnitude to groundwater impacts is indicative they are most likely associated with a shallow soil source. The highest soil vapour concentrations other than within the Focus Sites are at location VP29 and associated with the northern plume not attributable to the Focus Sites.

### 6.4.3 Identified Crawl Space Vapour Impacts

One sample (CS13) returned a positive result for TCE of 0.92 µg/m$^3$, below the adopted indoor air guidelines. No other samples from crawl spaces beneath the selected residences on Arabrie Avenue reported detectable concentrations of VHAs. These findings are consistent with results of sampling using summa canisters conducted by Fyfe in 2015.

## 6.5 Sources of VCH Contamination

Groundwater and soil vapour investigations to date are indicative of the following with respect to sources of VHA contamination:

- The Focus Sites Soil are assessed to have given rise both to on-site soil vapour impacts from shallow soil sources, and to groundwater impacts emanating from those sites
- A potential additional source may be present and contributing to elevated TCE and PCE vapour concentrations in VP08 (not tested in 2017) on the southern portion of Calstock Avenue
- The investigation results provide a strong indication of the presence of a further site or sites to the north of the Focus Sites contributing to groundwater and soil vapour impacts across the northern portion of the Assessment Area. Numerous historical commercial/industrial premises have been identified in the probable source area, confirming the potential validity of this assessment.

It is noted that further assessment of the Focus Sites as potential source sites, and investigation of other potential source sites, were outside the scope of this assessment.

## 6.6 Exposure Pathways and Receptors

### 6.6.1 Introduction

An “exposure pathway” is a means by which a population or individual (“receptor”) may be exposed to site-derived contaminants. Receptors may be either human (e.g. building occupants) or environmental (e.g. discharge to a river or lake). Potential exposure pathways are evaluated for completeness based on the existence of:

- a source of chemical contamination;
- a mechanism for release of contaminants from identified sources;
- a contaminant retention or transport medium (e.g. soil, air, groundwater etc.);
- potential receptors of contamination; and
- a mechanism for chemical intake by receptors at the point of exposure (i.e. ingestion, dermal contact or inhalation).

Whenever one or more of the exposure pathway elements is missing, the exposure pathway is incomplete that is, if there is contamination present, but no exposure route to receptors, then there no risk to human health and/or the environment.

### 6.6.2 Summary of Exposure Pathways and Receptors

**Table 6-2** below presents a summary of the identified potential receptors and associated exposure pathways for the contaminants of potential concern for this investigation.

**Table 6-2 Summary of Exposure Pathways and Receptors**

| Aspect | Summary |
|---|---|
| Sensitive Receptors | Ecological:<br>• Groundwater within the Assessment Area (and potentially down-gradient)<br>Human:<br>• Current and future occupants of and visitors to residential properties<br>• Current and future workers at commercial/industrial properties<br>• Possible future residents of redeveloped commercial/industrial properties<br>• Current and future commercial/industrial workers on the Focus Sites<br>• Current and future recreational users of the Yanyarrie Avenue reserve<br>• Current and future maintenance and construction workers<br>• Down-gradient groundwater bores users<br>Fyfe (2015) noted that a survey of residential properties within the former Assessment Area did not identify any groundwater bores in private use; however, it is noted that the on-line Waterconnect database indicates domestic and other potential use of bore water within the current (expanded) Assessment Area |
| Contaminant Transport Mechanisms | Impacts in the uppermost groundwater body:<br>• Flow within the aquifer to hydraulically down-gradient surface water bodies (none identified nearby) and/or groundwater wells<br>• Vapour generation and/or flow via subsurface preferential pathways<br>• Downward movement of DNAPL into underlying aquifers<br><br>Impacted soils on the Focus Sites:<br>• Leaching into underlying soils and groundwater<br>• Mobilisation via surface water run-off or dust generation (if present in surface soils in unpaved areas)<br>• Vapour generation and/or flow via subsurface preferential pathways<br>Transport mechanisms applicable to the Focus Sites might also be applicable to other source sites |
| Exposure Mechanisms | Within the broader area of impacted groundwater:<br>• Direct contact with impacted groundwater (use of bores within area of plume)<br>• Incidental ingestion of extracted groundwater<br>• Inhalation of vapours<br><br>On the Focus Sites<br>• Direct contact with surface or subsurface soils and with groundwater<br>• Incidental ingestion of soils, dust or groundwater<br>• Inhalation of dust or vapours<br>Exposure mechanisms applicable to the Focus Sites might also be applicable to other source sites |

### 6.6.3 Exposure Pathway Summary for Vapour Intrusion

With respect to the exposure pathway of vapour intrusion; on the basis of the varied land uses across the investigation area, the following potential exposure pathways and receptors have been identified for this human health risk assessment:

- Inhalation of volatile chemicals by occupants of residential dwellings;

- Inhalation of volatile chemicals by occupants of commercial/industrial dwellings;
- Inhalation of volatile chemicals by construction workers in trenches, etc ; and
- Inhalation of volatile chemicals in outdoor airspaces.

In general, the potential for exposure to sub-surface derived volatile chemicals in *outdoor* air is materially less than in indoor air, due to lower concentrations and lower assumed duration of exposure (less time outdoors). Additionally, exposure to receptors other than residents (e.g. occupational workers) is likely to be less than for residents due to reduced exposure time and duration. As such, quantitative assessment of commercial exposure would only be undertaken where unacceptable risks to residents are identified.

## 6.7 Data Gaps and Uncertainties

A number of data gaps in relation to the site conceptual model are noted:

- There is limited information as to the identity of potential source sites other than the Focus Sites. AECOM is not aware of any detailed study of historical site activities across the eastern portion of the Assessment Area or the area further to the east. While the existence of a number of former commercial/industrial operations that could represent historical sources of VHA impacts was identified by AECOM, a detailed review was outside the scope of this assessment.
- While not considered material to the broad understanding of groundwater flow beneath the site, the inferred groundwater contours exclude one well at which groundwater levels had evidently not stabilised. A refined assessment of standing water levels would be possible once sufficient time for stabilisation to have occurred.
- VHA impacts in groundwater remain undelineated (to below the adopted criteria) to the south of the current Assessment Area, both in the eastern portion and notably at MW31 (off Railway Terrace, installed with the aim of delineating groundwater impacts south-west of MW27). Groundwater impacts are also not delineated up-gradient (east) of the northern plume area, where it is apparent that further source(s) exist.
- It has not yet been established whether there is a link between the groundwater impacts reported for MW21 and the impacts in the vicinity of the Focus Sites to the east, or indeed the up-gradient materially impacted well MW07. The apparent disconnect is due largely to the reported low TCE concentrations for wells MW8 and MW10. Further groundwater investigation up-gradient of MW21, inclusive of at least a further well between MW08 and MW10, should assist with understanding of the origin of the impacts at MW21.
- Other than sampling of one existing private well in Stage 3 (which identified VCH impact), there has been no investigation of potential VHA impacts to the deeper (Q2) aquifer.
- Soil vapour impacts are largely delineated within the Assessment Area, other than to the east (up-gradient) where further investigation would be required to identify the sources and delineate impacts, and to the north at the western extent of the plume, where further temporal data may provide additional understanding of the nature and origin of the observed impacts.

Apparent increases in soil vapour in a number of vapour bores off Arabrie Avenue (H1 to H10) are based on sampling in 2015 and 2017 only. Further temporal data is required to assess trends in these and other vapour bores.

# 7.0 Groundwater Fate and Transport Modelling

## 7.1 Objectives and Methodology

The objectives of modelling the potential future migration of TCE and its breakdown products in the groundwater are to:

- Assess whether the chlorinated hydrocarbon plumes are likely to expand, be stable or shrink over time.
- Assess potential timescales and rates at which contaminant concentrations may change.
- Inform the suitability of the current Assessment Area boundary and associated monitoring network.
- Inform the EPA's proclamation of a Groundwater Prohibition Area.

The solute transport modelling has been undertaken using the US EPA model BIOCHLOR (version 2.2, release date June 2002).[3] BIOCHLOR is a screening model that simulates the natural attenuation of chlorinated hydrocarbons in groundwater. BIOCHLOR includes three different model types:

- Solute transport without decay
- Solute transport with biotransformation modelled as a sequential first-order decay process
- Solute transport with biotransformation modelled as a sequential first-order decay process with two different reaction zones (*i.e.*, each zone has a different set of rate coefficient values).

Although BIOCHLOR was developed to simulate the decay/biotransformation of the contaminants, the first-order decay process that it incorporates can be considered to represent the combined mass loss from all relevant processes (i.e. volatilisation and possible vertical migration to deeper aquifers, as well as biotransformation). Volatilisation from the groundwater surface results in a mass loss that is proportional to the contaminant concentration present in the dissolved phase (Henry's Law); it can therefore be simulated using a first-order rate equation. For sites where the groundwater is generally well oxygenated with predominantly oxidising conditions, there may be little or no current biotransformation taking place, in which case volatilisation may be a significant or dominant mass loss process. Data gathered from the EPA site assessment area supports this conceptual model due to the typically oxidised shallow groundwater conditions and the lack of significant proportions of breakdown products including ethene or VC.

The BIOCHLOR software is based on the Domenico analytical solute transport model (Domenico, 1987) and is programmed in a Microsoft Excel spreadsheet. It simulates one-dimensional advection, three-dimensional dispersion, linear adsorption and biotransformation (via dechlorination) as a sequential first-order decay process.

The US EPA Center for Subsurface Modelling Support (CSMoS) notes that Domenico-based fate and transport models can generate errors for given sets of input parameters when compared with exact solutions.[4] The error is sensitive to high values of longitudinal dispersivity but is insignificant when longitudinal dispersion is reasonably low. CSMoS advises that BIOCHLOR can be safely used for advection-dominated transport conditions (*i.e.*, plumes that are relatively long and narrow, as is the case at Edwardstown) but recommends caution when the transport processes are highly influenced by dispersion (*i.e.,* when the aquifer is relatively impermeable, resulting in broader plumes).

The solute transport modelling incorporates the assumptions and limitations listed in **Table 7-1**.

[3] http://www.epa.gov/ada/csmos/models/biochlor.html
[4] http://www.epa.gov/ada/csmos/domenico.html

**Table 7-1 Solute Transport Modelling Assumptions and Limitations**

| Assumption or Limitation | Justification |
|---|---|
| Steady state groundwater flow. | Although there will be short-term fluctuations in groundwater levels and flow rates due to recharge events and seasonal variations, solute transport over the longer term (*i.e.* years to decades, as is relevant in this case) will be controlled by the long-term average flow conditions. |
| Homogeneous, isotropic, laterally extensive aquifer. | Similar geological conditions were encountered during drilling of the monitoring wells across the area. Furthermore, the inferred groundwater elevation contours and the apparent shape of the chlorinated ethene plume are consistent with relatively uniform aquifer conditions. |
| TCE is assumed to be still present below the groundwater level in the source zone, and will act as a continuing source of dissolved phase contamination that could migrate off-site. | TCE is expected still to be present in the saturated zone within the source area, adsorbed to soil particles and in dissolved phase. TCE will continue to dissolve, desorb and diffuse from this 'secondary' source zone into the ambient groundwater flow. |
| The modelling only considers the upper (Q1) aquifer and does not consider potential migration of contaminants in deeper aquifers. | It is assumed that risks to deeper aquifers will be assessed in subsequent phases of work. |
| Aquifer recharge is not explicitly modelled. | Conservative assumption, in that the addition of uncontaminated recharge would dilute contaminant concentrations. However, the hydraulic gradient (which is simulated in the model) is the result of the overall aquifer recharge pattern. |
| Mass loss of TCE, DCE and VC from the groundwater is simulated to occur at rates that are constant over time and across the aquifer. | Standard modelling assumption in the absence of other data. Considered reasonable if it produces acceptable calibration results (subject to ongoing verification as future monitoring results become available). |
| Degradation or other mass loss of ethene is not simulated. | Information published by the Organisation for Economic Co-operation and Development (OECD) as part of its Screening Information Data Set for industrial chemicals states that "Relevant studies have indicated a low toxicity of ethylene (ethene) and no risk to human health has been identified either from occupational exposure or exposure of general public, either exposed directly or indirectly via the environment." [5] |

## 7.2 Model set up

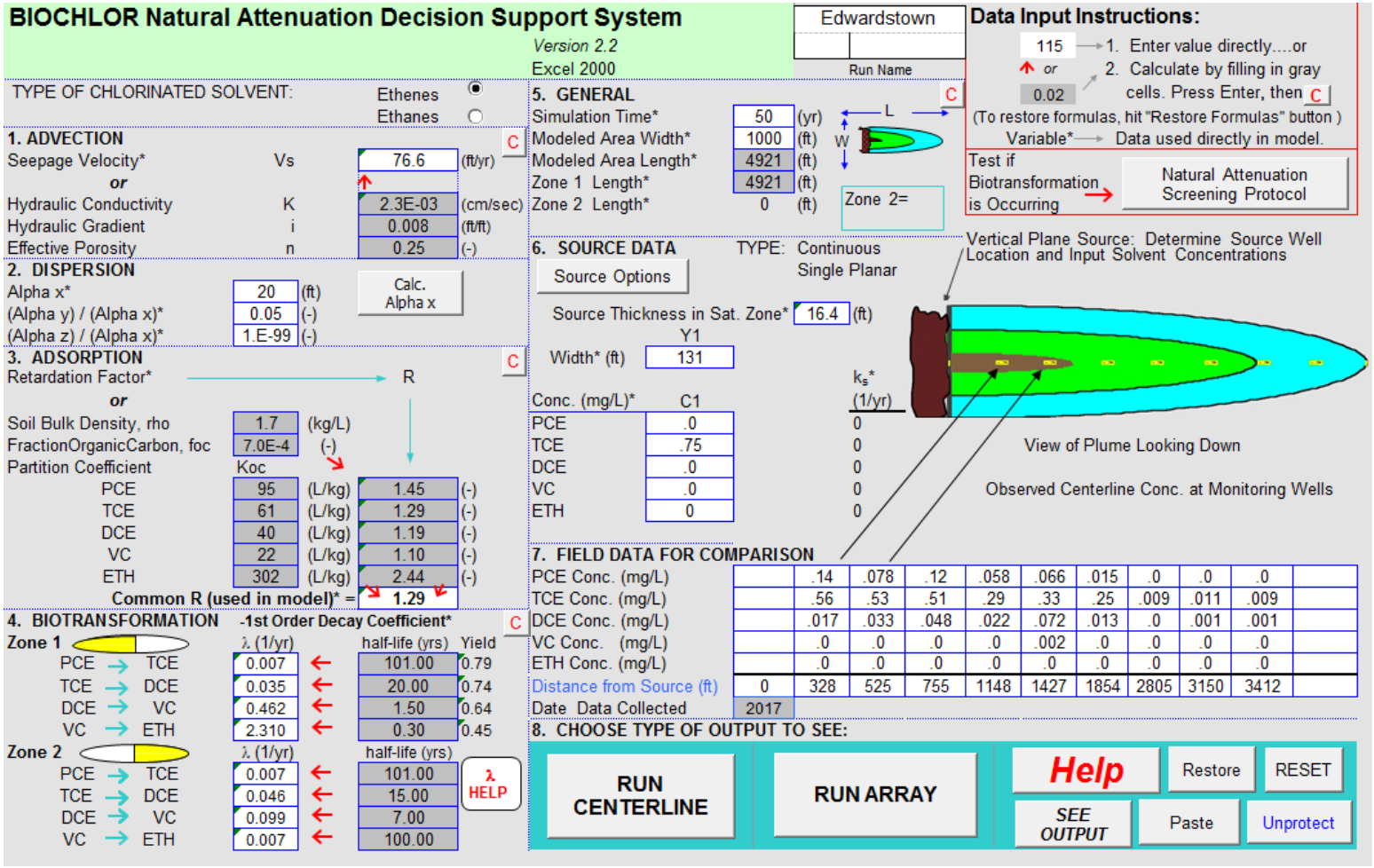
The BIOCHLOR model has been set up using site-specific data where possible. Model input data is summarised in **Table 7-2** and a screen shot of the model input screen is provided in **Figure 7-1**. Given the paucity of temporal data the simplest conceptualisation of a continuous source over was manipulated to provide the best match against observed data. The sensitivity of the model results to the values of the various input parameters is discussed in **Section 7.4**.

[5] http://www.inchem.org/documents/sids/sids/74851.pdf

**Table 7-2 Solute Transport Model Input Parameters**

| Parameter | Value | Source of Data |
|---|---|---|
| Hydraulic conductivity | 2 m/d | Calibration parameter at higher end of revised K range (see S6.2.4). |
| Hydraulic gradient | 0.008 | Inferred from January 2017 contours (Figure 5) |
| Effective porosity | 25% | Calibration parameter but within typical range for fine sands (Domenico and Schwartz, 1990). |
| Seepage velocity | 23 m/year | Calculated from the hydraulic conductivity, hydraulic gradient and effective porosity using Darcy's law. |
| Dispersivity – longitudinal | 6.1 m | Calibration parameter. Low value; consistent with advection-dominated transport. |
| Dispersivity – transverse | 0.3 m | Calibration parameter at 5% of longitudinal dispersivity. Lower than BIOCHLOR default assumption of 10% longitudinal dispersivity. |
| Dispersivity – vertical | zero | Conservatively assume no vertical dispersion |
| Soil bulk density | 1.7 kg/L | Typical value for unconsolidated sand-silt-clay deposits. |
| Fraction organic carbon | 0.007 | Geometric mean of site specific data. |
| Organic carbon partition coefficient (Koc) | | Downloaded from the US Department of Energy's Risk Assessment Information System on 3 April 2017 (http://rais.ornl.gov/). |
| PCE | 94.9 L/kg | |
| TCE | 60.7 L/kg | |
| 1,2-DCE (cis, trans) | 39.6 L/kg | |
| 1,1-DCE | 31.8 L/kg | |
| VC | 21.7 L/kg | |
| Mass loss half-lives: | | Calibration parameters, likely representing mass loss due to biodegradation plus volatilisation with some migration to deeper units and degradation. |
| PCE | 101 yrs | |
| TCE | 20 | |
| DCE (all isomers) | 1.5 | |
| VC | 0.3 | |
| Source zone thickness in saturated zone | 5 m | Not accurately known but does not affect the simulated rate of migration or plume shape (only affects mass calculations when decaying source hypothesis applied). A continuous source was applied to the model. |
| Source zone width | 40 m | Calibration parameter. Not accurately known. Potentially multiple source areas , however only a single source modelled. |
| Source concentrations | 0.75 mg/L TCE | Calibration parameter. Ignores PCE and assumes no DCE or VC in source. |

**Figure 7-1 Base Case Input Parameters – Biochlor 2.2**



## 7.3 Calibrated Model

### 7.3.1 Calibration Process

The main model input parameters that were varied during model calibration were:

- Hydraulic conductivity (within adjusted ranges for site-derived data)
- Effective porosity (within literature ranges for fine sand)
- Dispersivity (longitudinal and transverse based on matching observed centreline plume length)
- Contaminant decay rates (for TCE and DCE assuming a dominant TCE source) and
- Source concentration (noting that some historical degradation of the source area(s) has been assumed).

Model calibration was assessed by qualitatively comparing simulated concentrations of TCE along the plume centreline as per **Figure 7-2**) with observed concentrations of these chemicals in relevant monitoring wells, based on the February 2017 data set. It is noted that a maximum of three data points collected over an 18 month period is available for a selection of wells which is insufficient to assess source degradation. Further it is noted that key wells used to define the shape of the TCE plume were installed in January 2017 have been sampled once only.

The calibration parameter values were varied during model calibration until a reasonable match of simulated and observed concentrations was obtained ("base case" model). Except where stated otherwise, the plots provided below relate to a time after approximate matched concentrations have been reached.

As noted in **Section 5.8** and **Section 6.1.2**, a cursory review of readily available historical information indicated that potentially contaminating activities at the Focus Sites may date at least to the mid to late 1960s, and also confirm the presence, in the mid-1960s to early 1970s, of a number of businesses that based on the probable site activities could have been sources of VHA impact to soil and groundwater.

Without the actual source release time being known, an arbitrary release date of approximately 50 years ago (1967) was initially assumed, given the available site history information regarding potential sources in the vicinity of the site. Model calibration ultimately was ultimately best achieved assuming a source origin approximately 45 years before present (1972). The observed plume orientation lends itself to the assumption that a second source area north of the Focus Sites may well exist, so modelling has assumed an approximate source concentration and location unsupported by actual source data, and thereby reliant on calibration to the observed plume.

### 7.3.2 Plume Centreline

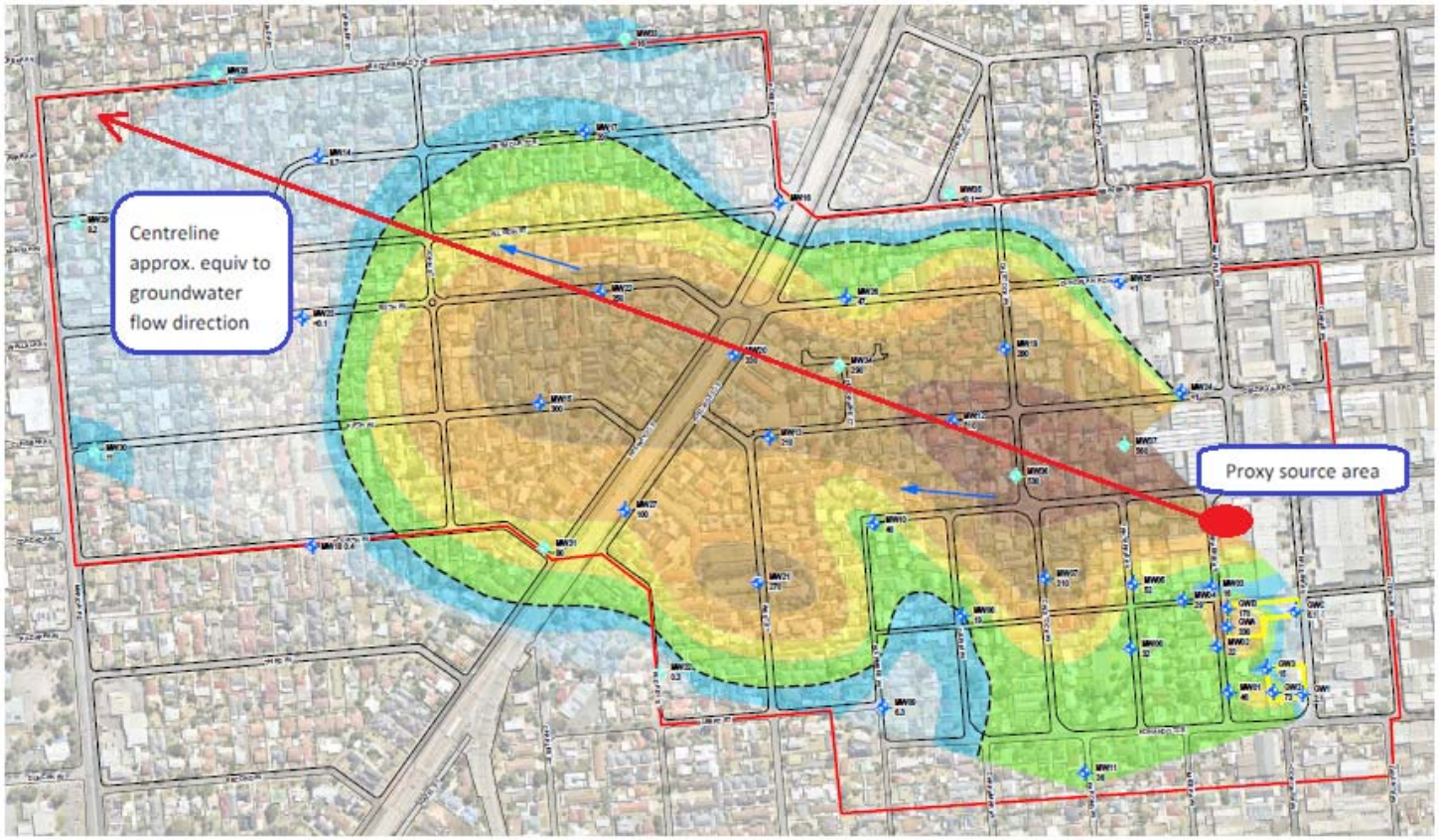
Simulated concentrations of TCE along the plume centreline at time (in years) since assumed source release (nominally 1972) are shown in **Figure 7-3**), together with observed concentrations of these chemicals in wells located on or close to the inferred centreline of a long narrow plume, potentially north and parallel to a second narrow plume.

The wells are unlikely to be located precisely on the plume centreline so concentrations at the centreline are likely to be somewhat higher than those observed in the wells. The relative proximity of the wells to the centreline is shown on **Figure 7-2**.

A reasonable match is achieved at t=45 yrs when degradation is incorporated. **Figure 7-4** shows that continued running of the model past the simulated matched concentrations at t=45 yrs suggests that the TCE plume is not yet at 'steady state' and will not attain stability until somewhere around t=200 yrs, with concentrations exceeding the drinking water guideline of 20 ug/L potentially extending to almost 2 km from the modelled release point assuming some degradation via volatilisation.

Given the simulated expansion of the plume, the model time period was refined around the current time period and potential increases at the leading edge of the plume (well MW29, off-set from the plume centreline) and at Marion Road along the inferred direction of groundwater flow.

**Figure 7-2 Conceptual Model Centreline and Data Matching Information**




| Distance from source | 100 m<br>328 ft | 160 m<br>525 ft | 230 m<br>755 ft | 350 m<br>1148 ft | 435 m<br>1427 ft | 565 m<br>1854 ft | 855 m<br>2805 ft | 960 m<br>3150 ft | 1040 m<br>3412 ft |
|---|---|---|---|---|---|---|---|---|---|
| Data point | MW37 (off-set) | MW36 (off-set) | MW12 (on line) | MW34 (off-set) | MW20 (on line) | MW22 (on line) | MW14 (off-set) | MW28 (off-set) | MW29 (off-set) |
| TCE 2017 (ug/L) | 560 | 530 | 510 | 290 | 330 | 250 | 8.7 | 11 | 9.2 |
| PCE 2017 (ug/L) | 140 | 78 | 120 | 58 | 66 | 15 | <0.1 | 0.1 | 0.2 |
| 1,1-DCE (ug/L) | 4.6 | 25 | 31 | 14 | 17 | 5.7 | <0.1 | 0.3 | 0.2 |
| 1,1-DCA (ug/L) | 0.9 | <1 | <1.5 | <1.5 | <1.4 | 1.3 | <0.1 | <0.1 | <0.1 |
| 1,2-DCE (ug/L) | 12.4 | 8.4 | 17.2 | 7.5 | 55 | 7.5 | 0.4 | 0.2 | 0.5 |
| VC (ug/L) | <0.2 | <2 | <2 | <2 | 2.3 | <2 | <0.2 | <0.2 | <0.2 |

**Figure 7-3 Base Case Centreline Match at Time after Initial Source Release (Assumed at 1967)**

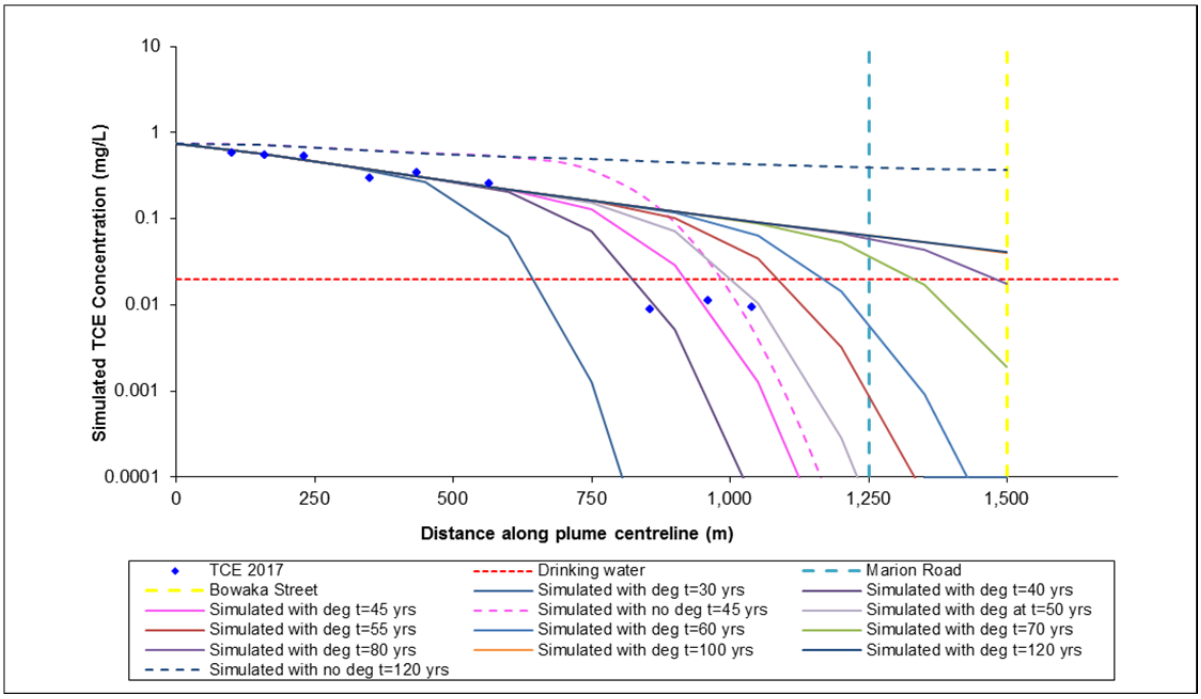



**Figure 7-4 Base Case Centreline Outputs Run to 'Steady State'**

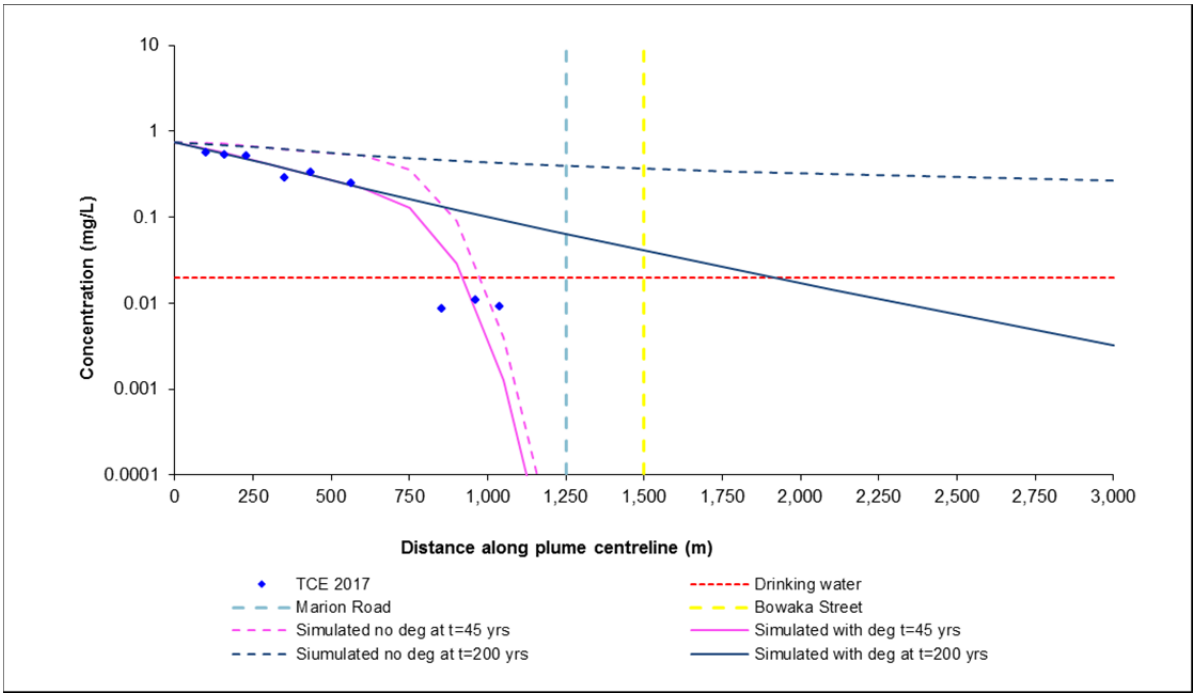
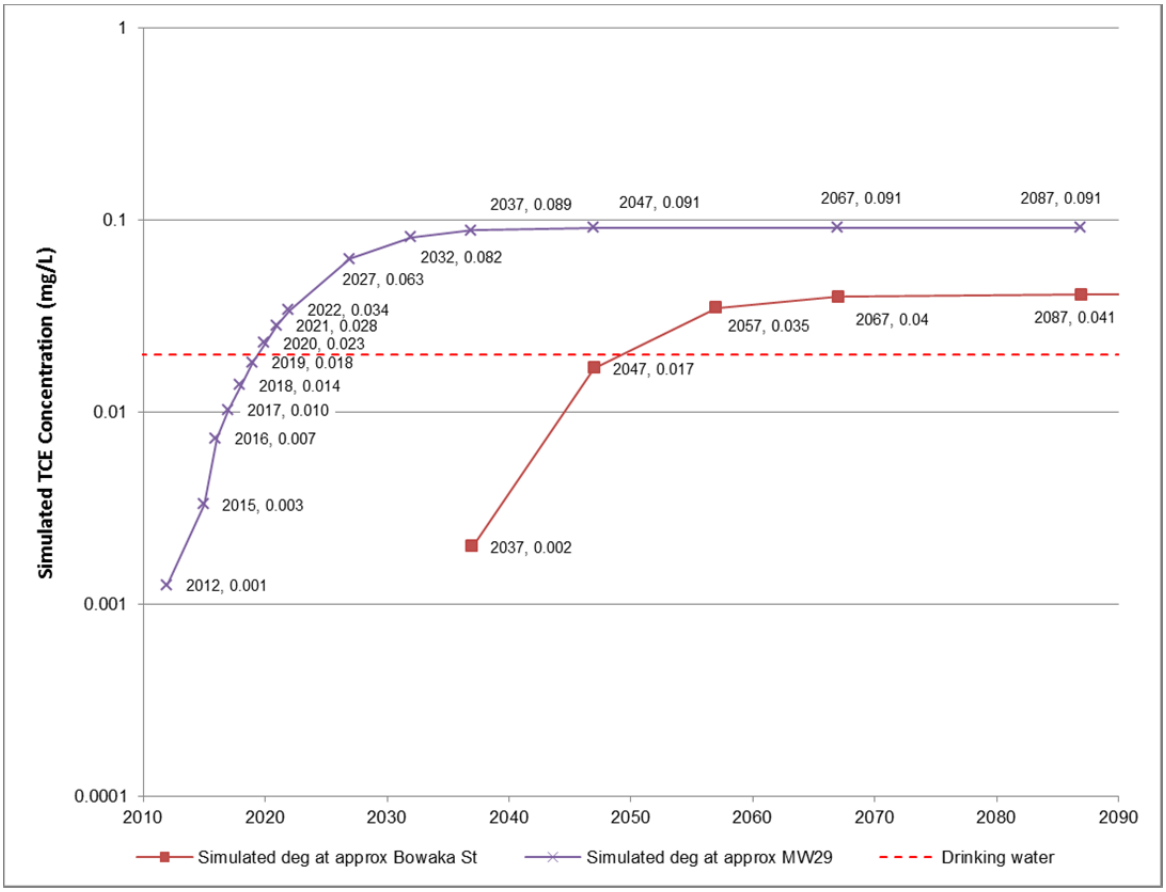



**Figure 7-5** shows the simulated TCE concentration for the base case scenario (including degradation) at distances of 1050 m and 1500 m along the centreline approximating the locations of MW29 and Bowaka Street, Park Holme. The predicted maximum TCE concentration at MW29 is ~100 µg/L (0.091 mg/L), occurring approximately 30 years from now. If the model provides a reasonable approximation of in-situ conditions, over the next few years we may expect concentrations in the vicinity of this well to rise from currently around 10 µg/L (2017) to greater than the drinking water guideline by 2020.

Similarly, TCE levels are predicted to approach the drinking water guideline at Bowaka Street in 30 years' time and stabilise at approximately 40 µg/L (twice the guideline) in around 50 years' time.

**Figure 7-5 Peak Simulated TCE Concentration (mg/L) at Approximately MW29 and Bowaka Street, Park Holme**




## 7.4 Sensitivity Analysis

### 7.4.1 Approach

The sensitivity of the base case BIOCHLOR model to the values of the various input parameters has been assessed by varying each of the input parameters in turn to determine the effect on the simulation results. The results that have been used for this comparison are the simulated TCE concentrations after 45 years along the plume centreline, compared against average observed concentrations in inferred centreline wells (noting that true centreline concentrations are likely to be somewhat higher because the plume is relatively narrow and the wells are unlikely to be precisely located on the centreline).[6]

The parameters for which the sensitivity of the model has been assessed are listed in **Table 7-3** together with their base case values and the parameter ranges used for sensitivity testing.

[6] For some of the sections of this sensitivity assessment the 'base case' results shown are for model parameters that differ slightly from the calibrated model. The difference in base case model results is minor and would not affect the findings of the sensitivity assessment.

**Table 7-3 Solute Transport Model Sensitivity Testing Parameter Values**

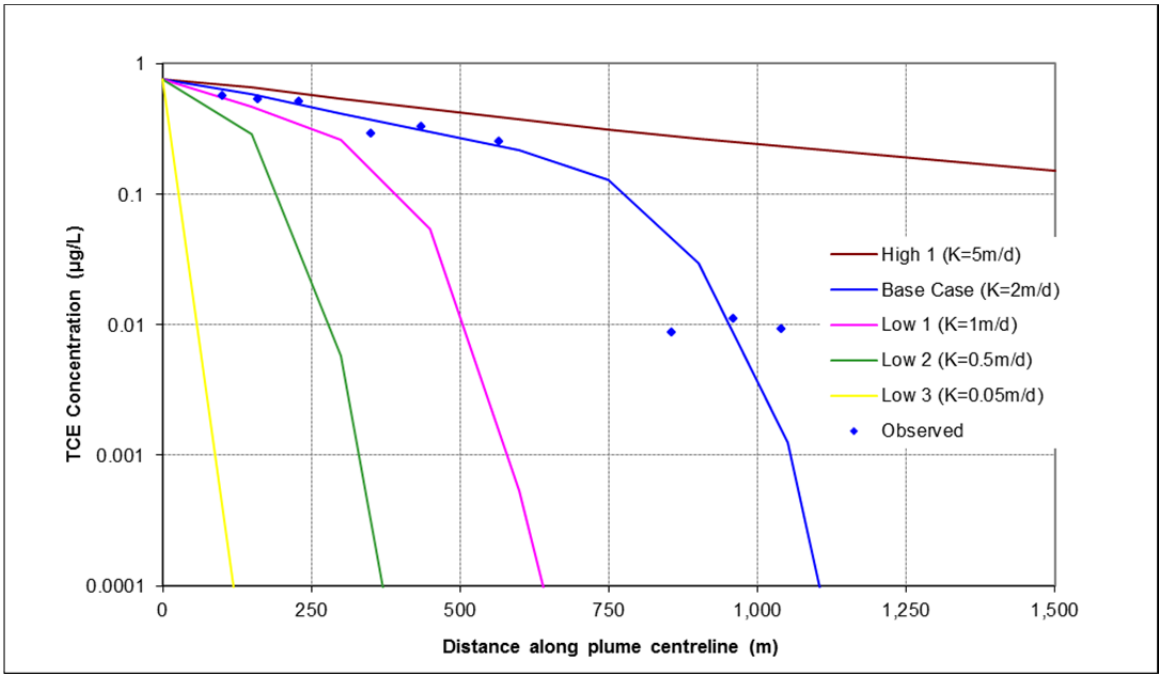
| Parameter | "Low 3" | "Low 2" | "Low 1" | Base case | "High 1" | "High 2" |
|---|---|---|---|---|---|---|
| Hydraulic conductivity (m/d) | 0.05 | 0.5 | 1 | 2 | 5 | - |
| effective porosity | - | 0.15 | 0.2 | 0.25 | 0.3 | 0.35 |
| Longitudinal dispersivity (Ld in m) | - | - | 1 | 6.1 | 30 | 100 |
| Transverse dispersivity (% of Ld) | - | - | 0.025 | 0.05 | 0.1 | 0.25 |
| Fraction of organic carbon | - | - | 0 | 0.0007 | 0.001 | 0.0027 |
| TCE mass loss half-life (yrs) | - | 50 | 30 | 20 | 10 | 5 |
| Source thickness (m) | - | 1 | 3 | 5 | 10 | 30 |
| Source width (m) | 1 | 5 | 20 | 40 | 75 | 100 |
| Source concentration (mg/L) | - | - | 0.6 | 0.75 | 2.5 | 7.5 |

### 7.4.2 Model Sensitivity to Hydraulic Conductivity

The sensitivity of the simulated plume centreline TCE concentrations to the hydraulic conductivity (directly affecting seepage velocity via the Darcy's Law relationship) is illustrated in **Figure 7-6**. This shows that the modelling results are very sensitive to hydraulic conductivity values, with significantly higher or lower hydraulic conductivities resulting in a poor match between observed and simulated TCE centreline concentrations.

It is noted that adopting the upper end of the range of revised hydraulic conductivity values was required to provide a data match and that the original values (e.g. 0.05 m/d) at the Low 3 scenario or the geometric mean of the revised values (0.5 m/d) both provided a poor matches to the centreline data.

**Figure 7-6 Base Case Sensitivity to Hydraulic Conductivity**

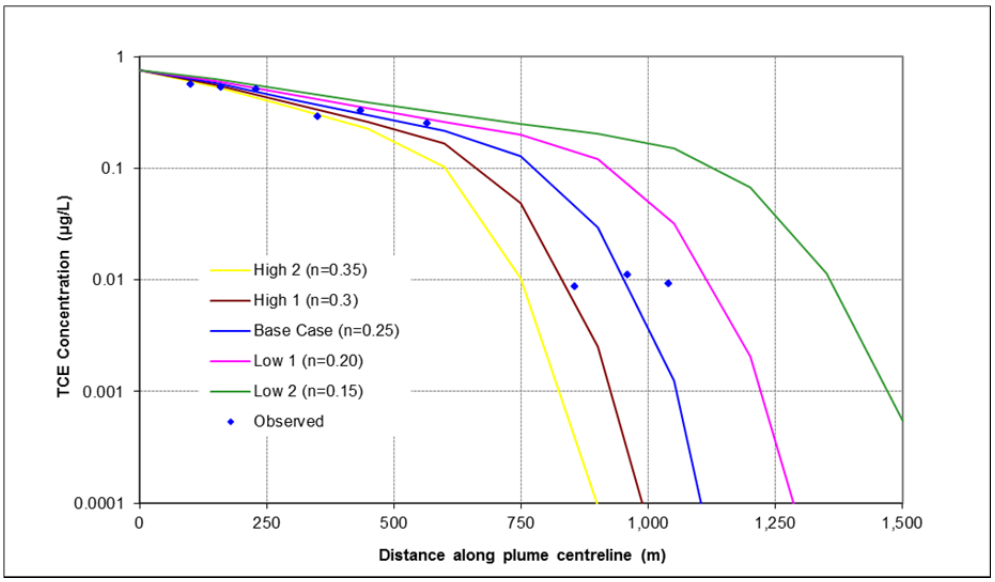


### 7.4.3 Model Sensitivity to Effective Porosity

The sensitivity of the simulated plume centreline TCE concentrations to the effective porosity (directly affecting seepage velocity via the Darcy's Law relationship) is illustrated in **Figure 7-7**. This shows that the modelling results are reasonably sensitive to effective porosity values.

A major finding of the calibration and sensitivity analysis is that to achieve the observed extent of the TCE plume along the main axis seepage velocities need to be relatively high. This implies that there may be preferential migration via thinner sandy layers or that the centreline of the plume(s) has not been adequately identified by the current monitoring network.

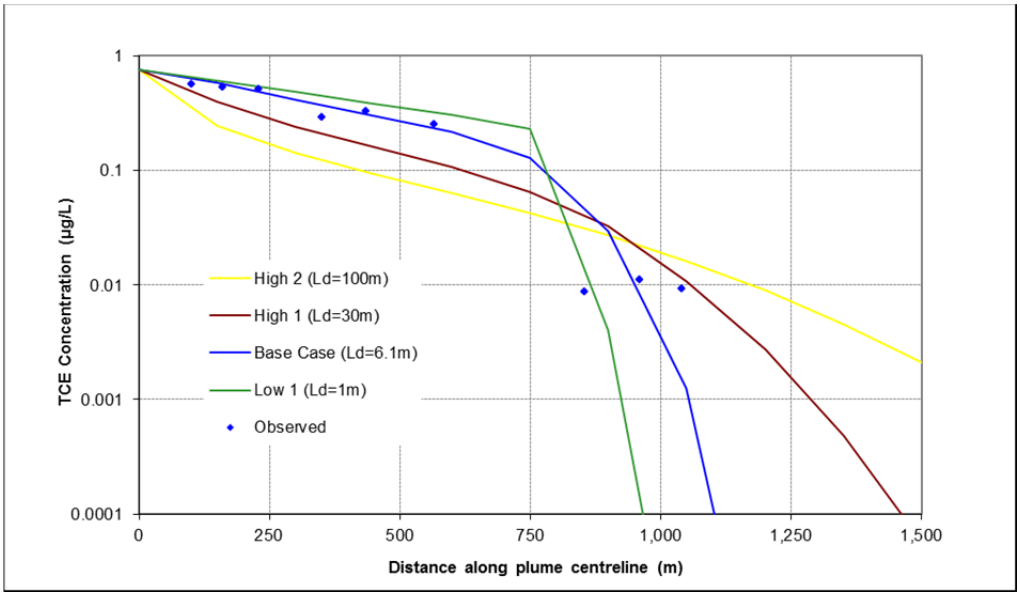
**Figure 7-7 Base Case Sensitivity to Effective Porosity**




### 7.4.4 Model Sensitivity to Dispersivity

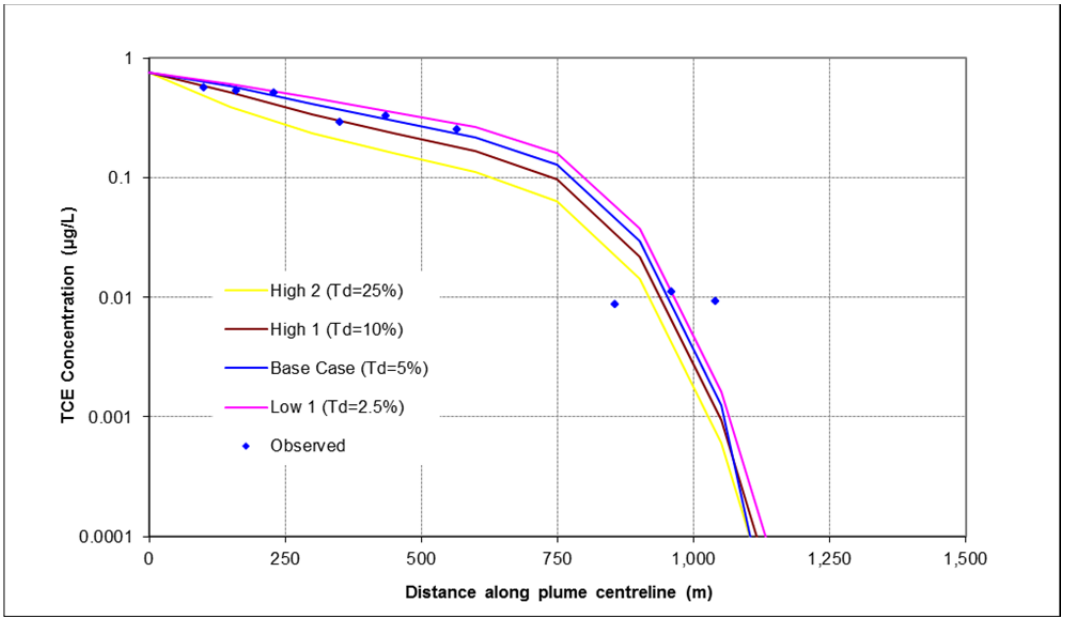
The sensitivity of the simulated plume centreline TCE concentrations to the longitudinal dispersivity is illustrated in **Figure 7-8**. This shows that the modelling results are reasonably sensitive to longitudinal dispersivity which needs to be quite low to match the observed leading edge of the plume along the centreline.

**Figure 7-8 Base Case Sensitivity to Longitudinal Dispersivity**



The sensitivity of the simulated plume centreline TCE concentrations to the transverse dispersivity is illustrated in **Figure 7-9**. This shows that as the matched longitudinal dispersivity was low, the change in the proportion of dispersivity in the transverse plan has only a minimal effect on the simulated data. The best match was achieved when the transverse dispersivity was set at 5% of the longitudinal dispersivity.

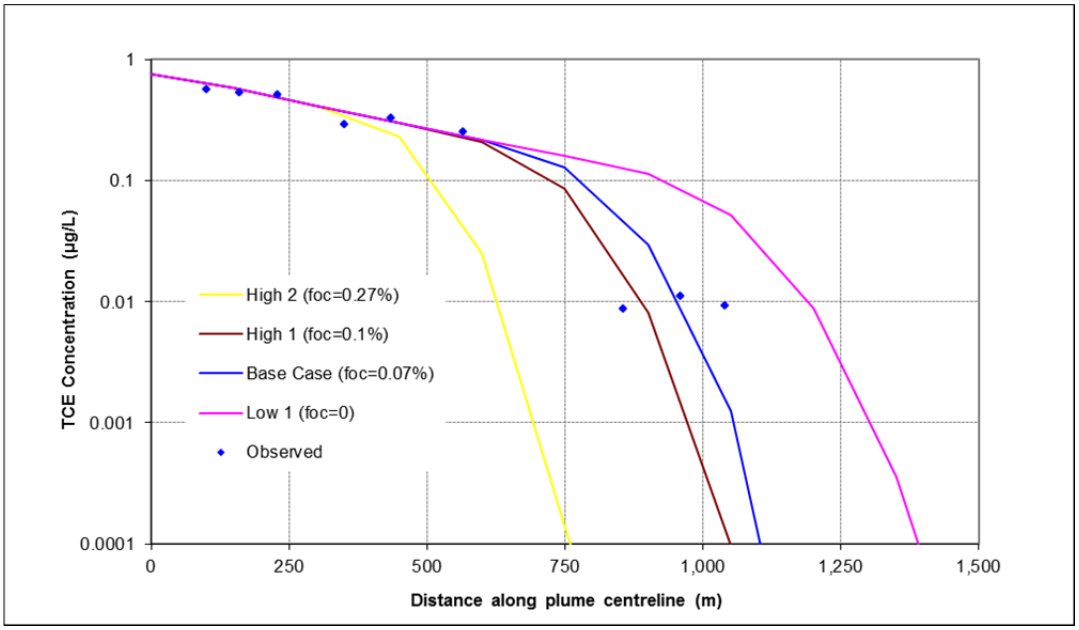
**Figure 7-9 Base Case Sensitivity to Transverse Dispersivity**




## 7.4.5 Model Sensitivity to Fraction of Organic Carbon

The sensitivity of the simulated plume centreline TCE concentrations to the organic carbon fraction, which affects the degree to which migration of TCE is retarded compared to groundwater, is illustrated in **Figure 7-10**. Total organic carbon was reported for 10 samples ranging from 0.04% to 0.27% with a geometric mean of 0.07% which was used for the base case. The plot shows that with other factors unchanged, there needs to be some retardation of the plume to match the centreline; however, the values at the upper end of the reported range result in too much slowing of plume migration.

**Figure 7-10 Base Case Sensitivity to the Fraction of Organic Carbon**

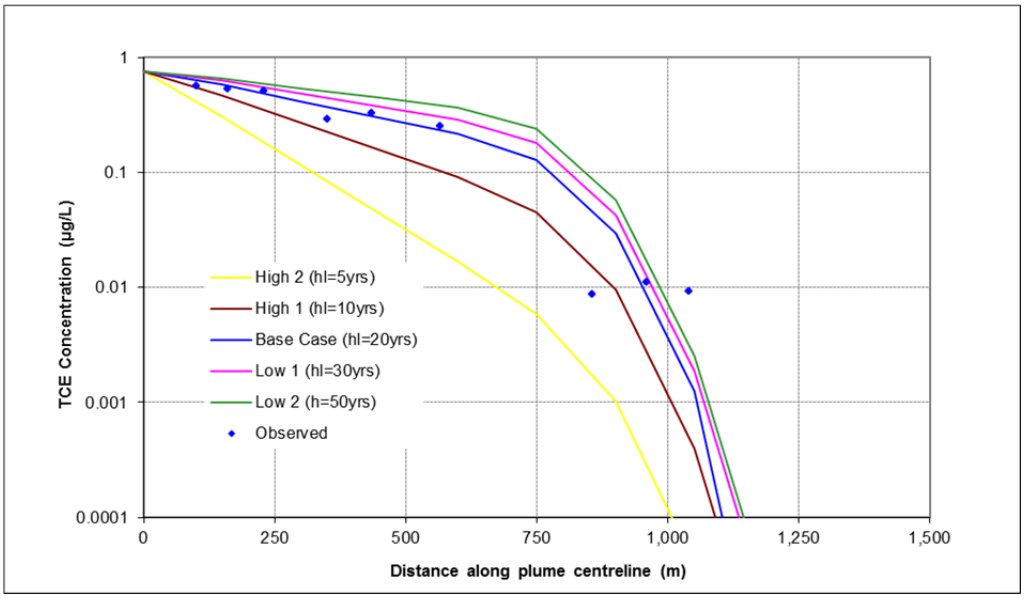


### 7.4.6 Model Sensitivity to TCE Mass Loss Half-life

The sensitivity of the simulated plume centreline TCE concentrations to the half-life of TCE is illustrated in **Figure 7-11**.

The plot shows that the TCE simulation results are sensitive to shorter half-lives with the longer, more conservative half-lives. This is consistent with the assumption that mass loss is currently driven by volatilisation following an initial period of degradation possibly by reductive dechlorination in the presence of co-disposed contaminants such as hydrocarbons.

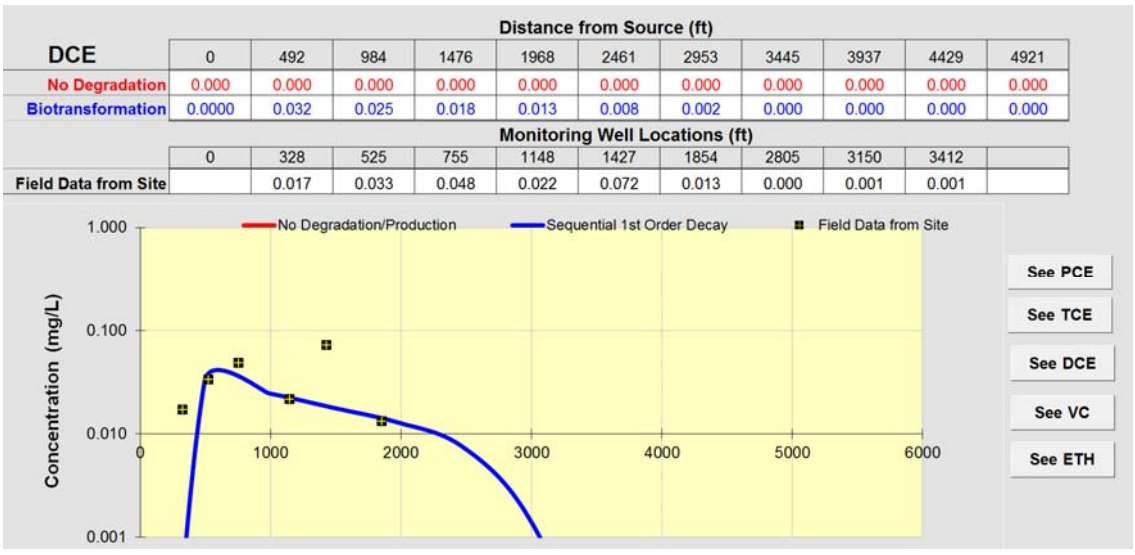
**Figure 7-11 Base Case sensitivity to TCE Mass Loss Half-life**




The modelled half-lives of PCE (100 yrs) and VC (101 yrs) were kept very long as to be conservative. DCE was assumed to degrade a rate faster than TCE and a relatively good match was achieved (see screenshot presented as **Figure 7-12**). It is noted that the observed chlorinated solvent breakdown products include significant proportions of both 1,1-DCE and 1,2-DCE (see **Figure 7-2**) which may imply other parent source products such as 1,1-TCA with abiotic breakdown to 1,1-DCE.

Given the potential for a combination of source types and areas the match for DCE is considered adequate for the purposes of the model which is focused on the simulated future extent of TCE impacts.

**Figure 7-12 Base Case DCE Centreline Match at t=45 yrs**

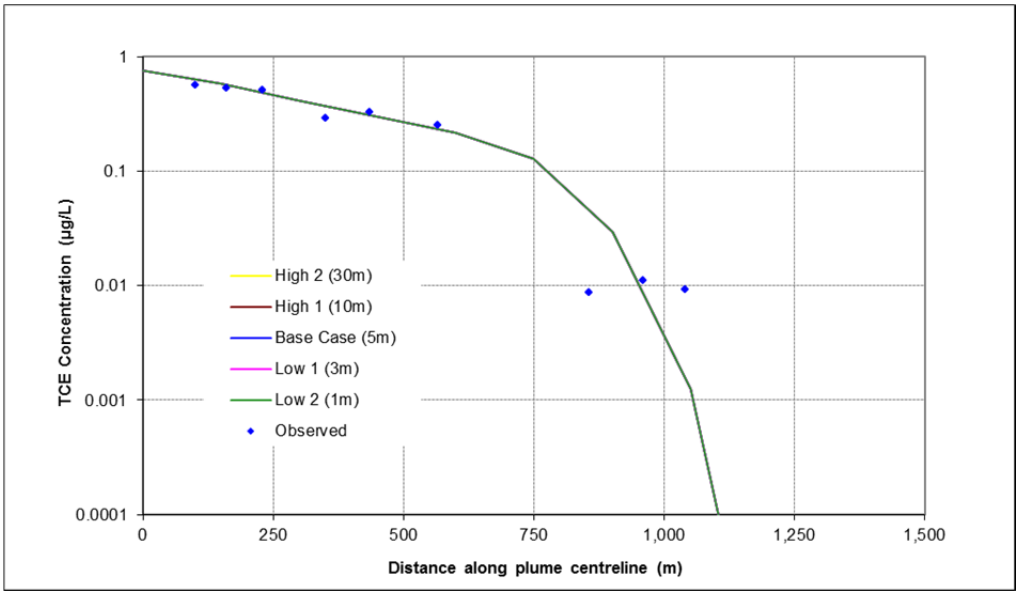


### 7.4.7 Model Sensitivity to contaminant source assumptions

The simulation results for solute migration and plume size are independent of the assumed source thickness because the model has been used to simulate the two-dimensional migration of contaminants (*i.e.* it represents concentrations that are vertically-averaged across the modelled aquifer unit), see **Figure 7-13**.

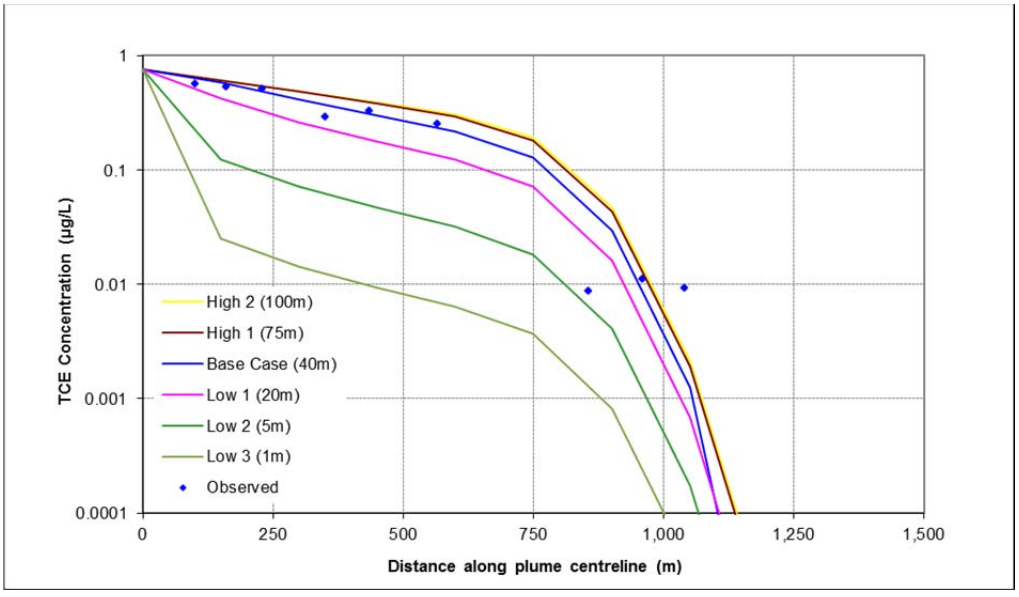
However, although it is not directly represented in the model, the thickness of the contaminated zone affects the half-life for mass loss by volatilisation. If the contaminated zone is limited to a relatively thin layer at the top of the saturated zone, losses from volatilisation will be proportionally more significant than if the contaminated zone extends over a vertical thickness of several metres.

**Figure 7-13 Base Case Sensitivity to Source Zone Thickness**



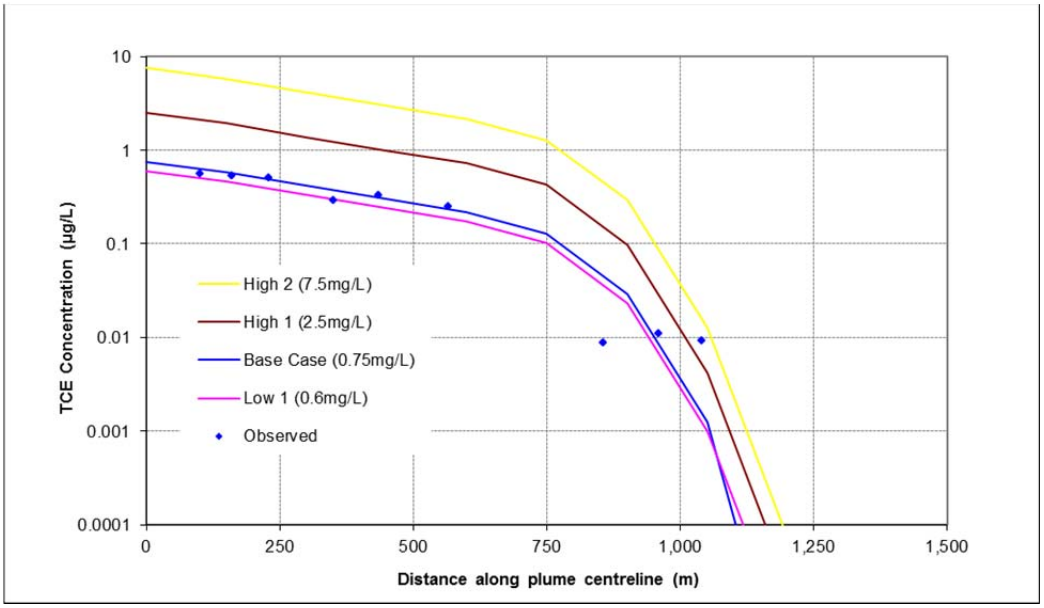

The sensitivity of the simulated plume centreline TCE concentrations to the modelled source width is illustrated in **Figure 7-14**. This shows that the simulation results are sensitive to the source width. The base case source width is 40 m. This represents the effective total width of aquifer that is acting as an ongoing source of dissolved TCE at the assumed source concentration; it need not be a continuous 40 m width but could be a number of smaller zones of impact with varying concentrations across a wider area.

**Figure 7-14 Base Case Sensitivity to Source Zone Width**



The sensitivity of the model results to the assumed source concentration is illustrated in **Figure 7-15**, with higher source concentrations resulting in higher plume concentrations.

**Figure 7-15 Base Case Sensitivity to Source Zone Concentration**




The effects of changing source concentration are directly linear; thus, the simulated plume concentrations from a 7.5 mg/L source are ten times the simulated concentrations resulting from a 0.75 mg/L source.

# 8.0 Updated Vapour Intrusion Risk Assessment

## 8.1 Introduction

This section builds on the qualitative conceptual site model to consider the potentially complete and significant exposure pathway of vapour intrusion quantitatively. It uses vapour modelling from measured sub-surface concentrations to establish whether identified groundwater or soil vapour concentrations may represent unacceptable vapour risks to building occupants.

Noting that vapour intrusion risk modelling was previously completed by AECOM in 2016 as part of the Stage 3 investigations, the focus of this assessment is to consider the effect of the additional site data obtained from the Stage 4 investigations on the conclusions of the previous assessment, and in particular, to consider the sensitivity of the modelling to assumptions in relation to moisture content (and associated porosity) of site soils, as well as any material changes in concentration evident from the current investigations.

Sections below detail the approach to the modelling, which was generally consistent with that described in AECOM's Stage 3 Assessment.

## 8.2 Previous Vapour Intrusion Risk Assessments

### 8.2.1 Fyfe 2015

The Fyfe assessment identified negligible difference in modelled vapour concentrations between slab on ground and crawl space foundation construction; as such their assessment adopted a single attenuation factor to assess vapour intrusion risks for both slab-on-ground and crawl space scenarios.

Based on predicted indoor air concentrations from soil vapour data, Fyfe inferred indoor air concentration contours, on the basis of which:

- 25 residential properties were estimated to fall within the EPA "Investigation" TCE response level of 2 to <20 µg/m$^3$, for which there are assessed to be no immediate health concerns, but further assessment may be warranted.
- 155 properties were estimated to fall within the EPA "Validation (Safe)" TCE response level of >LOR to <2 µg/m$^3$.
- Remaining properties within the Assessment area corresponded to the "No Action (Safe)" (nothing detected) response level.
- Indoor air concentrations in the warehouse at Focus Site FS2 exceeded NEPM Tier 1 assessment criterion (assuming an attenuation factor of 0.1).
- Predicted indoor air concentrations in a number of commercial/industrial properties in the immediate area of FS1 and FS2 fall within the >LOR to <2 µg/m$^3$ response level.

Fyfe concluded there was a group of residential properties, located in the north of the assessment area, around vapour bores VP18 and VP29, that potentially fell into the EPA "further investigation" range (2-20 µg/m$^3$ TCE), with the remaining area being below the 2 µg/m$^3$ guideline.

Fyfe identified no basements or cellars in a residential survey they undertook as part of EPA Stage 2 works; however they modelled this scenario and found potentially unacceptable risks across the investigation area for this potential scenario.

### 8.2.2 AECOM 2016

As part of the Stage 3 investigation, soil geotechnical properties including soil bulk density, moisture content and particle density were measured to enable an assessment of the air-filled filled porosity as a key vapour modelling parameter. The results of geotechnical testing showed consistently high water saturation (> 90%) in the vadose zone soils, and this data was incorporated into updated vapour transport modelling to form the quantitative basis of the vapour intrusion risk assessment.

Due to the high relative soil moisture measured, vapour modelling from measured soil vapour concentrations resulted in no predicted exceedances of the 2 µg/m$^3$ indoor air guideline for TCE, the

primary contaminant of concern. This is despite the fact that the highest measured soil vapour concentration from May 2016 (36,000 µg/m$^3$ TCE at VP29) exceeded that previously measured by the earlier investigations (9,800 µg/m$^3$ TCE in VP18).

It was noted that vapour modelling is highly sensitive to the assumed soil moisture and the lower indoor risks estimated in this assessment compared to the earlier report by Fyfe relate principally to the measured and adopted soil porosity and moisture data, and the potential for seasonal influences on moisture content (such as in summer, when soil moisture may typically be materially lower) warrants consideration.

AECOM noted that consistent with the earlier risk assessment, it was inferred that based on the shallow depth to water and measured soil vapour concentrations, VHA impacts across a substantial portion of the investigation area might pose an unacceptable vapour intrusion risk were there to be basements present.

## 8.3 Toxicity Assessment

The NEPM adopts inhalation toxicity data based on several sources for PCE, TCE, and cis-1,2-DCE. A detailed toxicity review and assessment for these chlorinated hydrocarbons is included in the NEPM Schedule B7, Appendix 6, available from the Australian Government Website[7].

The adopted toxicity data is summarised in **Table 8-1** below.

**Table 8-1 Chlorinated COPC Toxicity Data Summary (NEPC 2013)**

| Chemical of Potential Concern | Critical Effect Summary | Threshold Risk Value or Guideline | Ref |
|---|---|---|---|
| PCE | Inhalation Tolerable Concentration (TC) in air based on neurotoxicological effects as the most sensitive endpoint. Based on a LOAEC of 20 mg/m$^3$ from a chronic occupational study with an uncertainty factor of 100. | 0.2 mg/m$^3$ | WHO 2006 |
| TCE (carcinogenic affects – non-threshold) | Inhalation Unit Risk based on non-Hodgkin's lymphoma, renal cell carcinoma and liver tumours in humans (epidemiological), with a 4-fold adjustment for multiple tumour sites. | Unit Risk = 0.004 (mg/m$^3$)$^1$ | US EPA 2011 |
| TCE (non- carcinogenic affects – threshold) | RfC based on route-extrapolation from, and oral studies for, the critical effects of heart malformations in rats and immunotoxicity in mice, and incorporation of uncertainty factors ranging from 10 to 100. | 0.002 mg/m$^3$ | US EPA 2011 |
| cis-1,2-DCE | Inhalation value obtained from extrapolation from oral US EPA value. A review of genotoxicity by WHO (2011) provided unclear results. A review conducted by the US EPA (2010) suggested that overall 1,2-DCE is not genotoxic or mutagenic. On this basis, the NEPC considers the adoption of a threshold dose-response appropriate. | 0.007 mg/m$^3$ | US EPA 2010 |

## 8.4 Quantitative Exposure Assessment

### 8.4.1 Introduction

This section outlines quantitative vapour intrusion modelling and sensitivity analysis undertaken to assess the potential for human health risk associated with the presence of VHA impacts in the subsurface across a portion of the investigation area.

[7] http://www.comlaw.gov.au/Details/F2013C00288/Html/Volume_15

The modelling has been conducted to assess vapour intrusion risk within the Assessment Area (**Figure 1**). This has been delineated based on the scope of AECOM's engagement and the extent of the groundwater well and soil vapour monitoring network.

Modelling has been undertaken using an Excel-spreadsheet-based model, using the Johnson and Ettinger algorithms, outlined in **Appendix S**. Spreadsheets incorporating the assumptions and calculations are also included in **Appendix S**.

### 8.4.2 Scope of Modelling

Three building constructions are contemplated in considering risks due to vapour intrusion for this assessment:

- Slab-on-ground (typically a concrete "stiffened raft" footing or strip footings and concrete floor slab poured on the ground surface);
- Timber floor with crawl space (where the timber floor is supported typically from concrete strip footings or stumps, such that a shallow (generally ventilated) crawl space is present between the ground surface and the timber floor structure); and
- Basement (assumed to have a concrete foundation beneath ground level).

Modelling has also been undertaken based on measured concentrations both in soil vapour and in groundwater.

### 8.4.3 Estimating Exposure Concentrations

#### 8.4.3.1 Introduction

In order to evaluate the risks to human health via inhalation of vapours it is necessary to estimate an exposure point concentration for each COPC. The exposure point concentration is calculated as a concentration (expressed as µg/$m^3$) in air within the breathing zone of the receptor. For different exposure pathways the exposure point breathing zone may be indoor air (ground floor or basement), outdoor air or within an excavation or utility pit. The exposure point concentration in the case of indoor air may be estimated via a number of different methods depending on the data available. These methods are discussed below.

#### 8.4.3.2 Groundwater Source Concentrations

This method involves modelling indoor air concentrations using measured groundwater concentrations and information on overlying soils and relevant buildings. This modelling is typically conducted using the Johnson & Ettinger (J&E) vapour transport model (US EPA, 2003) and also as documented in ASTM 1739-95 (2010) and comprises the following four distinct steps (listed here in relation to a concrete slab-on-ground scenario):

- Modelling the partitioning of the volatile contaminant between the aqueous phase in groundwater and the vapour phase immediately above the water table.
- Modelling the migration of contaminant vapours upwards through the unsaturated zone soils to beneath the concrete slab underlying the building.
- Modelling the migration of contaminant vapours through the concrete slab into the building.
- Modelling the dilution of the contaminant vapours within indoor air on the basis of the air exchange (ventilation) rates within the building.

This process involves the use of a series of assumptions and conservative simplifications of complex process at each stage of the modelling process, and consequently typically provides an overestimate of actual indoor air concentrations.

For screening purposes, the highest groundwater concentrations measured across the February 2017 investigations have been used for modelling potential exposure concentrations. These concentrations are summarised in **Table 8-2** for those analytes that exceeded drinking water guidelines.

**Table 8-2 Source Concentration Modelling Inputs - Groundwater**

| COPC | Location ID | Maximum 2017 Concentration (µg/L) |
|---|---|---|
| PCE | MW37 | 140 |
| TCE | MW37 | 560 |
| 1,1-DCE | MW12 | 31 |
| cis-1,2-DCE | VP29 | 2.3 |

#### 8.4.3.3 Soil Vapour Source Concentrations

The use of measured soil vapour concentrations from within the unsaturated zone in conjunction with the J&E model reduces the uncertainty to some extent by removing the need to model the partitioning process (Step 1 above). While the uncertainty inherent in Step 2 (migration through the unsaturated zone) can also be reduced by using soil vapour data obtained from relatively shallow depths close to the depth of the building foundation (including sub-slab data), it should be noted however, that concentrations at shallower depth are likely to be more variable over time than deeper soil vapour samples. In addition, the inherent assumption in using soil vapour concentrations as inputs to modelling is that the vapour source is present at the depth of the vapour sample. This likely results in an over-estimate of vapour intrusion risks as the models are sensitive to assumed source depth where advection is incorporated.

The J&E model is used to model migration from the point of measurement to the slab, through the slab, and dilution within the building.

For screening purposes, the highest soil vapour concentrations measured across the February 2017 and May 2016 investigations have been used for modelling potential exposure concentrations. These concentrations are summarised in **Table 8-3**.

**Table 8-3 Source Concentration Modelling Inputs – Soil Vapour**

| COPC | Location ID | Maximum 2016 Concentration ($\mu g/m^3$) | Maximum 2017 Concentration ($\mu g/m^3$) | Adopted Modelling Concentration ($\mu g/m^3$) |
|---|---|---|---|---|
| PCE | VP29 | 14000 | 14000 | 14000 |
| TCE | VP29 | 36000 | 33000 | 36000 |
| cis-1,2-DCE | VP29 | 270 | 300 | 300 |

#### 8.4.3.4 Direct Measurement of Indoor Air Concentrations

The final method for assessing concentrations of COPC in indoor air is via direct measurement. This can be conducted using a number of methods including adsorbent tubes and evacuated canisters. Direct measurement of indoor air concentrations has the great advantage of removing the need for mathematical modelling of partitioning, migration and dilution processes; however, there are a number of factors which make the process of obtaining a truly representative sample of indoor air problematic. These factors include:

- Temporal variations in indoor air concentrations due to variations in ventilation regimes within the building and variations in atmospheric conditions.
- Spatial variations within a given building due to the influence of preferential migration pathways such as drains, cracks in slabs and service lines.
- Non-site related sources of COPC. The principal COPC for this investigation (PCE and TCE) are used in a range of consumer products and processes such as dry-cleaning, aerosol paints, degreasers, automotive chemicals, furniture polish and cleaners that may be present in homes

and workplaces. Consequently there is scope for indoor air sampling to be affected by sources present in the home, such that reported concentrations of COPC in indoor air may be unrelated to site-derived contamination.

No direct measurement of COPC concentrations in indoor air was undertaken for this investigation, although ambient air sampling within crawl spaces was undertaken at selected properties. The crawl space sampling did not indicate any unacceptable vapour risks to crawl space homes, as detailed in **Section 5.7**.

#### 8.4.3.5 Vapour Models

Details of the vapour models used are attached as **Appendix S**. Short summaries of the model are provided below.

**Residential & Commercial Buildings – Concrete Floors**

The Johnson & Ettinger (J&E) vapour transport model (US EPA, 2003) has been used to estimate the potential concentrations of volatile COPC within residential and commercial buildings above impacts identified in groundwater. Parameters in the model were adjusted to characterise emissions into a building constructed on a concrete slab.

The model incorporates pressure-driven (advective) flows into the building, such as those associated with wind effects on the structure, stack effects due to heating or unbalanced mechanical ventilation. The US EPA vapour intrusion model allows the advective flow component ($Q_{soil}$) to be specified or calculated based on an empirical relationship between permeability, crack width in the foundation and differential pressure. Johnson (2002), however, recommends that $Q_{soil}$ should not be used as an independent variable but should be calculated on the basis of the ratio $Q_{soil}/Q_{building}$ (where $Q_{building}$ is the building ventilation rate) and this approach has been adopted by CRC CARE (2011) in the derivation of health screening levels (HSLs) for petroleum hydrocarbons. One limitation of this fixed ratio approach to estimating the contribution of advection is that it necessarily minimises the significance of (sensitivity of the model to) air exchange rates where advection is a material contributor. That is, for a fixed Qs:Qb, if you double the building air exchange rate (increase ventilation), you double the flux of soil vapour entering the building.

CRC CARE Technical Report No 10 (Friebel and Nadebaum 2011) adopted the fixed ratio approach in the derivation of HSLs, subsequently incorporated into the NEPM, and this approach is adopted here.

Where a soil vapour source term has been used rather than a groundwater source, the model has been adjusted so that the measured soil vapour concentration at the relevant vapour well depth is entered as the source term, rather than using a soil vapour concentration calculated via partitioning from the groundwater source via Henry's Law. It is noted that this approach may lead to significant variation from model predictions from a groundwater source, particularly where the measured vapour concentrations are shallow and advective flows are potentially material. Shallow vapour concentrations are potentially more prone to temporal variability and the assumption of a shallow vapour source ignores the potentially rate limiting step of contaminants having to diffuse more slowly up to this depth from a deeper source.

#### 8.4.3.6 Geological Assumptions

For the purposes of the modelling conducted by AECOM in 2016, on the basis of a review of investigation area bore logs, it was assumed that the unsaturated soils consist of 0.5 m of gravel fill overlying natural silty clay soils. This approach has been unchanged for the updated modelling.

The gravel fill is assumed to have a conservative (low) moisture content of 2%. This very low moisture content is less than the lowest measured (3%) moisture content reported in the Stage 3 investigations for a 0.5 m thick gravelly sand fill layer in VP46_0.3-0.4 (AECOM (2017), Table 6, Appendix B).

For samples below 0.5 m, the natural soil was previously modelled with reference to measured soil geotechnical properties. The range and average measured properties for the 2016 (and 2017) sampling events are summarised below in **Table 8-4**; the degree of saturation measured in 2016 ranged from 92.1 to 99.1%, with an average of 96.3%, indicating little air-filled porosity. For the purpose of model inputs in Stage 3 investigations, properties for the deeper layer were adopted on the basis of laboratory results; these samples showed an average specific gravity of 2.69 g/ml, and the dry density of 1.79 was adopted on the basis of typical reported material values. A moisture content of

0.173 ml/g, within the range of tested values, was selected to give a volumetric air content of 0.025, being the highest (most conservative) of the values reported and twice the average air porosity of 0.012 ml/g (refer to **Table 8-4**).

**Table 8-4 Summary of Geotechnical Properties from 2016 and 2017 Sampling**

| | Bulk Density ($t/m^3$) | Dry Density ($t/m^3$) | Void Ratio | Degree of Saturation (%) | Porosity (%) | Water Porosity (%) | Air Porosity (%) | Specific Gravity ($t/m^3$) |
|---|---|---|---|---|---|---|---|---|
| Range of Properties from 2016 Sampling (4 samples) | 2.09 – 2.15 | 1.74 – 1.86 | 0.45 – 0.55 | 92.1 – 99.1 | 31.0 – 35.3 | 28.6 – 34.7 | 0.29 – 2.45 | 2.68 – 2.70 |
| Average Properties from 2016 Sampling (4 samples) | 2.12 | 1.79 | 0.50 | 96.3 | 33.5 | 32.3 | 1.20 | 2.69 |
| Range of Properties from 2017 Sampling (10 samples) | 1.94 – 2.18 | 1.56 – 1.89 | 0.42 – 0.73 | 82.3 – 100.0 | 29.5 – 42.3 | 29.4 – 41.6 | 0.04 – 7.0 | 2.66 – 2.71 |
| Average Properties from 2017 Sampling (10 samples) | 2.06 | 1.71 | 0.57 | 94.9 | 36.3 | 34.6 | 1.64 | 2.69 |

Observed moisture content across all geotechnical samples (all deeper than 0.5 m) in 2017 ranged from 15.6% to 26.7%, with an average of 20.4%, in comparison to the 2016 results of a range of 13.2% to 25.4% and an average of 18.1% reported in 2016. It is apparent that the unseasonably wet weather had perhaps not resulted in the summer drying of soils anticipated.

Of the ten geotechnical samples collected in 2017, only one was from an area with a sealed surface (bitumen pavement), with the remainder drilled in bare or grassed road verges or yards. It is noted that this beneath-bitumen sample (VP63_0.7-1.2) reported the highest soil moisture content (26.7%). While a bitumen pavement is arguably not as effective a moisture seal as a domestic floor slab, this is potentially indicative that sub-slab moisture may not necessarily be lower than that observed in areas of unsealed ground. There is insufficient data for a conclusive assessment in this regard; however conservatively lower moisture data measured from unsealed areas has been used to estimate vapour migration.

Parameters for the updated soil vapour transport modelling were selected with reference to the combined 2016 and 2017 data set:

- Properties for the upper gravel/sandy gravel fill layer have been conservatively assigned based on a gravel with very low (2wt%) moisture content.
- For the deeper layer, comprising predominantly clay, with silty and sandy clay, the average specific gravity for both 2016 and 2017 sampling of 2.69 g/ml was again used, but the dry density (previously set at 1.79) was lowered to the overall average of 1.73 on the basis of typical reported material values. A moisture content of 16.6% or 0.166 ml/g, was selected to give a volumetric air content of 0.07, the highest (most conservative) of the values reported, a three-fold increase on the 2016 modelling, and four times the average air porosity (0.016) for the 2017 samples noted above (refer to **Table 8-2**). This moisture content is close to the lower end of the reported range, illustrating a suitable level of conservatism.

The air filled porosity value of 0.07 is noted to have been associated not with the lowest soil moisture, but with the lowest bulk density, such that adoption of the above values is noted to allow for a wider range of site soil conditions than considered by the Stage 3 vapour intrusion modelling.

It is noted that even the adopted value is a low volumetric air content (wet soil) when compared to default literature values, such as those incorporated into the petroleum hydrocarbon HSLs in the

NEPM. This elevated moisture effectively acts as an impediment and slows vapour migration. This is considered consistent with the observations of relatively low vapour concentrations compared to equilibrium estimates from groundwater, as discussed in **Section 5.6.1**. A summary of the modelling inputs are provided in **Table 8-5** (in comparison to the adopted 2016 parameters) and detailed along with the modelling calculations in **Appendix S.**

**Table 8-5 Geological Modelling Inputs**

| Input Parameter | Units | Value Residential (2016) | Value Residential (2017) | Comments |
|---|---|---|---|---|
| Depth of Top of Source (bgs) - vapour | m | 1.5 | 1.5 | Soil Vapour Depth |
| Depth of Top of Source (bgs) – gw | m | 2 | 2 | Conservative depth to water |
| Thickness of Capillary Fringe | m | 0.2 | 0.2 | Estimated for sandy clay |
| Thickness of Vadose Zone | m | 1.8 | 1.8 | Depth to groundwater (2m) - Capillary Fringe |
| Average Soil Temperature | C | 25 | 25 | Site-specific assumption |
| Vadose Zone Layer 1 Characteristics | Gravel/Sandy Gravel Fill | | | |
| Thickness of Layer 1 | m | 0.5 | 0.5 | Assumptions for a gravel + conservative site derived moisture data |
| Moisture Content | ml/g | 0.02 | 0.02 | |
| Organic Carbon Fraction | | 0.003 | 0.003 | |
| Soil Bulk Density | g/ml | 1.9 | 1.9 | |
| Density of Solids | g/ml | 2.65 | 2.65 | |
| Total Soil Porosity | ml/ml | 0.28 | 0.28 | |
| Volumetric Water Content | ml/ml | 0.038 | 0.038 | |
| Volumetric Air Content | ml/ml | 0.245 | 0.245 | |
| Vadose Zone Layer 2 Characteristics | Clay - Sandy Clay | | | |
| Thickness of Layer 2 | m | 1.3 | 1.3 | Based on site specific measurements for the deeper sediments |
| Moisture Content | ml/g | 0.173 | 0.166 | |
| Organic Carbon Fraction | | 0.003 | 0.003 | |
| Soil Bulk Density | g/ml | 1.79 | 1.73 | |
| Density of Solids | g/ml | 2.69 | 2.69 | |
| Total Soil Porosity | ml/ml | 0.33 | 0.357 | |
| Volumetric Water Content | ml/ml | 0.31 | 0.287 | |
| Volumetric Air Content | ml/ml | 0.025 | 0.070 | |
| Capillary Fringe | Sandy Clay – based on vadose zone layer 2 | | | |
| Volumetric Water Content | ml/ml | 0.406 | 0.347 | Consistent with site data and CRC CARE for a clay |
| Volumetric Air Content | ml/ml | 0.010 | 0.010 | |

Where modelling has been undertaken assuming a soil vapour source, this has assumed a source located at a depth of 1.5 m, the depth of the soil vapour bores in the monitored network (noting some deeper vapour wells are present, but were not sampled as part of this investigation).

#### 8.4.3.7 Building Assumptions

The Fyfe (2016) assessment identified negligible difference in modelled vapour concentrations between slab on ground and crawl space foundation construction; as such this assessment focusses on slab on ground construction.

The input parameters describing features of these building types relevant to the modelling of exposure point air concentrations are listed in the spreadsheet tables in **Appendix S** and summarised in **Table 8-6** below. It is noted that these parameters are consistent with those adopted by Fyfe (2015) and AECOM for the Stage 3 investigation (AECOM, 2017).

**Table 8-6 Residential Slab on Ground Building Modelling Inputs**

| Input Parameter | Units | Value Residential | Comments |
|---|---|---|---|
| Width of Building | m | 10 | Default Assumption |
| Length of Building | m | 15 | Default Assumption |
| Foundation/Wall Thickness | m | 0.1 | CRC CARE |
| Height of Room | m | 2.4 | CRC CARE |
| Air exchange rate - indoors | exch/hr | 0.6 | CRC CARE |
| Fraction of Cracks in Walls and Foundation | | 0.001 | CRC CARE |
| $Q_{soil}/Q_{building}$ | - | 0.005 | Default for residential (CRC CARE) |
| Volumetric Water Content in foundation cracks | ml/ml | 0.12 | Default value ASTM 1739-95 |
| Volumetric Air Content in foundation cracks | ml/ml | 0.26 | Default value ASTM 1739-95 |

#### 8.4.3.8 Receptor Exposure Assumptions

**Residents**

Assumptions for exposure patterns for residents have been taken from enHealth 2012.

- It is assumed that residents will spend:
  - 20 hours per day indoors
  - 2 hours per day outdoors (negligible contribution to exposure outdoors)
- Residents are assumed to be potentially exposed to site-derived impacts for 35 years.
- Basements are assumed to be occupied for 8 hours per day (such as bedroom use), with the remaining 12 hours per day indoors spent upstairs (ground level).

As noted in **Section 6.6**, residents are considered to be the most sensitive receptor. Modelling of exposure for other receptor groups is therefore only warranted where potentially unacceptable risks are observed for residential receptors.

## 8.5 Risk Characterisation

### 8.5.1 Methods for Quantifying Risks to Human Health

Risk characterisation is the final step in a quantitative risk assessment. It involves the incorporation of the exposure assessment and toxicity assessment to provide a quantitative assessment of potential health risks. In the assessment presented, evaluation of exposures to the COPC involves an assessment of threshold and non-threshold risks.

The calculation of risks has been undertaken using an in-house spreadsheet model, RiskE (URS Australia). The equations utilised within RiskE apply risk assessment methodology as outlined in **Appendix S**, following protocols established by enHealth and USEPA. The output from this model has

been incorporated into the tables presented in the text of the report and into the calculation sheets also contained in **Appendix S**.

#### 8.5.1.1 Hazard Index for Threshold Effects

The potential for adverse threshold effects resulting from inhalation exposure to an individual COPC, is evaluated by comparing an exposure concentration with the adopted guideline or RfC. The resulting ratio is referred to by the US EPA as the hazard quotient (US EPA, 1989) and is derived in the following manner for inhalation exposures:

$$Hazard\ \ Quotient\ \ (inhalation\ ) = \frac{Exposure\ \ Concentrat\ \ ion\ in\ Air}{(RfC - Background\ )\ or\ \ TWA}$$

If the exposure concentration in air for the individual COPC exceeds the RfC with consideration of background intakes, (*i.e.*, if the hazard quotient exceeds one), this indicates potentially unacceptable exposures. The hazard quotient does not represent a statistical probability of an effect occurring.

To assess the overall potential for adverse health effects posed by simultaneous exposure to multiple chemicals, the hazard quotients for each chemical and exposure pathway have been summed. The resulting sum is referred to by the US EPA as the hazard index (HI). The HI approach assumes that multiple sub-threshold exposures to several chemicals could result in a cumulative adverse health effect, and exposures are summed over all intake routes.

#### 8.5.1.2 Acceptable Risk

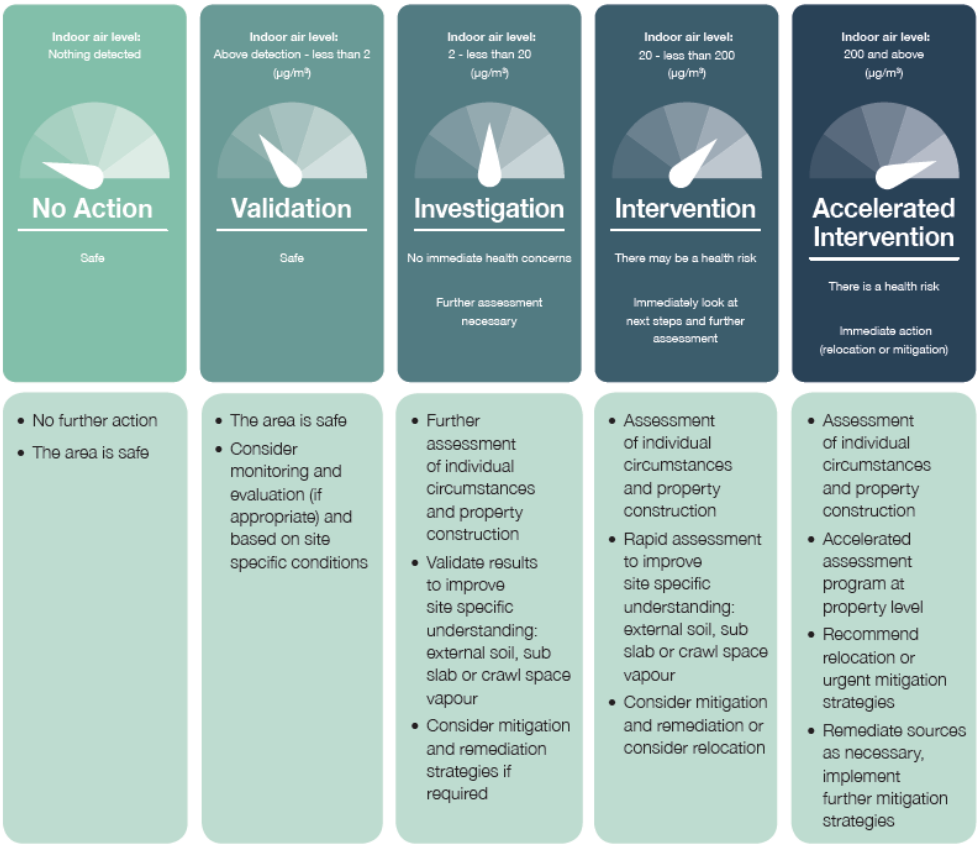
An “acceptable” risk in this assessment has been defined as a HI no greater than 1.0 (as per risk assessment industry practice, supported by protocols outlined in enHealth (2012a) and US EPA guidance).

It is noted that the EPA and SA Health recently collaborated in development of an Indoor Air Level Response Range for the Clovelly Park / Mitchell Park area, where intrusion of TCE vapour to residences was the issue of concern. The reference concentration for TCE of 2 µg/m$^3$ (as per **Figure 8-1**) was adopted as the upper end of the “Validation” range, where concentrations are deemed safe, but ongoing monitoring may be appropriate. TCE results up to one order of magnitude above this concentration (20 µg/m$^3$) fell into the “Investigation” range, wherein although no immediate health concerns were considered to be associated with such levels, further assessment was required. These concentrations (2 and 20 µg/m$^3$) are equivalent to HI of 1 and 10.

A HI of <1 indicates the exposure point concentration falls below the reference concentration for that chemical. For each exposure scenario, HI for each of the three chemicals of potential concern (PCE, TCE, cis-1,2-DCE) are summed. This approach (simple additivity) is consistent with a screening level approach recommended in enHealth (2012a). Accordingly:

- Where the sum of HIfor the COPC for any modelled scenario is <1, this is considered to be equivalent to results within the “Validation” range of the EPA/SA Health Indoor Air Level Response Range.
- Where the sum of HI for the COPC for any modelled scenario is >1 but <10, this is considered to be equivalent to results within the “Investigation” range of the EPA/SA Health Indoor Air Level Response Range.
- Where the sum of HI for the COPC for any modelled scenario is >10 but <100, this might be considered to be equivalent to results within the “Intervention” range of the EPA/SA Health Indoor Air Level Response Range, indicative of a potential health risk and warranting further action.

**Figure 8-1 EPA TCE Investigation Ranges (Clovelly Park – Mitchell Park)**




### 8.5.1.3 Non-Threshold Carcinogenic Risks

The potential for unacceptable non-threshold carcinogenic risks associated with exposure to COPC has been evaluated using US EPA methodology.

Non-threshold carcinogenic risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential non-threshold carcinogen. The numerical estimate of excess lifetime cancer risk is calculated as follows for inhalation exposures:

*Carcinogenic Risk (inhalation) = Exposure Concentration in Air x Inhalation Unit Risk*

The total non-threshold carcinogenic risk is the sum of the risk for each chemical for each pathway.

### 8.5.1.4 Acceptable Risk

The adopted acceptable risk is defined as no more than to 1 x $10^{-5}$ incremental lifetime risk of cancer, consistent with enHealth (2012a) and the 1999 NEPM (as amended 2013).

For the COPC at the site, TCE is the only potentially carcinogenic contaminant. As noted in **Section 8.3**, the critical toxicological effect for TCE is associated with threshold (non-carcinogenic) effects. As such, this quantitative assessment has focussed on threshold effects only.

## 8.5.2 Modelled Exposure Point Vapour Concentrations and Hazard Indices – Soil Vapour Source

Based on the maximum measured soil vapour concentrations, and adopted geological parameters, no unacceptable vapour intrusion risks are predicted, with all modelled indoor air concentrations below guidelines, as summarised in **Table 8-7**, below. The overall Hazard Quotient of 0.32, while approximately an order of magnitude greater than calculated as part of the Stage 3 investigation on the basis of the 2016, is 3 times lower than the acceptable level, and lies within the “Validation” range of the EPA/SA Health Indoor Air Level Response Range.

**Table 8-7 Modelled Indoor Air Concentrations from Vapour**

| COPC | Indoor Air Screening Criteria (µg/m$^3$) | 2016 Calculated Indoor Concentration (µg/m$^3$) | 2017 Calculated Indoor Concentration (µg/m$^3$) |
|---|---|---|---|
| PCE | 200 | 0.015 | 0.197 |
| TCE | 2 | 0.06 | 0.698 |
| cis-1,2-DCE | 8 | 0.001 | 0.007 |

Based on this February 2017 data, *no unacceptable vapour intrusion risks are predicted in the residential area*.

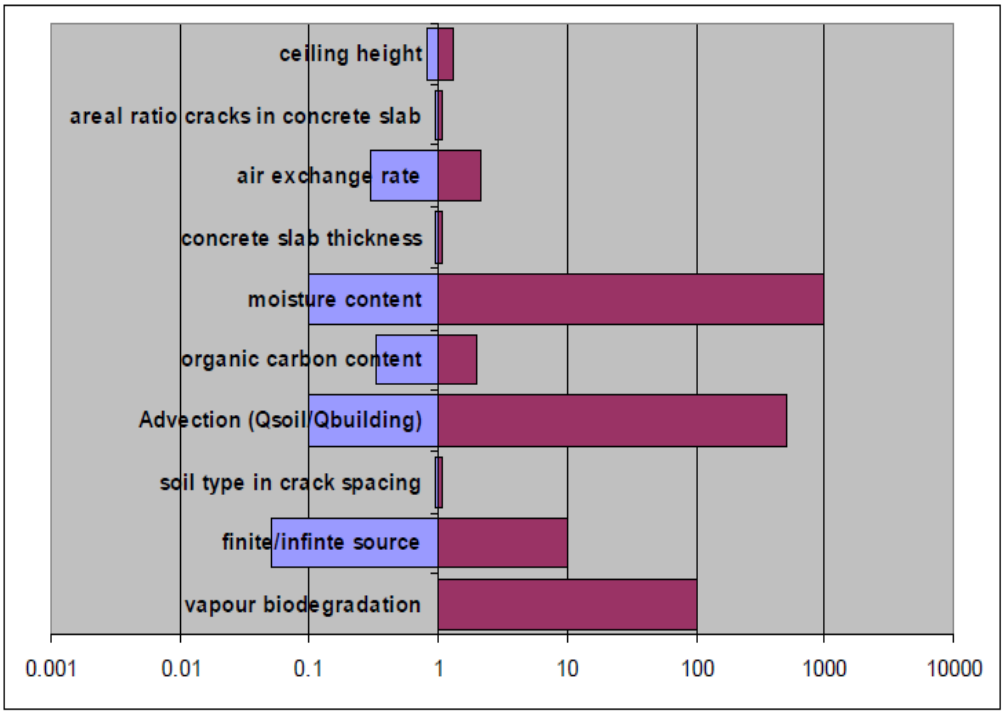
It is noted that these modelled results, although greater than those calculated in 2016, remain lower than the TCE concentrations in the 2-20 µg/m$^3$ EPA *further investigation* range calculated by Fyfe (2015). This is noted to be principally associated with the assumed soil properties adopted by Fyfe being materially more conservative than those measured in this investigation. This is considered further in the sensitivity section below.

## 8.6 Sensitivity Analysis of Key Risk Modelling Inputs

### 8.6.1 Introduction

CRC CARE Technical Report 10 derived Health Screening Levels for petroleum hydrocarbons using the Johnson and Ettinger model. As part of the sensitivity analysis document (Part 3), a summary of the key input parameters was included (refer to **Figure 8-2**).

**Figure 8-2 CRC CARE Technical Report 10, Part 3 Sensitivity Analysis Summary (Figure 4)**



This CRC CARE assessment found the key parameters that the modelling was sensitive to were:

- Moisture content;
- The advection (pressure driven flow) rate;
- *Vapour biodegradation* (*not considered applicable to TCE*);
- Source life for soils (finite/infinite source) – not considered applicable for groundwater sources;
- Organic carbon content (relevant for modelling from a soil source only); and
- The indoor air exchange rate.

Other parameters were found to be relatively insensitive.

### 8.6.2 Volumetric Air Content, Moisture Content and Soil Bulk Density

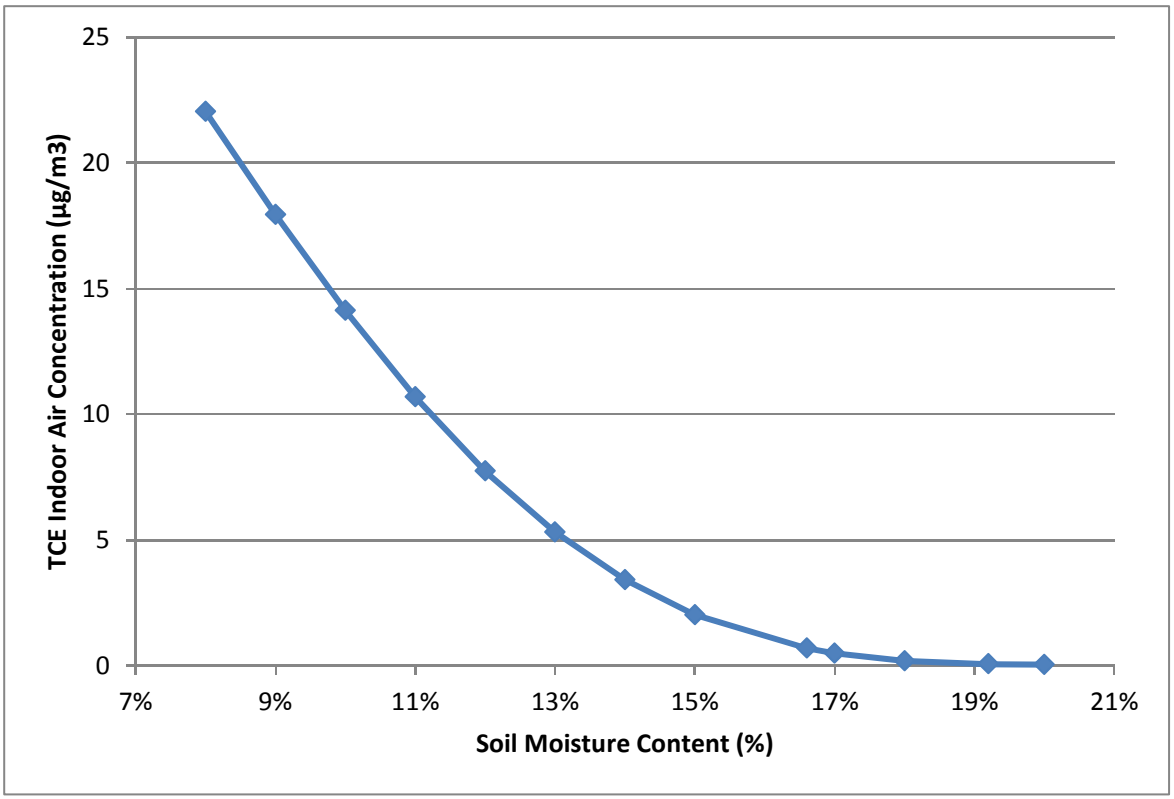
The volumetric air content, moisture content and soil bulk density are related parameters as far as the J&E model are concerned, in that they affect the air-filled pore space, through which the models assumes the majority of vapour transport occurs. As can be seen from **Figure 8-1** above, moisture content is potentially the most significant variable considered in the J&E model.

Increasing the soil bulk density decreases the available soil pore space and thereby reduces vapour transport (all else being equal). Increases in moisture content similarly reduce the available air-filled porosity as the moisture takes up more of the available pore space, thereby reducing vapour migration.

While CRC CARE TR10 incorporates default soil properties for three classes of soil (sand, silt and clay) in the risk modelling undertaken here, data derived from site-specific soil testing has been preferentially used in selection of parameters (**Section 8.4.3.6**).

**Figure 8-3** below shows the effect on modelled TCE concentrations in indoor air of varying the assumed soil moisture content for soils below the surface fill layer.

**Figure 8-3 Modelled Indoor Air TCE as a Function of Soil Moisture Content (0.5-1.5 m bgl)**



An input soil moisture content of 19.2% to give a volumetric air content of 0.025 (as modelled for Stage 3) returns a comparable indoor air TCE concentration of 0.067 µg/m$^3$. Modifying the moisture content (while keeping other parameters constant) from the initial (2017) input value of 16.6% down to only 12% results in a predicted increase in the indoor air concentration of greater than 10-fold, from 0.698 µg/m$^3$ to 7.74 µg/m$^3$. Decreasing it further, to 8%, (corresponding to an air-filled porosity of 21.8%) results in a predicted concentration of 22.0 µg/m$^3$, above the EPA/SA Health 20 µg/m$^3$ *Investigation* range, and into the *Intervention* range.

As such, it is important to understand that the potential indoor air risk posed by TCE is heavily influenced by soil moisture. The potential for seasonal changes in soil moisture, and the soil moisture conditions beneath sealed surfaces (noting these is currently little site data in this respect), should be considered as part of further investigations.

Allowing for potential drying of soils under extended hot and dry meteorological conditions leading to a theoretical soil moisture content of 8% (consistent with the CRC CARE Technical Report 10 assumptions for a sand/sandy clay), the lower threshold of the Investigation range would correspond to a measured soil vapour concentration of 3,267 µg/m$^3$. On this basis, even under such severe drying conditions (noting the lowest reported soil moisture from geotechnical samples to date of 15.3%), the requirement for further assessment would be limited to a band within the northern plume area currently represented by vapour bores VP66, VP18, VP41, VP29, VP30 and VP52; this zone presumably also extends up-gradient to the east to the as-yet undetermined source sites. This corresponds to approximately the area shaded dark green in **Figure 13**.

At present, only the reported concentration at VP29 (33,000 µg/m$^3$) would result in a modelled indoor air concentration exceeding the Investigation level under the dry soil site conditions (excluding the highly elevated vapour concentrations at the Focus Sites, which have only been identified at bores within those sites and thus not warranting consideration with respect to residential vapour intrusion risk).

### 8.6.3 Modelled Exposure Point Vapour Concentrations and Hazard Indices – Groundwater Source

#### 8.6.3.1 Site Specific Geological Parameters

To supplement the vapour intrusion modelling from soil vapour concentrations, detailed above, modelling from groundwater has also been undertaken, based on the maximum measured groundwater concentrations.

The same geological parameters were used as for the soil vapour source, although the depth to the source was adjusted to 2 m, a conservative (shallowest) standing water level.

No unacceptable vapour intrusion risks were calculated, with all modelled indoor air concentrations below guidelines, as summarised in **Table 8-8**, below. Predicted indoor air concentrations based on groundwater data were close to, but marginally higher than those calculated based on soil vapour concentrations. The overall Hazard Quotient of 0.52, compares reasonably well with that calculated based on the highest measured soil vapour concentrations (HI = 0.32; **Section 8.5.2**). Modelling inputs and outputs are presented in **Appendix S.**

**Table 8-8 Modelled Indoor Air Concentrations from Soil Vapour and Groundwater**

| COPC | Indoor Air Screening Criteria (µg/m$^3$) | 2017 Indoor Concentration-Vapour Source (µg/m$^3$) | 2017 Indoor Concentration – Groundwater Source (µg/m$^3$) |
|---|---|---|---|
| PCE | 200 | 0.197 | 0.29 |
| TCE | 2 | 0.698 | 1.12 |
| 1,1-DCE | 210 | - | 0.09 |
| VC | 3 | | 0.001 |

#### 8.6.3.2 CRC CARE (2010) Geological Parameters

As discussed above for the soil vapour data, the assumed soil moisture content is a sensitive parameter in vapour intrusion modelling. Revising the soil geological parameters from those measured on site (**Section 8.3.4.6**) to the more conservative sand/sandy-clay parameters adopted in the generation of the NEPM petroleum HSLs (CRC CARE 2010), results in an increase in predicted soil vapour concentrations (**Table 8-9**), with TCE exceeding the adopted indoor air guideline of 2 µg/m$^3$ by approximately a factor of two, based on the highest groundwater concentrations and this dry soil assumption.

On the basis of this CRC-CARE assumed 8% soil moisture, a TCE groundwater concentration of approximately 300 µg/L is predicted to give rise to concentrations of TCE in indoor air above the 2 µg/m$^3$, within the EPA f*urther Investigation* range.

**Table 8-9 Modelled Indoor Air Concentrations from Groundwater**

| COPC | Indoor Air Screening Criteria (µg/m$^3$) | Indoor Concentrations – Site Specific Geology (µg/m$^3$) | Indoor Concentrations – CRC CARE Geology (µg/m$^3$) |
|---|---|---|---|
| PCE | 200 | 0.29 | 1.13 |
| TCE | 2 | 1.12 | 3.84 |
| 1,1-DCE | 210 | 0.09 | 0.52 |
| VC | 3 | 0.001 | 0.043 |

## 8.7 Basements in Residential Dwellings

Fyfe (2016) reported that they identified no basements or cellars in a December 2015 survey of their Assessment Area, however, returned responses did not cover the entire area. It is noted that no such survey was undertaken as part of the Stage 3 or Stage 4 assessments, and that the current investigation area is larger than at the time of the Fyfe survey. The Fyfe assessment included quantitative consideration of basements, on the basis of the potential for some to exist currently, or in the future.

With regard to the assessment of basements, the Fyfe modelling was undertaken from measured groundwater concentrations, assuming an average depth to water of 2.5 m and basement depth of 2.4 m (i.e. 100 mm only between groundwater and basement foundation). The report concluded:

> *The vapour intrusion model predicts that construction of basements would at least require further investigation and potential remediation at, and surrounding, all locations where groundwater has been investigated.*

In the Stage 3 investigation, the depth to water ranged from 2.09 to 4.26 m, with an average depth of approximately 2.7 m below ground level; the Stage 4 investigation reported standing water levels as shallow as 2.08 m (MW29). Evidently then, in some parts of the investigation area, a standard 2.4 m deep basement would be below the water table and would therefore need to be engineered to prevent groundwater ingress. The absence of reported basements is therefore consistent with the shallow groundwater depth.

A semi-quantitative assessment of vapour intrusion into basements can be made by considering the reported soil vapour concentrations and applying an attenuation factor. The US EPA vapour intrusion database[8] provides measured sub-slab soil vapour to indoor air attenuation factors of 0.03 (95%ile) and 0.003 (50%ile).

Applying the more conservative 95%ile attenuation factor to the TCE indoor air guideline of 2 µg/m$^3$ gives a soil vapour screening guideline of 66 µg/m$^3$.

[8] US EPA Vapour intrusion database, available on line at http://www.epa.gov/oswer/vaporintrusion/documents/OSWER_2010_Database_Report_03-16-2012_Final_witherratum_508.pdf

Additionally, if it is assumed that use of a basement would not involve continuous occupation, but could involve use for up to eight hours a day, such as for bedroom use and that concentrations upstairs from a basement are assumed to have a concentration *one-third* of that of the basement (consistent with guidance from CRC CARE 2013) an intake factor of 0.6 can be applied to this soil vapour value to give soil vapour screening levels of approximately:

- 100 µg/$m^3$ in soil vapour - for soil vapour to indoor air (95%ile attenuation factor) at TCE of 2 µg/$m^3$
- 1000 µg/$m^3$ in soil vapour - for soil vapour to indoor air (90%ile attenuation factor) at TCE of 20 µg/$m^3$.

Review of **Figure 13** suggests a significant portion of the northern Assessment Area would likely exceed these soil vapour levels and therefore warrant further assessment if basements were present or proposed. It is noted however that there are limitations associated with attempting to assess vapour intrusion into basements using soil vapour concentrations as the source data, particularly where, as in this instance, the depth of the soil vapour data (1.5 m bgl) is shallower than the assumed depth of basements. No depth-based soil vapour concentration assessment has been undertaken, apart from on the Focus Sites at the eastern end of the Assessment Area.

## 8.8 Intrusive Workers

Risks to intrusive workers, such as those who may enter trenches to install or maintain pipes or sub-surface infrastructure, are considered to be qualitatively similar to outdoor air environments, whereby there is limited potential for build-up of high concentrations; however exposure to vapours emanating from impacted groundwater is a potentially complete exposure pathway. While soil vapour concentrations are substantially elevated in some parts of the Assessment Area, intrusive workers are not assumed to be exposed to such soil vapour concentrations, as the act of digging the trenches allows for far greater dilution/mixing with ambient air (principally due to the wind) which reduces exposure concentrations.

This pathway was considered quantitatively by using the algorithms presented in ASTM (2010) *Risk Based Corrective Action at Petroleum Release Sites*. The depth to water in the Assessment Area (> 2 m bgl) is greater than the typical depth of the base of excavations, assumed to be 1.5 m, consistent with the depth of most services, and as such, groundwater ingress into trenches was not modelled.

Consistent with the approach adopted in CRC CARE Technical Report 10 (2011), deep trench works (such as sewer) have not been quantitatively considered. These works would likely be below the water table and would require site specific health and safety considerations to address protections for confined spaces and geotechnical considerations.

Modelling of vapour migration from groundwater into shallow trenches assumed:

- groundwater at a depth of 2 m
- a maximum trench depth of 1.5 m
- geology consistent with site data and as assumed for the residential modelling (less the overlying (excavated) soils)
- air flow (wind speed) within the trench of 1/$10^{th}$ that of outdoor air, due to a more enclosed environment
- that the trench was located above the highest groundwater concentrations identified in the monitoring program.

Calculated concentrations within a trench were estimated to be more than two orders of magnitude lower than commercial industrial (indoor air) guidelines. As such, even ignoring the substantially lower frequency and duration of likely exposure by intrusive workers compared to occupational workers, the vapour concentrations within the trench are not predicted to pose any unacceptable risk. Methodology, assumptions and concentration estimates are provided in **Appendix T.**

It is noted that this assessment does not replace occupational health and safety requirements under state legislation or industry codes of practice including requirements for works in confined spaces.

# 9.0 Conclusions and Recommendations

## 9.1 Scope of Works

The investigations conducted by AECOM in January and February 2017 within the SA EPA South Eastern Edwardstown Assessment Area included:

- expansion of the existing groundwater well monitoring network by a further 10 wells;
- conduct of a groundwater monitoring event encompassing 43 new and existing wells, with analysis targeting selected VHA compounds;
- installation of 14 new soil vapour wells, and vapour sampling of a total of 74 new and existing soil vapour wells, with samples analysed for selected VHA compounds;
- collection and analysis of soil samples for moisture content analysis and physical parameters to refine vapour intrusion modelling parameters;
- collection of crawl space air samples from five residential properties located near the Focus Sites within the eastern portion of the Assessment Area;
- update of the conceptual site model on the basis of the additional data, and refinement of vapour intrusion risk assessment modelling; and
- completion of groundwater fate and transport modelling in relation to the VHA impacts on the basis of the available site data.

## 9.2 Findings

The groundwater investigations are assessed to have delineated the down-gradient extent of VHA impacts in the shallow aquifer to concentrations less than the adopted drinking water guideline (20 µg/L), other than to the south although TCE concentrations exceed laboratory limits of reporting in samples collected from most perimeter wells.

The source and up-gradient extent of the VHA plume in the northern portion of the Assessment Area is yet to be determined. Groundwater concentrations were generally consistent with those identified in the Stage 3 investigations.

While some VHA soil vapour concentrations were reported for Assessment Area perimeter bores, based on a comparison of vapour results to groundwater concentrations, it is considered that elevated soil vapour concentrations associated with the groundwater plumes are encompassed by the Assessment Area, other than to the east where the source and thus extent are unknown. Maximum measured soil vapour concentrations were consistent with those reported for the Stage 3 investigation.

Crawlspace vapour sampling was not indicative of VHA concentrations representing risk to human health for the selected residential properties along Arabrie Avenue, with all results less than guidelines.

Groundwater impacts and associated soil vapour impacts attributable to the Focus Sites are evidently present; however, it is apparent that a significant proportion of the VHA impacts across the Assessment Area are related to a separate source (or sources) potentially located within or adjacent the north-eastern portion of the Assessment Area. A cursory review of historical records indicates a number of sites within or immediately east of the Assessment Area with the potential to represent historical sources of VHA.

As for the Stage 3 investigation, soil geotechnical properties including soil bulk density, moisture content and particle density were measured to enable an assessment of the air-filled porosity as a key vapour modelling parameter. The results obtained again showed generally high water saturation (average > 90%) in the vadose zone soils, although a greater range of air-filled porosity than previously assessed, and this data was incorporated into updated vapour transport modelling to form the quantitative basis of the vapour intrusion risk assessment.

As a result of the notably higher air-filled porosity input value used, indoor air vapour concentrations modelled from measured soil vapour concentrations based on field-measured parameters were an order of magnitude higher than estimated for the Stage 3 investigation; however, the modelling resulted in no predicted exceedances of the 2 µg/m$^3$ indoor air guideline for TCE, the primary contaminant of concern.

Assessment of the potential for vapour intrusion into outdoor, shallow (1.5 m deep) excavations that might be entered (e.g. by workers maintaining underground services) found concentrations would be more than two orders of magnitude below commercial industrial guidelines and not considered to represent an unacceptable vapour inhalation risk.

It is noted that the vapour modelling is highly sensitive to the assumed soil moisture. A sensitivity analysis indicated that with materially drier vadose zone conditions (approximately half the driest observed) indoor air concentrations would be predicted to exceed the indoor air guideline for TCE, although it is highlighted that even then the calculated indoor air concentrations would generally be within the SA EPA/SA Health *Further Investigation* range (i.e. < 20 µg/m$^3$), with the exception near VP29, where the highest vapour concentrations were reported.

Consistent with the earlier risk assessment, the shallow depth to water and measured soil vapour concentrations mean that VHA impacts across a substantial portion of the investigation area might pose an unacceptable vapour intrusion risk were there to be basements present.

## 9.3 Groundwater Modelling

Saturated zone solute transport modelling has been undertaken using the US EPA model BIOCHLOR, which uses the Domenico analytical solute transport model to simulate one-dimensional advection, three-dimensional dispersion, linear adsorption and biotransformation (via dechlorination) as a sequential first-order decay process. The model was set up using site data, where available, and model calibration assessed by qualitatively comparing simulated groundwater TCE concentrations (as the primary COPC), along the plume centre-line with observed concentrations from the February 2017 data set.

Due to the limitations in the available data relating to potential source sites, particularly in the north of the Assessment Area, the 1D-model conservatively assumed ongoing plume migration based on a continuing source, with source concentrations inferred from observed well concentrations in the inferred down-gradient plume centreline.

Based on this preliminary modelling the following were predicted:

- In order to match the observed decline in concentration from the several hundred micrograms per litre in the middle and up-gradient areas of the plume to relatively low concentrations at the down-gradient extent of the investigation area, it was necessary to assume that the *plume is still expanding*. However, it is noted that the relatively large distances between groundwater wells in the Assessment Area and inferred source zone may mean that the current well network does not intersect the highest concentrations and this may affect modelling calibration and predictions.
- Concentrations in the vicinity of MW29 (near the current down-gradient extent of the Assessment Area) are predicted to rise from currently around 10 µg/L (2017) to greater than the drinking water guideline (20 µg/L) by 2020. It is noted that wells providing plume delineation have only been sampled once with a maximum of three data points available for wells within the Assessment Area monitoring network over an 18 month period.
- TCE would not be expected to have reached Bowaka Street, Park Holme (approximately 275 m west of the current extent of the Assessment Area) at the current time, however impacts are predicted to slowly migrate further west and approach the drinking water guideline at this distance in approximately 30 years' time.

## 9.4 Data Gaps

While the Stage 4 investigations have progressed the understanding of the nature and extent of VHA impacts to the subsurface across the Assessment Area, the potential risks posed, and their likely fate and transport, there remain a number of data gaps pertinent to an appropriate level of understanding of these issues, inclusive of the data gaps identified in relation to the site conceptual model as noted previously:

- There is limited information as to the identity of potential source sites other than the Focus Sites. AECOM is not aware of any detailed study of historical site activities across the eastern portion of the Assessment Area or the area further to the east. While the existence of a number of former commercial/industrial operations that could represent historical sources of VHA impacts was identified by AECOM, a detailed review was outside the scope of this assessment.
- While not considered material to the broad understanding of groundwater flow beneath the site, the inferred groundwater contours exclude one well at which groundwater levels had evidently not stabilised. A refined assessment of standing water levels would be possible once sufficient time for stabilisation to have occurred.
- VHA impacts in groundwater remain undelineated (to below the adopted criteria) to the south of the current Assessment Area, both in the eastern portion and notably at MW31 (off Railway Terrace, installed with the aim of delineating groundwater impacts south-west of MW27). Groundwater impacts are also not delineated up-gradient (east) of the northern plume area, where it is apparent that further source(s) exist.
- TCE impacts have not been delineated to below laboratory limits of reporting in any direction, apart from the north-east.
- It has not yet been established whether there is a link between the groundwater impacts reported for MW21 and the impacts in the vicinity of the Focus Sites to the east, or indeed the up-gradient materially impacted well MW07. The apparent disconnect is due largely to the reported low TCE concentrations for wells MW8 and MW10. Further groundwater investigation up-gradient of MW21, inclusive of at least a further well between MW08 and MW10, should assist with understanding of the origin of the impacts at MW21.
- Other than sampling of one existing private well in Stage 3 (which identified VHA impact), there has been no investigation of potential VHA impacts to the deeper (Q2) aquifer. Interactions between the unconfined aquifer and deeper water bearing zones which may have been intersected for productive or drainage purposes historically or currently, have not been considered in this assessment.
- Soil vapour impacts are largely delineated within the Assessment Area, other than to the east (up-gradient) where further investigation would be required to identify the sources and delineate impacts, and to the north at the western extent of the plume, where further temporal data may provide additional understanding of the nature and origin of the observed impacts.
- Apparent increases in soil vapour in a number of vapour bores off Arabrie Avenue (H1 to H10) are based on sampling in 2015 and 2017 only. Further temporal data is required to assess trends in these and other vapour bores.
- The vapour intrusion risk assessment has identified the potential for greater indoor air concentrations, potentially exceeding SA EPA TCE Investigation criteria and into the Intervention range, in the event soils are subject to substantial drying. An ongoing assessment of soil conditions in areas of higher groundwater impact would be warranted, potentially inclusive of assessment of the soil moisture regime beneath concrete floor slabs (or equivalent sealed surfaces) in this area.
- The one-dimensional groundwater modelling undertaken indicated that the extent of the VHA plume is unlikely to currently be stable, with future concentrations in excess of drinking water guidelines predicted to extend beyond the current Assessment Area. It is noted that due to the absence of information regarding sources, the limited temporal data and relatively large distances between groundwater wells, particularly in the down-gradient, western area, uncertainties relating to the plume fate and transport are large and *limited confidence is placed in the predictions of the*

*groundwater modelling*. Additional well installation targeting potential up-gradient sources, down-gradient extent beyond the current Assessment Area and infilling at key locations within the current Assessment Area and additional temporal data would aid in refining the model and improving confidence in model predictions.

# 10.0 References

AEC Environmental, 2009, Preliminary Groundwater Investigation McLeod Plating – 4-6 Erudina Avenue, Edwardstown, AEC Environmental Project Ref 4023, 30 June 2009.

AEC Environmental, 2014, Groundwater Monitoring Event – 4-6 Erudina Avenue, Edwardstown, AEC Environmental Project Ref J124834, 30 May 2014.

AECOM, 2017, Stage 3 EPA Assessment, South Eastern Edwardstown, AECOM Australia Pty Ltd report 60504760 dated October 2017.

ANZECC/ARMCANZ, 2000, Australian and New Zealand guidelines for fresh and marine water quality, national water quality management strategy October 2000.

AS1726 1993, Australian Standard, Geotechnical Site Investigations, council of Australian Standards, 13 April 1993.

ASTM, 2010, Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites E1739-95, ASTM International, Reapproved 2010

Bioscreen US EPA 1997 https://www.epa.gov/water-research/bioscreen-natural-attenuation-decision-support-system

CCME, 2007, Canadian Soil Quality Guidelines, Trichloroethylene, Environmental and Human Health Effects, Scientific Supporting Document. Canadian Council of Ministers of the Environment (CCME), 2007.

CRC CARE, 2011, Health screening levels for petroleum hydrocarbon in soil and groundwater, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia, September

CRC CARE, 2013, Petroleum hydrocarbon vapour intrusion assessment: Australian guidance, CRC CARE Technical Report no. 23, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia

DEWNR, 2016a, NatureMaps website, Department of Environment, Water and Natural Resources, Government of South Australia, accessed 23 June 2016, http://www.naturemaps.sa.gov.au/.

DEWNR, 2016b, Groundwater Data Online Database, WaterConnect, Department of Environment, Water and Natural Resources, Government of South Australia, accessed 23 June 2016, https://www.waterconnect.sa.gov.au/GD.

DfW 2012, Groundwater level and salinity status report 2011 – Central Adelaide PWA, Government of South Australia, through Department for Water, Adelaide

Domenico, P.A., 1987, An Analytical Model for Multidimensional Transport of a Decaying Contaminant Species. Journal of Hydrology, 91 (1987) 49-58.

Domenico, P.A and Schwartz, F.W., 1990 Physical and Chemical Hydrogeology, Wiley New York, 1990

DWLBC Report, 2004/47, Aquifer Storage Capacities of the Adelaide Region, Department of Water, Land and Biodiversity Conservation, 2004.

enHealth, 2012a. Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards Update, June 2012

enHealth, 2012b. Australian Exposure Assessment Handbook, June 2012.

Fetter, C.W. 2001, Applied Hydrogeology, Fourth Edition, Prentice Hall Inc.

Friebel, E, Naudebaum, P, 2011, Health screening levels for petroleum hydrocarbons in soil and groundwater, Part : Technical development document, CRC CARE Technical Report no 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia

Fyfe, 2016. South-Eastern Edwardstown Stage 2 Environmental Site Assessment. 7 March 2016.

Gerges N, 2006, Overview of the hydrogeology of the Adelaide metropolitan area, Report DWLBC 2006/10, Government of South Australia, through Department of Water, Land and Biodiversity Conservation, Adelaide.

Greencap, 2015, Environmental Assessment Works, EPA Assessment Area South Eastern Edwardstown, J131841, July 2015.

ITRC, 2007, Vapor Intrusion Pathway: A Practical Guideline, VI-1, Technical and Regulatory Guidance, Interstate Technology and Regulatory Council, Vapor Intrusion Team, Washington, D.C, January 2007, www.itrcweb.org.

Johnson 2002, Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapor Intrusion Model, American Petroleum Institute, May 2002

Marion Council, 2016, Development Plan, Government of South Australia, Department of Planning, Transport and Infrastructure, consolidated 28 April 2016, http://www.dpti.sa.gov.au/__data/assets/pdf_file/0007/247633/Marion_Council_Development_Plan.pdf

National Environment Protection Council (NEPC), 2013. Amended 1999 National Environment Protection Measure (Assessment of Site Contamination)

NHMRC and ARMCANZ, 2011 Australian Drinking Water Guidelines - 6. National Water Quality Management Strategy, National Health and Medical Research Council and the Agriculture and Resource Management Council of Australia and New Zealand), updated Feb 2016

NHMRC 2008, Guidelines for Managing Risks in Recreational Waters, National health and Medical Research Council, Australian Government, 2008.

R Shen, K Pennell, E Suuberg, 2012, A numerical investigation of vapour intrusion – The dynamic response of contaminants vapors to rainfall events, School of Engineering, Brown University, Providence, USA

SADME,1986, 1:50,000 Geological Map of Gawler 6628-IV, South Australian Department of Mines and Energy.

SA EPA, 2003, Environment Protection (Water Quality) Policy and Explanatory Report 2003, South Australian Environment Protection Authority, 2003.

SA EPA 2007, Regulatory Monitoring and Testing – Groundwater Sampling, South Australian Environmental Protection Authority, June 2007

SA EPA, 2009, Site Contamination – Guidelines for the Assessment and Remediation of Groundwater Contamination, South Australian Environment Protection Authority, February 2009.

SA EPP (Water Quality), 2015, South Australian Environment Protection (Water Quality) Policy 2015 under the Environment Protection Act 1993, Government of South Australia.

Sheard M.J. and Bowman G.M. 1996, Soils, stratigraphy and engineering geology of near surface materials of the Adelaide Plains', Mines and Energy South Australia Report Book 94/9, July 1996. reprinted March 1998.

UK Environment Agency, 2003, An illustrated handbook of DNAPL transport and fate in the subsurface', Environment Agency R&D Publication 133

UK Environment Agency, 2009, Updated Technical Background to the CLEA model, http://www.environmentagency.

gov.uk/static/documents/Research/CLEA_Report_-_final.pdf

US EPA, 1989, Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual. Interim Final, Office of Emergency and Remedial Response, US EPA, Washington DC. OSWER Directive 9285.7-0/a.

US EPA, 1992. Estimating Potential for Occurrence of DNAPL at Superfund Sites. OSWER Publication 9355.4-07FS. National Technical Information Service (NTIS) Order Number PB92-963338CDH.

US EPA, 2003, User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings. June 2003.

US EPA, 2012a, Conceptual Model Scenarios for the Vapor Intrusion Pathway, US EPA Office of Solid Waste and Emergency Response (EPA 530-R-10-003), February 2012

US EPA, 2012b, EPA's Vapor Intrusion Database: Evaluation and Characterisation of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings, EPA 520-R-10-002, March 16 2012.

US EPA, 2012c, Toxicological review of tetrachloroethylene, EPA/635/R-08/011F, Feb 2012 https://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/0106tr.pdf

US EPA, 2014, Vapor Intrusion Screening Level (VISL) Calculator User's Guide, May 2014.

US EPA, 2015, Technical guide for assessing and mitigating the vapor intrusion pathway from subsurface vapor sources to indoor air, OSWER Publication 9200.2-154, June 2015

US EPA, 2016, Regional screening levels (RSLs), https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-may-2016

WHO, 2011, Guidelines for Drinking Water, Fourth Edition, World Health Organisation, 2011.

# 11.0 Report Limitations

The conclusions and all information in this Report is provided strictly in accordance with and subject to the following limitations and recommendations:

a. This Report has been prepared for the benefit of the South Australian Environment Protection Authority (SA EPA).

b. Except as required by law, no third party may use or rely on, this Report unless otherwise agreed by AECOM in writing. Where such agreement is provided, AECOM will provide a letter of reliance to the agreed third party in the form required by AECOM.

c. This Report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by AECOM for use of any part of this Report in any other context.

d. This conclusion is based solely on the information and findings contained in this Report.

e. This conclusion is based solely on the scope of work agreed between AECOM and SA EPA and described in Section 1.3 ("Scope of Works") of this Report.

f. This Report is dated 12 October 2017 and is based on the conditions encountered during the site investigations conducted, and information reviewed, from January to February 2017. AECOM accepts no responsibility for any events arising from any changes in site conditions or in the information reviewed that have occurred after the completion of the site investigations.

g. The investigations carried out for the purposes of the Report have been undertaken, and the Report has been prepared, in accordance with normal prudent practice and by reference to applicable environmental regulatory authority and industry standards, guidelines and assessment criteria in existence at the date of this Report.

h. Where this Report indicates that information has been provided to AECOM by third parties, AECOM has made no independent verification of this information except as expressly stated in the Report. AECOM assumes no liability for any inaccuracies in or omissions to that information.

i. AECOM has tested only for those chemicals specifically referred to in this Report. AECOM makes no statement or representation as to the existence (or otherwise) of any other chemicals.

j. Except as otherwise specifically stated in this Report, AECOM makes no warranty or representation as to the presence or otherwise of asbestos and/or asbestos containing materials (“ACM”) on the site. If fill has been imported on to the site at any time, or if any buildings constructed prior to 1970 have been demolished on the site or materials from such buildings disposed of on the site, the site may contain asbestos or ACM. Without limiting the generality of sub-clauses (h) and (m), even if asbestos was tested for and those test results did not reveal the presence of asbestos at specific points of sampling, asbestos may still be present at the site if fill has been imported at any time, or if any buildings constructed prior to 1970 have been demolished on the site or materials from such buildings disposed of on the site.

k. No investigations have been undertaken into any off-site conditions, or whether any adjoining sites may have been impacted by contamination or other conditions originating from this site.

l. Investigations undertaken in respect of this Report are constrained by the particular site conditions, such as the location of buildings, services and vegetation. As a result, not all relevant site features and contamination may have been identified in this Report.

m. Subsurface conditions can vary across a particular site and cannot be exhaustively defined by the investigations described in this Report. It is unlikely therefore that the results and estimations expressed in this Report will represent conditions at any location removed from the specific points of sampling.

n. A site which appears to be unaffected by contamination at the time the Report was prepared may later, due to natural phenomena or human intervention, become contaminated.

o. Except as specifically stated above, AECOM makes no warranty, statement or representation of any kind concerning the suitability of the site for any purpose or the permissibility of any use, development or re-development of the site.

p. Use, development or re-development of the site for any purpose may require planning and other approvals and, in some cases, environmental regulatory authority approval. AECOM offers no opinion as to whether the current use has any or all approvals required, is operating in accordance with any approvals, the likelihood of obtaining any approvals for development or redevelopment of the site, or the conditions and obligations which such approvals may impose, which may include the requirement for additional environmental works.

q. AECOM makes no determination or recommendation regarding a decision to provide or not to provide financing with respect to the site.

r. The ongoing use of the site and/or the use of the site for any different purpose may require the owner/user to manage and/or remediate site conditions, such as contamination and other conditions, including but not limited to conditions referred to in this Report.

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