June, 2016

BEVERLEY ASSESSMENT AREA, SOUTH AUSTRALIA

Beverley Stage 3b Validation (Site Specific) Assessment Works

Submitted to:
Environment Protection Authority
Level 8, 250 Victoria Square
ADELAIDE SA 5000

REPORT

Report Number. 1546385-002-R-Rev0

Distribution:

1 Electronic Copy to Environment Protection Author
1 Electronic Copy to Golder Associates Pty Ltd

Golder Associates

Record of Issue

Company	Client Contact	Version	Date Issued	Method of Delivery
Environment Protection Authority	Dale McGill	1546385-002-R-RevA	25 May 2016	Hand Delivered
Environment Protection Authority	Dale McGill	1546385-002-R-RevB	17 June 2016	Email
Environment Protection Authority	Dale McGill	1546385-002-R-Rev0	28 June 2016	Email

Executive Summary

The South Australian Environment Protection Authority (SA EPA) engaged Golder Associates Pty Ltd (Golder) to conduct a soil vapour, sub-floor vapour, and indoor air investigation at targeted locations within a defined Assessment Area located in a portion of Beverley and Woodville South. These works were undertaken between February and April 2016.

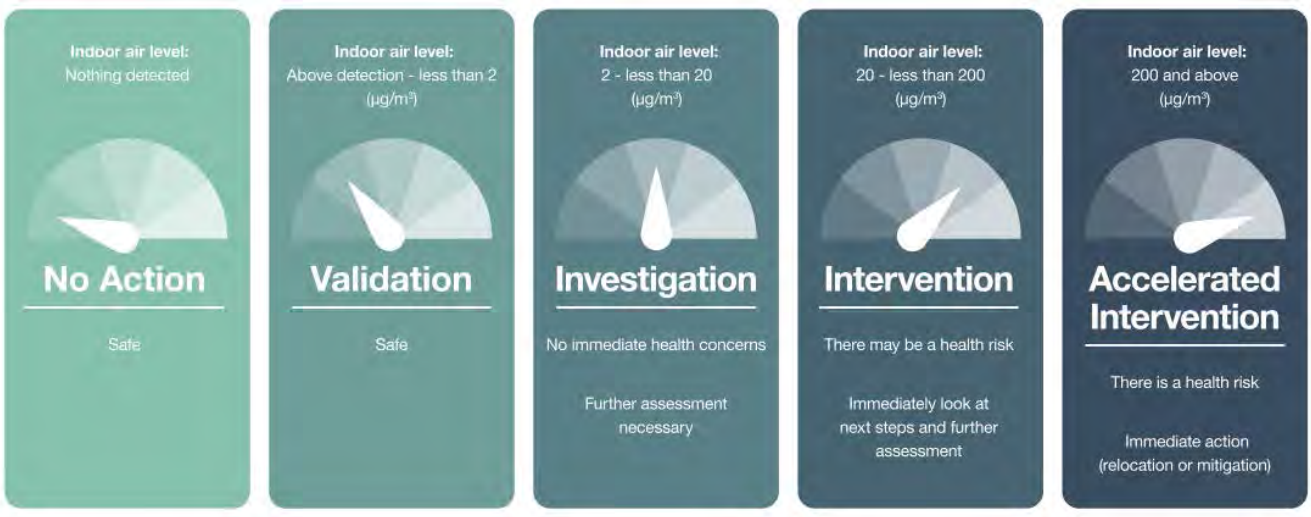
Chemicals of interest (COIs) for this investigation included volatile organic compounds (VOCs), with particular focus on the chlorinated hydrocarbons perchloroethene (PCE), trichloroethene (TCE), cis- and trans-dichloroethene (DCE), and vinyl chloride. This data was used to develop an updated conceptual site model (CSM), vapour intrusion assessment (VIA), and human health risk assessment (HHRA) for the Assessment Area.

Golder understands that SA EPA approached 48 land owners in relation to undertaking site-specific investigation works on their properties, and this report documents the assessment works undertaken on the 21 properties whose owners provided consent to the EPA to undertake testing. The remaining property owners did not contact SA EPA or did not consent to the assessment work.

Based on the investigations completed at least two plumes of chlorinated hydrocarbon (predominantly TCE) contamination of shallow groundwater exist within the Assessment Area, with a third potential plume identified on the northwest boundary of the Assessment Area. Soil vapour impacts from TCE, inferred to be associated with these groundwater impacts, have been recorded in portions of the Assessment Area and have been reasonably well defined in most areas.

Based on the developed CSM, identified COI and property (building) types within the Assessment Area, vapour intrusion models were prepared to estimate attenuation (migration) of volatile chemicals from soil vapour at different depths and from ambient air samples immediately below building structures (crawl space and sub-slab samples), into overlying buildings.

Reported concentrations of TCE in soil vapour at depth below surface, sub slab soil vapour and crawl space air were multiplied by these attenuation factors to obtain theoretical estimated indoor air concentrations. These estimated concentrations, as well as reported concentrations directly measured in indoor air, were compared with TCE response ranges developed by the Government of South Australia to identify the significance of the results and the level of action required. These response ranges are provided in the image below.



TCE Indoor Air Response Ranges (Government of South Australia, 2014)

A total of 21 properties were assessed for one or more of soil vapour, sub-slab vapour, crawl space air, and/or indoor air as part of the 2016 assessment works. A comparison of the results for each property to the adopted response ranges is provided below. This comparison also summarises historical results for an additional five properties which were investigated in 2015 and not reassessed as part of the 2016 works.

Summary of Property Classification – Response Ranges

Property ID	Response Range Classification	Basis of Classification
Property 1	Investigation	Indoor Air (direct measurement)
Property 2	Validation	Indoor Air (direct measurement)
Property 3	Validation*	Crawl Space Air (estimated concentration)
Property 4	Investigation	Crawl Space Air (estimated concentration)
Property 4 (Basement)	Investigation*	Indoor Air (direct measurement)
Property 5	Investigation	Indoor Air (direct measurement)
Property 6	Validation*	Indoor Air (direct measurement)
Property 7	Intervention	Indoor Air (direct measurement)
Property 8	Validation	Indoor Air (direct measurement)
Property 9	Investigation	Indoor Air (direct measurement)
Property 10	Intervention*	Crawl Space Air (estimated concentration)
Property 11	Investigation	Crawl Space Air (estimated concentration)
Property 12	Intervention	Crawl Space Air (estimated concentration)
Property 13	Validation	Soil Vapour (estimated concentration)
Property 14	No Action*	Soil Vapour (estimated concentration)
Property 15	Validation	Soil Vapour (estimated concentration)
Property 16	Investigation*	Soil Vapour (estimated concentration)
Property 17	Intervention	Indoor Air (direct measurement)
Property 18	Validation	Indoor Air (direct measurement)
Property 19	Investigation	Crawl Space Air (estimated concentration)
Property 20	Validation	Indoor Air (direct measurement)
Property 20 (Basement)	Investigation	Indoor Air (direct measurement)
Property 21	Investigation	Crawl Space Air (estimated concentration)
Property 22	No Action	Crawl Space Air (estimated concentration)
Property 23	No Action	Crawl Space Air (estimated concentration)
Property 24	Investigation	Crawl Space Air (estimated concentration)
Property 25	Intervention	Crawl Space Air (estimated concentration)
Property 26	Intervention	Crawl Space Air (estimated concentration)

* Not assessed in 2016 Golder Assessment. Response Range classification based on data from 2015 Golder Assessment.

Basement rooms were identified at two properties during property-specific sampling works. As the presence of basement levels poses a potential for higher concentrations of TCE within indoor air than in overlying buildings, the follows actions are recommended to address the potential for additional health risks to occur within the Assessment Area:

- Undertake a building survey for all properties within Residential Zones where a response range classification of 'Investigation' or higher is indicated (as discussed below). The survey should seek to identify the presence, construction type and usage of basement structures within these zones.
- Assess TCE concentrations in indoor (basement) air where basement rooms are identified. Assessment priority should be based upon the response range classification of the Zone in which the property is located (as discussed below), with consideration for the sensitivity of the individual basement usage indicated by the building survey (i.e. a sensitive occupancy or usage of a basement level may justify a higher priority for assessment than indicated by the zone classification).

No property-specific data has been collected for many properties within the Assessment Area. To allow consideration of areas beyond those where property-specific investigations have been conducted, the Assessment Area has been divided into "Residential Zones" based on the estimated (theoretical) indoor air concentration of TCE estimated from active soil vapour data. Each Residential Zone comprises a contiguous series of properties for which an identical response range classification has been assigned.

The boundary of each Residential Zone has been interpreted based on available soil vapour data within each zone and near the boundaries of adjacent zones, as well as the current understanding of the conceptual site model for the Assessment Area. It is acknowledged the data for spatial distribution of soil vapour data is limited throughout many Residential Zones, and uncertainty exists regarding the appropriate classification of properties which are more distant from sample data.

A summary of the number of properties within each Residential Zone and the corresponding Response Range Classification is provided below, and the boundaries of the Residential Zones presented in Figure 8 of this report. As site-specific assessments of many residential properties based on sub-slab vapour, crawl space air, or indoor air have already been conducted within several Residential Zones as part of the 2015 and/or 2016 assessment works, the results of these assessments have also been summarised, as well as recommendations for further assessment within each Zone.

Summary of Response Range Classifications for Residential Zones (From Soil Vapour Data)

Residential Zone	Estimated Number of Residential Properties Within Zone	Investigation Priority Classification Based on Soil Vapour Data	Response Range Classification of Investigated Properties within Zone	Recommended Action
1	21	No Action	1 Property: No Action	No further investigation recommended.
2	44	Validation	1 Property: Investigation	Where not already completed, confirm soil vapour results.
3	33	Validation	1 Property: Intervention	Based on limited soil vapour data and elevated crawl space air concentrations reported at a property within this Zone, undertake additional soil vapour sampling. Also confirm existing soil vapour results. Based on the outcomes of this soil vapour assessment, further property-specific investigation may be required, as per Zone 5. Undertake indoor air sampling at the previously assessed property in this zone.
4	24	Investigation	2 Properties: Intervention	Additional soil vapour sampling to refine area wide screening assessment. Based on the outcomes of this soil vapour assessment, as well as property specific investigations already undertaken in eight properties, further property-specific investigation is required in focussed properties within this zone, as per Zone 5. Assess presence of basements within this Zone.
			3 Properties: Investigation	
			2 Properties: Validation*	
			1 Property: No Action	
5	5	Intervention	1 Property: Intervention	Where not already completed, implement property-specific investigations, including: • building construction survey

Residential Zone	Estimated Number of Residential Properties Within Zone	Investigation Priority Classification Based on Soil Vapour Data	Response Range Classification of Investigated Properties within Zone	Recommended Action
			2 Properties: Investigation	• crawl space sampling and/or sub-slab sampling (dependent on building construction) • soil gas sampling • property-specific vapour intrusion assessment. Where indoor air sampling has confirmed the Intervention classification, consider implementing mitigation measures as per the *SA EPA Vapour Mitigation Strategy (2015).*
6	35	Validation	1 Property: Investigation	Confirm soil vapour and crawl space results.
7	12	Investigation	1 Property: Intervention 1 Property: Investigation 3 Properties: Validation*	As a high level of zone-wide assessment has been completed to date, as well as property specific investigations already undertaken on five properties, implement property-specific investigations as per Zone 5. Where indoor air sampling has confirmed the Intervention classification, consider implementing mitigation measures as per the *SA EPA Vapour Mitigation Strategy (2015).*
8	3	Intervention	1 Property: Intervention* 1 Property: Validation	Where not already completed, implement property-specific investigations for the remaining property not previously assessed as per Zone 5.
9	4	Validation	No Properties Assessed	Where not already completed, confirm soil vapour results.

* Includes response range classifications based on data from 2015 Golder Assessment for one property not assessed in 2016 Golder Assessment.

Table of Contents

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

The South Australian Environment Protection Authority (SA EPA) engaged Golder Associates Pty Ltd (Golder) to conduct a soil vapour, sub-floor vapour, and indoor air investigation at targeted locations within a defined Assessment Area located in a portion of Beverley and Woodville South, as defined on Figure 1. These works were undertaken between February and April 2016.

Chemicals of interest (COIs) for this investigation included volatile organic compounds (VOCs), with particular focus on the chlorinated hydrocarbons perchloroethene (PCE), trichloroethene (TCE), cis- and trans-dichloroethene (DCE), and vinyl chloride. This data was used to develop an updated conceptual site model (CSM), vapour intrusion assessment (VIA), and human health risk assessment (HHRA) for the Assessment Area.

A preliminary investigation of groundwater, soil vapour, sub-floor, and indoor air was previously completed by Golder between April and September 2015 (the 2015 Golder Assessment). Data from this investigation was used to generate preliminary CSM, VIA, and HHRA reports for the Assessment Area. The primary objective of this investigation (the 2016 Golder Assessment) was to obtain additional soil vapour, sub-floor, and indoor air data to confirm the preliminary HHRA results and refine the conceptual understanding of the site. The updated conceptual model also considered a recent investigation of groundwater and soil vapour completed by JBS&G Australia Pty Ltd (JBS&G) in April 2016 (the 2016 JBS&G Assessment).

The three primary components of the 2016 Golder Assessment include the following:

- **CSM:** The primary objective of the CSM is to develop a conceptual model around the potential volatile chlorinated hydrocarbon sources, specific chemicals of concern, transport mechanisms and receptors within the Assessment Area. To this end, the CSM draws upon historical data as well as data collected as part of the 2016 Golder Assessment.
- **VIA:** The primary objectives of the VIA included modelling of potential vapour intrusion for property (building) types within the Assessment Area and estimation of site specific screening criteria for assessment of soil vapour, sub-floor, and indoor air sampling results.
- **HHRA:** The primary objectives of the HHRA were to compare concentrations of COIs identified by the sampling works against the site-specific screening criteria established in the VIA. The results of this screening were used to assess potential health risk within broad zones of the Assessment Area and at specific residential properties at which sampling was undertaken.

Golder understands that SA EPA approached 48 land owners in relation to undertaking site-specific works on their properties, and this report documents the assessment works undertaken on properties whose owners provided consent to the EPA to undertake testing. The remaining property owners did not contact SA EPA or did not consent to the assessment work.

2.0 DESCRIPTION OF ASSESSMENT AREA

The current Assessment Area falls within the larger 2007/2008 EPA Assessment Area comprising parts of Allenby Gardens, Beverley, Woodville South, Woodville West and Findon. The 2007/2008 Assessment Area delineated the extent of TCE impacts at that time. In conjunction with South Australia Health and the Department of Environment, Water, and Natural Resources, in 2008 the EPA provided advice to residents that groundwater should not be extracted in this zone.

As a result of further groundwater and soil vapour investigations within the 2007/2008 EPA Assessment Area, and a screening risk assessment undertaken by Public Health Toxicology, an area extending west from Haynes Crescent to Main Street was identified by the EPA as requiring additional investigation. This area forms the current Assessment Area, as illustrated in Figure 1.

3.0 SCOPE OF ASSESSMENT WORKS

The works were undertaken in general accordance with the proposed scope of services outlined in Golder's proposal *Beverley Validation Works 05/22106* (ref. P1546385-001-R-Rev0), dated 16 December 2015. Assessment works were conducted between February and April 2016 and included the following:

- installation of seven soil vapour bores on public verges and 12 soil vapour bores on private properties within the Assessment Area
- collection of soil vapour samples from 25 locations on public verges and 29 locations on private properties within the Assessment Area
- collection of crawl space (sub-floor) samples from 41 locations beneath 16 residential properties
- collection of sub-slab (sub-floor) samples from four locations beneath three residential properties
- collection of indoor air samples from 30 locations within nine residential properties under occupied conditions
- collection of indoor air samples from eight locations within two residential properties under unoccupied conditions.

All samples were submitted to a National Association of Testing Authorities (NATA) accredited laboratory for analysis of PCE, TCE, DCE, vinyl chloride, and chloroform. Investigation and sampling methodologies for these assessments are detailed in Sections 3.1 and 3.2. Sample locations are presented in Figure 2.

3.1 Test methods

Golder holds National Association Testing Authorities accreditation for each of the sampling methodologies used in this programme (NATA Laboratory Accreditation No. 1910).

3.1.1 Soil vapour monitoring and sub-slab sampling

3.1.1.1 Installation

Where required, bores were installed for the collection of soil vapour samples using the following methodology:

- Bore locations were cleared by a qualified service locator prior to advancement.
- Bores were advanced to target depth using a hand auger to a depth of 1 m below ground level (bgl) and push tubes to depths beyond this (where required). Borehole diameters were approximately 75 mm (where installed by push tubes) to 90 mm (where installed by hand auger).
- Soil was logged using the Unified Soil Classification System. Bore logs are presented in Appendix A.
- The hand auger and drill rig push tube were decontaminated between samples with Decon 90 solution and rinsed with potable water.
- A 100 mm long stainless steel vapour probe implant was installed in the centre of a 300mm 8/16 grade sand pack at the bottom of each borehole and connected to the surface with 6 mm PTFE tubing, with the tubing capped at the surface.
- Bentonite powder and granules were placed above the sand pack to approx. 0.2 m bgl to create a seal.
- Vapour probes were finished at surface with flush steel gatic covers.

A diagram of the vapour bore installation is shown in Image 1.

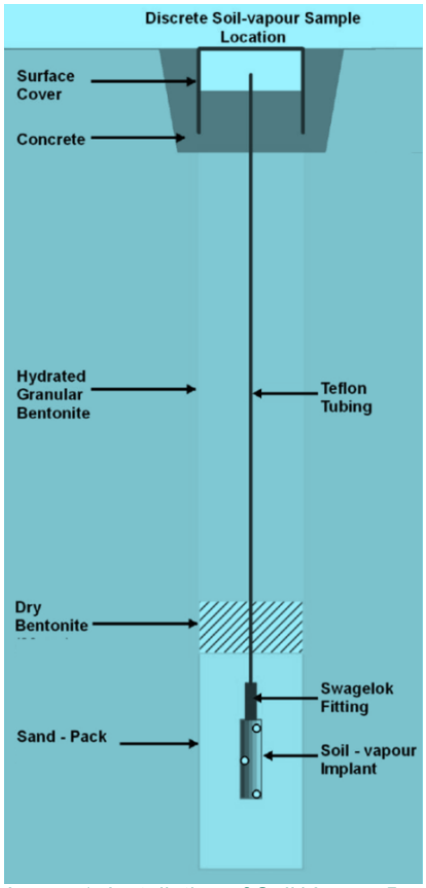


Image 1: Installation of Soil Vapour Bores

3.1.1.2 Sampling

The procedure for sampling VOCs using evacuated canisters, and for the subsequent analysis, is described in USEPA Method TO-15. The method involved the collection of whole air samples in passivated electropolished stainless steel canisters (SUMMA canisters). The VOCs were subsequently separated by gas chromatography (GC), and measured by mass selective (MS) detector or multi-detector techniques.

Soil vapour monitoring was conducted by SGS Leeder Consulting (SGS). Sub-slab sampling was conducted by Golder Associates. The SUMMA canister sampling method is summarised as follows:

- The sampling train consisted of PTFE tubing and a SUMMA canister.
- The soil vapour bore and sampling train were purged using an SKC pump and calibrated rotameter to measure flowrate, with a volume equal to three times the total bore and sampling train volume, immediately prior to sample collection.
- Samples were collected in low volume (1 L) SUMMA canisters to reduce the possibility of atmospheric breakthrough and a false negative result.
- Integrity testing of sample equipment (SUMMA canister and flow controller) was conducted prior to sampling.
- SUMMA canisters were equipped with a flow restricting orifice and a vacuum gauge to enable sampling over five (200 ml/min) and twenty minute periods (50 ml/min) for soil vapour and sub-slab samples, respectively, to minimise the potential for atmospheric breakthrough.
- A helium shroud was used to quantify the tracer leakage rate for all soil vapour and sub-slab locations during sampling (see Section 4.3.2.3).

- A backup sample was collected using a carbon tube at soil vapour sampling locations. The sampling flow rates for the backup sample tubes are set at the commencement of sampling and monitored during sampling to ensure flow is maintained and the formation is capable of sustaining the removal of sample from the boreholes. The sampling period was accurately recorded to enable the calculation of the sample volume collected on each of the sorbent sampling tubes.

Sample analysis was conducted by SGS (NATA Laboratory Accreditation No. 14429).

3.1.2 Crawl space air monitoring

3.1.2.1 SUMMA canister

The procedure for sampling VOCs using evacuated canisters, and for the subsequent analysis, is described in USEPA Method TO-15.

The sampling train consisted of clean PTFE tubing, a flow controller and a 6 L SUMMA Canister. Samples were collected over a nominal 24 hr period at mid-level within the crawl spaces of selected properties.

Sample analysis was conducted by SGS.

3.1.3 Indoor air monitoring

3.1.3.1 SUMMA canister

The procedure for sampling VOCs using evacuated canisters, and for the subsequent analysis, is described in USEPA Method TO-15.

The sampling train consisted of a flow controller and a 6 L SUMMA Canister. Samples were collected over a nominal 72 hr period and positioned at a height estimated to be approximately within the breathing zone of residents.

Sample analysis was conducted by SGS.

3.1.3.2 Radiello passive sampler

Radiello samplers were installed using a backing plate and positioned at a height estimated to be within the breathing zone of residents. The samplers were left in place for approximately a one week period.

Sample analysis was conducted by SGS. Airborne contaminant concentrations were calculated using the reported analyte mass and measured sample period provided to SGS and the calculations subsequently verified by Golder.

3.1.4 Sample nomenclature revisions

Subsequent to sample collection, the following nomenclature changes were made for purposes of clarity and consistency with previous sample numbering:

Table 1: Sample nomenclature revisions

Original nomenclature	Revised nomenclature	Lab certificate number
L4608	5-1S-26/02/16	M160410
L4291	5-4S-26/02/16	M160410
L4547	5-5S-26/02/16	M160410
L4550	5-6S-26/02/16	M160410
L4602	7-2S-26/02/16	M160410
L4595	7-2SD-26/02/16	M160410
L4594	7-3S-26/02/16	M160410
L4522	7-4S-26/02/16	M160410
L4512	7-1S-26/02/16	M160410
L4605	19-1C-29/02/16	M160410B
L4520	19-2C-29/02/16	M160410B
14/3S-4/03/16	17-3S-4/03/16	M160410G
8-2S-16/03/16	8-6S-16/03/16	M160410N
8-2R-16/03/16	8-6R-16/03/16	M160410N
8-6P-23/03/16	8-2P-23/03/16	M160410P
8-6PD-23/03/16	8-2PD-23/03/16	M160410P
1-2S-1/04/16	1-4S-1/04/16	M160410Q
2-1S-1/04/16	2-4S-1/04/16	M160410Q
1-2R-1/04/16	1-4R-1/04/16	M160410U
2-1R-1/04/16	2-4R-1/04/16	M160410U
17-1-S-22/04/16	17-1S-22/04/16	M160410V
17-2-S-22/04/16	17-2S-22/04/16	M160410V
17-3-S-22/04/16	17-3S-22/04/16	M160410V
17-4-S-22/04/16	17-4S-22/04/16	M160410V
17-3-SD-22/04/16	17-3SD-22/04/16	M160410V
SV39-D	SV52-D	M160410D
SV39-D Field Dup	SV52-D Field Dup	M160410D
SV39-M	SV52-M	M160410D
SV40-D	SV51-D	M160410C
SV40-M	SV51-M	M160410C
SV40-M	SV44-M	M160410I
SV40-D	SV44-D	M160410I
SV01-D	SV01-M	M160410D
SV04-D	SV04-M	M160410D

3.2 Measurement uncertainty

Measurement uncertainty is compliant with the “ISO Guide to the Expression of Uncertainty in Measurement” and is a full estimate based on laboratory validation and quality data. Measurement uncertainties for SUMMA canisters and Radiello samplers are presented in the following sections.

3.2.1 SUMMA canister

The expanded uncertainty varies with the level of compound detected, but the maximum uncertainty (with a confidence level of 95% or greater) within the range 7.6 ng < x < 18.9 ng is 47.4%, within the range 18.9 ng < x < 94 ng is 30.2%, and within the range 94 ng < x < 283 ng is 25.5%.

3.2.2 Radiello passive sampler

The expanded uncertainty varies with the level of compound detected, but the maximum uncertainty (with a confidence level of 95% or greater) within the range 0.1 µg < x < 0.5 µg is 47%, and within the range 0.5 µg < x < 10 µg is 22%.

4.0 CONCEPTUAL SITE MODEL

4.1 Local and regional settings

4.1.1 Current land use and activities

The Assessment Area is located in a generally topographically flat mixed commercial/industrial and residential area in the north western suburbs of Beverley and Woodville South, South Australia. The location of commercial/industrial and residential properties within the Assessment Area, based on data from the SA Government database, is illustrated in Figure 3.

Current commercial/industrial land uses in the Assessment Area include, but are not restricted to, manufacturing industries including appliance manufacturing, irrigation suppliers, crash repairers, rug cleaners, a joinery, and a metal fabrication workshop.

The residential properties in the area are typically single-storey residences and the majority of these appear to be between 40 to 100 years old. Detailed assessment of the specific building construction types has generally not been undertaken; however based on the apparent age of the buildings and inspection of a small number of properties along West Street and William Street, it is expected that building floor construction will include a combination of timber floors with a subfloor void (crawl space) and concrete slab on ground. Basements and cellars are not expected to be common, but were encountered in two of 26 properties assessed thus far.

4.1.2 Local topography and surface drainage

The Assessment Area is generally flat at an elevation of approximately 10 m Australian Height Datum (AHD, Topographic Map, 1:25,000, Adelaide).

Surface water generally enters the local council stormwater drainage system through side entry pits within the road network and is connected to underground pipes which typically drain towards the north (towards Port Road).

There is a significant depression on the southern side of West Avenue due to the presence of a historic “pug-hole” from which clay was historically mined for brick making. The location of this depression is shown on Figure 2. This depression is approximately 3 to 4 metres deep and surface water within this depression enters a grated inlet pit at the base which is considered likely to be connected to a soakage drain (i.e. may drain directly into underlying groundwater).

4.1.3 Regional and area-specific geology

A review of the 1:50,000 geological map of the Adelaide Region indicates that the Assessment Area is underlain by soils and sediments of the Adelaide Plains including Callabonna Clay, Pooraka formation and Hindmarsh Clay in the subsurface. The Assessment Area is approximately 4 km west of the Para Fault.

Drilling works in the Assessment Area have generally identified gravelly or clayey sand and sandy clay fill overlying natural soils, with a typical fill depth of between 0.2 and 0.5 m bgl. Deeper fill material was encountered on Main Street at the location of monitoring well MW01, where fill was observed to a depth of 2.3 m bgl. Bore logs from the 2016 JBS&G Assessment report (Reference 51350_RP02_Rev2) also indicate the presence of approximately 6.1 m of fill below surface level approximately 30 m south of the current lateral extent of the pughole (MW17). This suggests that the historical depth and areal extent of this feature were greater than currently appear.

Fill across the Assessment Area was generally underlain by natural material comprising clay, sandy clay and clayey sand or silty clay, predominantly brown, orange brown and red brown in colour. Thin layers of sand or clayey sand were observed in the following locations:

- in the vadose zone at depths of between 0 (surface) and 1.5 m bgl and with a thickness of 0.2 to 1.0 m (MW08 – MW11, MW15, MW16, installed during the 2016 JBS&G Assessment)
- in the vadose zone at depths of between 4.1 and 4.5 m bgl and with a thickness of 0.1 to 0.5 m (MW01, MW02 and MW05, installed during the 2015 Golder Assessment)

- near the water table at depths of between 7.2 and 8.0 m bgl and with a thickness of 0.2 to 0.6 m (MW01-MW04, installed during the 2015 Golder Assessment)
- below the water table at depths of 11.0, 10 and 11.6 m bgl and with a thickness of 0.6 to 1.1 m (MW12 MW13 and MW18 installed during the 2016 JBS&G Assessment).

Refer to bore logs in Appendix A and conceptual cross section diagrams presented as Figures 4A and 4B that detail known lithology at the site.

Drilling records for a historical well installed within the Assessment Area in 2007 (GW80) indicate the presence of clay soil to approximately 17 m bgl, overlying silty sands to the maximum depth of 19.8 m bgl (URS, 2008). It should be noted that auger drilling techniques were used for the installation of this well; therefore the soil cuttings used for logging may not provide a clear indication of sand lenses within the deeper soils beneath the site, due to disturbance by the drilling process.

One-hundred and one soil samples were collected for analysis of moisture content from boreholes across the Assessment Area during the 2015 Golder Assessment, with a further ten samples collected during the 2016 Golder Assessment. The combined results of the 2015 and 2016 analyses are summarised by depth in Table 2. Full tabulated data from the geotechnical analyses are presented in Table B3, Appendix B.

The soil moisture content was found to vary with depth and soil type across the Assessment Area, with sandier layers in the vadose zone recording lower moisture content. In general, the average moisture content increases with depth, however, lower moisture content was recorded at a depth of approximately 4 to 5 m bgl due to sandier material frequently encountered at this depth.

Table 2: Summary of soil moisture content analysis – combined 2015 and 2016 data

Sample depth (m bgl)	Average moisture content of soil samples (%)	Minimum moisture content of soil samples (%)	Maximum moisture content of soil samples (%)
0 – 1	11.7	3.5	19.4
1 – 2	17.8	6.4	35.1
2 – 3	18.5	11.0	31.8
3 – 4	18.3	9.3	27.9
4 – 5	16.3	10.1	20.7
5 – 6	23.5	13.7	31.5
6 – 7	22.9	16.7	34.6

Twenty one soil samples were collected for geotechnical analysis of bulk density, dry density, and the average apparent particle density of the fraction less than 2.36 mm in diameter (APD 2.36) from boreholes across the Assessment Area during the 2015 Golder Assessment, with a further four samples collected during the 2016 Golder Assessment. The data from these analyses was added to the 2015 Golder data and summarised by soil type in Table 3 and by depth in Table 4. The geotechnical analysis results are provided in Table B3, Appendix B.

Table 3: Summary of geotechnical analyses by soil type – combined 2015 and 2016 data

Soil type	Bulk density (tonnes/m^3)	Dry density (tonnes/m^3)	APD 2.36 (g/cm^3)
Clayey sand	1.7	1.51	2.67
Sandy clay	1.83	1.54	2.73
Silty clay	1.61	1.39	2.73
Clay	1.97	1.56	2.77

Table 4: Summary of geotechnical analyses by depth – combined 2015 and 2016 data

Sample depth (m bgl)	Bulk density (tonnes/m^3)	Dry density (tonnes/m^3)	APD 2.36 (g/cm^3)
1 – 2	1.72	1.48	2.71
2 – 3	1.89	1.50	2.69
3 – 4	1.93	1.60	2.74
4 – 5	1.91	1.66	2.68
5 – 6	1.94	1.61	2.77
6 – 7	1.95	1.53	2.76

4.1.4 Regional and area-specific hydrogeology

There are up to six aquifer units within the Quaternary deposit (Q1 to Q6), west of the Para Fault. All six are likely to be present beneath the Assessment Area. There are also three deeper aquifers underlying the Tertiary Deposits (T1 to T3).

Based on historic and recent investigations within the Assessment Area (refer to Section 4), the shallow aquifer system (Q1) was encountered between 7.1 m and 8.5 m bgl. Standing water levels measured in the shallow aquifer during the 2016 JBS&G Assessment ranged from 7 m to 9 m bgl. Groundwater flow direction was inferred to be to the west-north west. This was in general accordance with the findings of the 2015 Golder Assessment, which estimated the groundwater flow direction to be generally westward, and historical assessments which indicated the groundwater flow direction to be to the west-northwest (URS 2012). Groundwater contours produced by JBS&G for their April 2016 sampling event are presented in Appendix C. Historical reports have also indicated variations in water level to be in the order of 0.6 m (URS 2012). Insufficient information is available to confirm the full range of seasonal variations in groundwater levels.

Information from previous investigations (URS 2012) indicated groundwater levels observed in a well (GW80) installed within the Q2 aquifer to be generally similar to those in the Q1 aquifer, indicating little or no vertical gradient between the two units. The degree of hydraulic separation between the two quaternary aquifers has not been clearly identified.

Rising head and falling head permeability tests were conducted in the nine groundwater wells as part of the 2015 Golder Assessment. Hydraulic conductivity ranged from 3 x 10^{-6} m/sec to 4 x 10^{-5} m/sec, with an average hydraulic conductivity of 3 x 10^{-5} m/sec. These results are reasonably consistent with the hydraulic conductivity results previously reported (URS 2012), which indicated a hydraulic conductivity range of 2.3 x 10^{-6} m/sec to 1.2 x10^{-5} m/sec.

To assess groundwater beneath the Assessment Area and evaluate a relationship between portions of the aquifer, a Piper plot diagram was constructed for groundwater wells sampled during the 2015 Golder Assessment. The Piper plot illustrated a change in ionic balance in groundwater within monitoring wells MW5 and MW6 compared to other wells sampled, which indicated that the local area may potentially be receiving additional recharge to groundwater. The source of potential additional recharge in this area is not known.

A second Piper Plot was constructed by JBS&G based on groundwater results from the 2016 Assessment. This analysis suggested generally similar conditions within the Assessment Area to those reported in the 2015 Golder Assessment.

4.2 Previous investigations

The Assessment Area has been subject to a number of previous environmental investigations. The following reports have been made available by SA EPA:

- Golder, Phase 2 Environmental Site Assessment, Pope Street, Beverley SA, dated June 2001.
- Golder, Additional Groundwater Investigations and Monitoring Electrolux Washing Plant, 19 Pope Street, Beverley, SA, dated June 2003.
- URS, Groundwater Monitoring Event-September 2006, 19 Pope Street, Beverley, SA, dated 15 January 2007.
- URS, Electrolux Home Products 19 Pope Street, Beverley: Additional Environmental Site Assessment, dated 21 May 2008.
- URS, Report 19 Pope Street, Beverley, South Australia Additional On-site and Off-site Environmental Assessment, dated 6 May 2010.
- URS, Groundwater and Soil Vapour Investigation and Detailed Risk Assessment for the Former Electrolux Washing Plant, 19 Pope Street, Beverley, South Australia, dated August 2012 (The DRA Report).
- URS, 19 Pope Street, Beverley South Australia, Groundwater Well Installation and Monitoring, 2013 Final Report dated August 2014.
- Golder, Beverley Assessment Area, South Australia, Conceptual Site Model (April to September 2015) (Reference 1418522-002-R-Rev0), dated 1 October 2015.
- Golder, Groundwater and Soil Vapour Data Report – Beverley Assessment Area, South Australia (Reference No. 1418522-003-R-Rev1), dated 27 May 2015.
- Golder, Beverley Assessment Area, South Australia, Stage 2 Vapour Monitoring Data Report (June 2015) (Reference 1418522-010-R-Rev0), dated 7 July 2015.
- Golder, Beverley Assessment Area, South Australia, Stage 3 Vapour Monitoring Data Report (July/August 2015) (Reference 1418522-012-R-Rev0), dated 1 October 2015.
- Golder, Beverley Assessment Area, South Australia, Stage 4 Indoor Vapour Monitoring Data Report (September 2015) (Reference 1418522-020-R-Rev0), dated 1 October 2015.
- Golder, Beverley Assessment Area, South Australia, Preliminary Vapour Intrusion Assessment (VIA) Report (October 2015) (Reference 1418522-021-R-Rev0), dated 1 October 2015.
- Golder, Beverley Assessment Area, South Australia, Preliminary Human Health Risk Assessment (HHRA) Report (October 2015) (Reference 1418522-022-R-Rev0), dated 1 October 2015.
- JBS&G, Stage 3 Beverly Assessment Works, Final Report, (Reference 51350_RP02_Rev2), dated 26 April 2016.

The information obtained from the first five reports listed above was considered in the preparation of the DRA report produced in 2012 (URS 2012). A summary of this DRA report is presented in Appendix D and a brief summary of relevant groundwater and soil vapour information from this DRA, together with the Golder 2015 Assessment and JBS&G 2016 Assessment is provided in the following sections. The tabulated results of the 2015 Golder Assessment (expressed at 25°C and 101.3kPa) are presented in Appendix E.

4.2.1 Groundwater

The previous investigations completed by URS have been focused on and around the former appliance manufacturer site located at 19 Pope Street Beverley. Groundwater monitoring wells installed outside the former appliance manufacturer site boundary for the purpose of the investigations at this site have been subsequently decommissioned with the exception of three wells located on Charles Road, referred to by Golder as XMW1, XMW2 and XMW3 and illustrated on the JBS&G Figure 2, supplied in Appendix C. These wells were referred to in the URS 2014 report as MW1, MW2 and MW3. It is understood that these wells remain in place associated with a Groundwater Management Plan to be implemented at the new industrial site (former appliance manufacturer site). Well XMW1 was not accessible during the 2015 Golder Assessment, as it was located within the site boundary of the new industrial site. The elevated concentrations of TCE in the eastern and western portions of the Assessment Area were inferred by URS to be the result of two separate plumes, as illustrated in the historic inferred TCE plume figure presented in Appendix D. Historically, the maximum concentration of TCE in the western portion of the Assessment Area was 6,320 µg/L in former monitoring well GW75, and the maximum concentration of TCE in the eastern portion of the Assessment Area was 4,070 µg/L in former monitoring well GW93.

Elevated concentrations of TCE (322 µg/L) have also been recorded in a well within the Q2 aquifer at a depth of 20 metres (GW80). GW80 was located within the site boundary of the former appliance manufacturer site.

The 2016 JBS&G Assessment included an investigation of groundwater at 20 locations within and adjacent to the Assessment Area. This assessment concluded that concentrations of some VOCs were reported in exceedance of the laboratory limits of reporting (LOR) in groundwater, as well as the following regulatory guidelines:

- TCE within the Assessment Area exceeded the World Health Organisation (WHO) (2011) drinking water criteria, the Australia and New Zealand Environment and Conservation Council (ANZECC) (2000) freshwater criteria and the ANZECC (2000) marine water criteria.
- 1,1 – DCE within the Assessment Area exceeded the WHO (2011) drinking water criteria.
- Vinyl chloride within the Assessment Area exceeded the WHO (2011) drinking water criteria.
- TRH C_6 - C_{10} within the Assessment Area exceeded the National Environment Protection (Assessment of Site Contamination) Measure (NEPM) (National Environment Protection Council [NEPC], 1999 as amended 2013) groundwater health screening levels (HSLs) for vapour intrusion for residential land use.

The 2016 JBS&G Assessment concluded that the extent of the TCE impacts to groundwater in exceedance of the adopted drinking water criteria has not been laterally delineated in the majority of directions.

Groundwater samples were previously collected at nine of these 20 locations as part of the 2015 Golder Assessment. Results from the 2016 Assessment at these locations were generally similar to those from 2015, and no general increasing or decreasing trends were identified across all locations.

4.2.2 Soil vapour

Soil vapour investigations in the northern portion of the former appliance manufacturer site in September 2011 identified TCE and cis-1,2-DCE present in soil vapour probes.

TCE concentrations in September 2011 were recorded at a maximum of 17,000 µg/m^3 at 1.5 m bgl depth in the central northern portion of the former appliance manufacturer site (URS soil vapour bore SV03) and 48,000 µg/m^3 at 4 m bgl and 130,000 µg/m^3 at 7 m bgl near the eastern boundary of this site (URS soil vapour bore SV01). Cis-1,2-dichloroethene concentrations were recorded in SV03 to a maximum of 19,000 µg/m^3.

Soil vapour investigations were not undertaken outside the former appliance manufacturing site until the 2015 Golder Assessment.

The 2016 JBS&G Assessment concluded that concentrations of the following VOCs were reported in soil vapour in exceedance of the laboratory LOR and/or applicable regulatory guidelines:

- PCE and 1,1 - DCE were reported at concentrations above the LOR.
- TCE and cis−1,2 - DCE were reported at concentrations above the NEPM (NEPC, 1999 as amended 2013) interim soil vapour health investigation levels (HILs) for residential and commercial land use.

The soil vapour results from the 2016 JBS&G Assessment were generally similar to those previously collected as part of the 2015 Golder Assessment, with the exception of one location (SV06-D) where a significantly higher TCE concentration was reported in February 2016 (3,300 µg/m^3) compared to that reported in April 2015 (33 µg/m^3).

4.3 2016 Golder Assessment

Data from the 2016 Golder Assessment is summarised in Section 4.3.1. Quality control measures and outcomes are summarised in Section 4.3.2. Tabulated results are factually presented in Appendix F, and laboratory certificates of analysis presented in Appendix G. Sample locations on public areas are presented in Figure 2.

4.3.1 Data summary

A summary of the concentrations of trichloroethene (TCE) at each location is presented in Tables 5 to 8.

Barometric pressure recorded at Bureau of Meteorology (BOM) station Adelaide Airport (approximately 5 km from the site) during the monitoring programme is presented in Image 2.

Table 5: Active soil vapour monitoring programme

Location	Sampling Date	Depth (m)	TCE Concentration (µg/m^3)*
SV01-M	2/03/2016	3.85	86,000
SV02-S	1/03/2016	1.85	82,000
SV02-M	1/03/2016	3.85	150,000
SV02-D	1/03/2016	6.35	140,000
SV03-S	29/02/2016	1.85	9,400
SV03-M	29/02/2016	3.85	33,000
SV03-D	29/02/2016	6.35	52,000
SV04-M	2/03/2016	3.85	8,400
SV08-S	17/03/2016	0.85	410
SV08-M	17/03/2016	1.85	1,300
SV08-D	17/03/2016	3.85	5,800
SV09-S	4/04/2016	0.85	4,900
SV09-M	4/04/2016	1.85	5,800
SV09-D	4/04/2016	3.85	16,000
SV10-S	4/04/2016	0.85	2,700
SV10-M	4/04/2016	1.85	6,900
SV10-D	4/04/2016	3.85	22,000
SV21-S	1/03/2016	0.85	16,000
SV21-M	1/03/2016	1.85	19,000
SV21-D	1/03/2016	3.85	29,000
SV22-S	1/03/2016	0.85	2,700
SV22-M	1/03/2016	1.85	29,000
SV22-D	1/03/2016	3.85	64,000
SV25-S	1/03/2016	0.85	28,000

Location	Sampling Date	Depth (m)	TCE Concentration (µg/m^3)*
SV26-S	2/03/2016	0.85	180
SV27-S	2/03/2016	0.85	860
SV28-S	2/03/2016	0.85	42,000
SV29-S	16/03/2016	0.85	1,200
SV30-S	16/03/2016	0.85	870
SV31-S	16/03/2016	0.85	2,300
SV32-S	29/02/2016	0.85	150
SV33-S	29/02/2016	0.85	980
SV34-S	29/02/2016	0.85	26
SV38-S	29/02/2016	0.85	44
SV39-S	16/03/2016	0.85	1,100
SV40-S	16/03/2016	0.85	710
SV41-M	2/03/2016	1.85	180
SV41-D	2/03/2016	3.85	450
SV42-M	2/03/2016	1.85	42,000
SV43-S	29/02/2016 & 11/03/2016	0.85	4,100, 11,000
SV43-M	29/02/2016 & 11/03/2016	1.85	15,000, 28,000
SV43-D	29/02/2016 & 11/03/2016	3.85	54,000, 100,000
SV44-M	16/03/2016	1.85	1,900
SV44-D	16/03/2016	3.85	4,100
SV45-M	16/03/2016	1.85	6,700
SV46-S	29/02/2016	0.85	11
SV47-S	23/03/2016	0.85	89
SV48-S	23/03/2016	0.85	580
SV49-S	16/03/2016	0.85	5,700
SV50-S	4/03/2016	0.85	110
SV51-S	22/04/2016	0.85	910
SV51-M	1/03/2016	1.85	110,000
SV51-D	1/03/2016	3.85	45,000
SV52-M	2/03/2016	1.85	1,400
SV52-D	2/03/2016	3.85	2,100

* Concentrations expressed at 25°C and 101.3kPa.
# Where primary and replicate samples taken, highest concentration reported here.

Table 6: Sub-slab monitoring programme

Location	Sampling Date	Depth (m)	TCE Concentration (µg/m^3)*
Property 7-2P	03/03/2016	Sub-slab	16,000
Property 5-3P	03/03/2016	Sub-slab	20,000
Property 7-2P	11/03/2016	Sub-slab	19,000
Property 8-1P#	23/03/2016	Sub-slab	14,000
Property 8-2P#	23/03/2016	Sub-slab	9,500

*Concentrations expressed at 25°C and 101.3kPa
#Estimated result only

Table 7: Crawlspace monitoring programme

Location	Sample Description	Sampling Date	TCE Concentration (µg/m^3)*
Property 1	Location 1	7/04/2016 – 8/04/2016	21
	Location 2	7/04/2016 – 8/04/2016	20
Property 2	Location 1	7/04/2016 – 8/04/2016	<2
	Location 2	7/04/2016 – 8/04/2016	17
Property 4	Location 1	7/04/2016 – 8/04/2016	6.1
	Location 2	7/04/2016 – 8/04/2016	6.8
Property 5	Location 1	3/03/2016 – 4/03/2016	31
	Location 2	3/03/2016 – 4/03/2016	19
Property 7	Location 1	3/03/2016 – 4/03/2016	22
	Location 3	3/03/2016 – 4/03/2016	68
	Location 4	3/03/2016 – 4/03/2016	42
Property 9	Location 1	18/03/2016 – 19/03/2016	46
	Location 3	18/03/2016 – 19/03/2016	20
Property 11	Location 1	17/03/2016 – 18/03/2016	12
	Location 2	17/03/2016 – 18/03/2016	11
Property 12	Location 1	16/03/2016 – 17/03/2016	61
	Location 2	16/03/2016 – 17/03/2016	100
Property 17	Location 1	10/03/2016 – 11/03/2016	170
	Location 2	10/03/2016 – 11/03/2016	45
	Location 3	10/03/2016 – 11/03/2016	110
	Location 4	10/03/2016 – 11/03/2016	28
Property 19	Location 1	29/02/2016 – 1/03/2016	16
	Location 2	29/02/2016 – 1/03/2016	17
Property 21	Location 1	16/03/2016 – 17/03/2016	6.9
	Location 2	16/03/2016 – 17/03/2016	8.9
	Location 3	16/03/2016 – 17/03/2016	7.2
Property 22	Location 1	17/03/2016 – 18/03/2016	<2
	Location 2	17/03/2016 – 18/03/2016	<2
Property 23	Location 1	18/03/2016 – 19/03/2016	<2
	Location 2	18/03/2016 – 19/03/2016	<2
Property 24	Location 1	23/03/2016 – 24/03/2016	4.8
	Location 2	23/03/2016 – 24/03/2016	14
Property 25	Location 1	23/03/2016 – 24/03/2016	25
	Location 2	23/03/2016 – 24/03/2016	56
Property 26	Location 1	23/03/2016 – 24/03/2016	8.5
	Location 2	23/03/2016 – 24/03/2016	25

* Concentrations expressed at 25°C and 101.3kPa.

Table 8: Indoor air monitoring programme

Location	Sample Description	Sample Type	Sampling Date	Condition	TCE Concentration (µg/m^3)*
Property 1	Location 1	Radiello	1/04/2016 – 8/04/2016	Occupied	1.3
		SUMMA canister	1/04/2016 – 4/04/2016	Occupied	<2
	Location 3	Radiello	1/04/2016 – 8/04/2016	Occupied	2.3
		SUMMA canister	1/04/2016 – 4/04/2016	Occupied	2.3
	Location 4	Radiello	1/04/2016 – 8/04/2016	Occupied	1
		SUMMA canister	1/04/2016 – 4/04/2016	Occupied	<2
Property 2	Location 2	Radiello	1/04/2016 – 8/04/2016	Occupied	0.81
		SUMMA canister	1/04/2016 – 4/04/2016	Occupied	<2
	Location 3	Radiello	1/04/2016 – 8/04/2016	Occupied	0.3
		SUMMA canister	1/04/2016 – 4/04/2016	Occupied	<2
	Location 4	Radiello	1/04/2016 – 8/04/2016	Occupied	0.34
		SUMMA canister	1/04/2016 – 4/04/2016	Occupied	<2
Property 5	Location 1	Radiello	26/02/2016 – 4/03/2016	Occupied	4.9
		SUMMA canister	26/02/2016 – 29/02/2016	Occupied	8.2
	Location 4	Radiello	26/02/2016 – 4/03/2016	Occupied	5.4
		SUMMA canister	26/02/2016 – 29/02/2016	Occupied	6.8
	Location 5	Radiello	26/02/2016 – 4/03/2016	Occupied	3.7
		SUMMA canister	26/02/2016 – 29/02/2016	Occupied	5.1
	Location 6	Radiello	26/02/2016 – 4/03/2016	Occupied	0.44
		SUMMA canister	26/02/2016 – 29/02/2016	Occupied	<2
Property 7	Location 1	Radiello	26/02/2016 – 4/03/2016	Occupied	4
		SUMMA canister	26/02/2016 – 29/02/2016 11/03/2016 – 14/03/2016	Occupied Unoccupied	<2 20
	Location 2	Radiello	26/02/2016 – 4/03/2016	Occupied	4.5
		SUMMA canister	26/02/2016 – 29/02/2016 11/03/2016 – 14/03/2016	Occupied Unoccupied	3.1 40
	Location 3	Radiello	26/02/2016 – 4/03/2016	Occupied	3.6
		SUMMA canister	26/02/2016 – 29/02/2016 11/03/2016 – 14/03/2016	Occupied Unoccupied	2.4 28
	Location 4	Radiello	26/02/2016 – 4/03/2016	Occupied	4.8
		SUMMA canister	26/02/2016 – 29/02/2016 11/03/2016 – 14/03/2016	Occupied Unoccupied	2.4 37
	Ambient	Radiello	26/02/2016 – 4/03/2016	Occupied	0.33
Property 8	Location 1	Radiello	16/03/2016 – 23/03/2016	Occupied	1.8
		SUMMA canister	16/03/2016 – 19/03/2016	Occupied	<2
	Location 4	Radiello	16/03/2016 – 23/03/2016	Occupied	1.7
		SUMMA canister	16/03/2016 – 19/03/2016	Occupied	<2
	Location 6	Radiello	16/03/2016 – 23/03/2016	Occupied	1
		SUMMA canister	16/03/2016 – 19/03/2016	Occupied	<2
Property 9	Location 3	Radiello	16/03/2016 – 23/03/2016	Occupied	4.8
		SUMMA canister	16/03/2016 – 19/03/2016	Occupied	6.1
	Location 4	Radiello	16/03/2016 – 23/03/2016	Occupied	4.5
		SUMMA canister	16/03/2016 – 19/03/2016	Occupied	5.3

Location	Sample Description	Sample Type	Sampling Date	Condition	TCE Concentration (µg/m^3)*
	Location 5	Radiello	16/03/2016 – 23/03/2016	Occupied	6.2
		SUMMA canister	16/03/2016 – 19/03/2016	Occupied	17
Property 17	Location 1	Radiello	4/03/2016 – 11/03/2016	Occupied	41
		SUMMA canister	4/03/2016 – 7/03/2016 22/04/2016 – 25/04/2016	Occupied Unoccupied	60 55
	Location 2	Radiello	4/03/2016 – 11/03/2016	Occupied	19
		SUMMA canister	4/03/2016 – 7/03/2016 22/04/2016 – 25/04/2016	Occupied Unoccupied	25 24
	Location 3	Radiello	403/2016 – 11/03/2016	Occupied	21
		SUMMA canister	4/03/2016 – 7/03/2016 22/04/2016 – 25/04/2016	Occupied Unoccupied	26 21
	Location 4	Radiello	4/03/2016 – 11/03/2016	Occupied	12
		SUMMA canister	4/03/2016 – 7/03/2016 22/04/2016 – 25/04/2016	Occupied Unoccupied	19 20
Property 18	Location 1	Radiello	1/04/2016 – 8/04/2016	Occupied	0.5
		SUMMA canister	1/04/2016 – 4/04/2016	Occupied	<2
	Location 2	Radiello	1/04/2016 – 8/04/2016	Occupied	0.71
		SUMMA canister	1/04/2016 – 4/04/2016	Occupied	<2
	Location 3	Radiello	1/04/2016 – 8/04/2016	Occupied	0.49
		SUMMA canister	1/04/2016 – 4/04/2016	Occupied	<2
Property 20	Location 1	Radiello	4/03/2016 – 14/03/2016	Occupied	3.3
		SUMMA canister	4/03/2016 – 7/03/2016	Occupied	4.4
	Location 2	Radiello	4/03/2016 – 14/03/2016	Occupied	0.47
		SUMMA canister	4/03/2016 – 7/03/2016	Occupied	<2
	Location 3	Radiello	4/03/2016 – 14/03/2016	Occupied	0.36
		SUMMA canister	4/03/2016 – 7/03/2016	Occupied	<2

* Concentrations expressed at 25°C and 101.3kPa.
** The condition 'Unoccupied' refers to the property being vacated and closed up (all windows and doors kept closed) for the entirety of the sampling period.

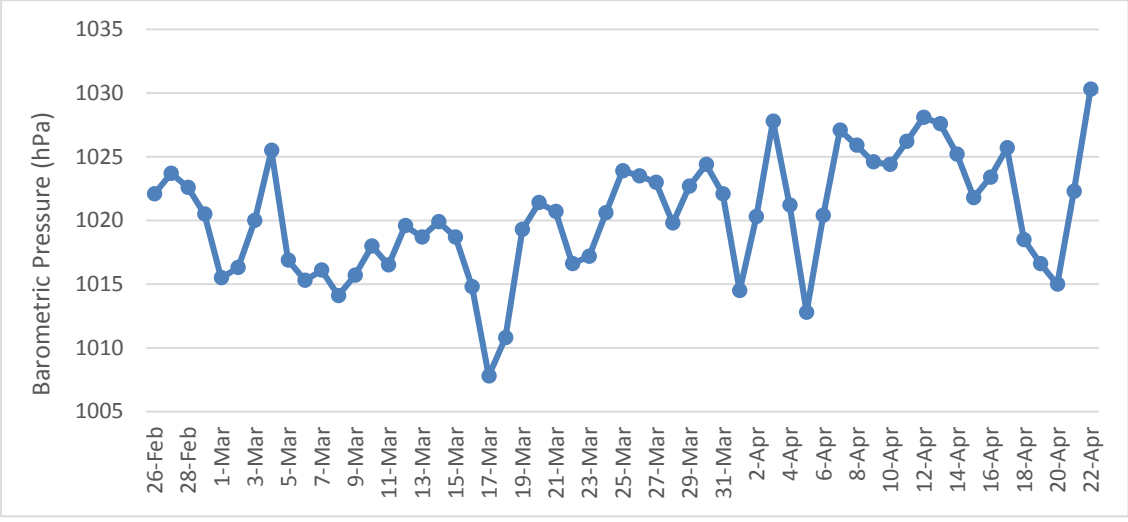


Image 2: Barometric pressure recorded at Adelaide Airport (26/02/2016 – 22/04/2016).

4.3.2 Quality control measures

The quality control (QC) measures taken throughout the monitoring program include replicate sampling, method blanks, analytical recoveries, leakage monitoring and sampling media certification.

Details of the quality control measures taken, together with the data quality objectives (DQO) are listed in Table 9.

Table 9: QC Measures

Measure	Frequency	Quality Objective (limit)
Field replicates/duplicates	1 in 10 samples or per event	<100% RPD
Field blanks	1 of each media type per event (indoor air sampling)	NA
Ambient air (background sampling)	1 per event	NA
Canister cleaning	100% canister certification	NA
Laboratory Blank	1 in 20 samples	Below PQL for all analytes
Laboratory Duplicate (LCSD)	1 in 20 samples	<30% RPD
Laboratory Method Spike	1 in 20 samples	70 – 130%
Laboratory Method Spike Duplicate	1 in 20 samples	70 – 130%
Estimated tracer leakage rate (helium)	One per sample (soil vapour by SUMMA canister)	<10%
Tracer detection (isopropanol)	One per sample (soil vapour by SUMMA canister)	10 mg/m^3

Notes:

RPD: relative percentage difference

Leakage rate: $C_{sample}/C_{representative\ shroud}$ (%)

PQL: Practical Quantification Limit

Other quality control/quality assurance measures included in the programme are as follows:

- PTFE tubing and other sample train equipment was replaced for each sample to prevent cross contamination.
- Test methods for soil vapour sampling employed a minimum sample volume to avoid convective flow through unsaturated soils, which can cause an increase in vapour phase contaminant concentrations at the expense of other phases.
- A small vacuum is maintained in SUMMA canisters at the completion of sampling. This is recorded and verified by the laboratory prior to analysis to check that the integrity of the sample has been maintained (the canister has not leaked) during transit.

QA/QC data was assessed and found to be compliant with the programme objectives and therefore the results of the sampling programme are accepted as valid.

4.3.2.1 Field replicates

Field replicates were collected for soil vapour sampling by SUMMA canister on bores SV02-D, SV03-S, SV10-D, SV25-S, SV47-S, SV49-S and SV52-D and Property 8-2PD (2016-739).

All analytes for these samples returned RPDs below the DQO.

4.3.2.2 Field duplicates

Field duplicates were collected for indoor air sampling by Radiello (7-2RD (2016-216) and 20-1RD (2016-239)) and by SUMMA canister (7-2SD (2016-207), 20-1SD (2016-231) and 17-3SD (2016-788)).

All analytes for these samples returned RPDs below the DQO.

4.3.2.3 Tracer leakage rate and detection

The following describes the tracer leakage rate and methodology employed by SGS for soil vapour sampling.

In order to detect the occurrence of atmospheric breakthrough, and hence a false negative result, a chamber constructed from inert materials (stainless steel, PTFE and polycarbonate) was placed over the top of the soil vapour bores during sampling. Helium was bled into the shroud at a flow rate of 2 – 4 L/min and a cloth soaked in isopropyl alcohol was also placed into the shroud.

Atmospheric breakthrough is detected by the presence of either helium or isopropyl alcohol in the analysed samples. The helium concentration in one shroud per event is measured by collecting a bag sample and analysing in the laboratory. This result is used to represent the helium concentration for every shroud and hence calculate an estimated leakage rate. The estimated leakage rate is defined as the fraction of the concentration of helium measured in the sample versus the representative helium shroud concentration, expressed as a percentage.

All estimated tracer leakage rates were below the DQO for the soil vapour sampling programme.

Samples taken from sub-slab bore 8-1P (11%) and 8-2P (48% and 43%) were above the tracer leakage quality objective of 10%. Laboratory results for these samples have not been adjusted for tracer leakage and are considered indicative only.

Atmospheric breakthrough may occur during sub-slab sampling due to the close proximity of the probe to the surface and the magnitude of this breakthrough is influenced by the integrity of the surface material.

4.3.2.4 Canister vacuum

All canisters reading a vacuum following sampling were also received by the laboratory under vacuum, indicating that leaks in transit are unlikely to have occurred. Field vacuum readings are considered indicative only and the internal calibration of this equipment may change during transit. Discrepancies may therefore exist between field vacuum readings and vacuum measurements taken using calibrated equipment in the laboratory. Consequently, a potential leak in transit was only considered likely when a canister noted as having been delivered after sampling under vacuum was received by the laboratory without vacuum.

Zero vacuum was reported for samples 17-3S-4/03/16 and 17-4S-4/03/16 in the field and laboratory after the sampling event. At low flow rates (approx. 83 ml/min), small differences in controller calibration can affect the estimated finishing time of the sample. No fault with the 72-hour flow controller was detected during sample installation for these samples. The period of sampling was equal to or less than 72 hours; however this is not expected to significantly affect the validity of sample results.

Standard quality control measures to detect a leak in transit for sample no. 17-3S-4/03/16 and 17-4S-4/03/16 were unable to be conducted. A leak in transit is considered extremely unlikely as the mechanical failure of two separate valves (QK and TOV valve) would need to occur simultaneously in order for a leak to occur. The validity of these sample results is therefore considered unlikely to have been affected.

4.3.2.5 Field blanks

Field blank sample nos. B-1R (2016-246) and BLANK-S (2016-789) were collected to assess if contaminants were present within the sampling media and equipment.

All field blanks returned results below the reporting limit.

4.3.2.6 Ambient air sampling

Ambient air sample no. 2016- 220 was collected on Property 7 to compare to indoor air results. Ambient air results are presented in Appendix F.

The following was detected above the reporting limit:

- Sample no. 2016-220: TCE (0.33 µg/m^3).

Based on the low concentration of TCE reported and absence of other COIs in the ambient sample, the presence of COIs in ambient air is not inferred to significantly contribute to reported indoor air, sub-floor, or soil vapour concentrations.

4.3.2.7 Laboratory blanks

Laboratory blanks were analysed to assess if contaminants were present within the laboratory instrumentation and sampling media.

All laboratory blanks returned results that met the DQO.

4.3.2.8 Laboratory analytical recoveries

The laboratory determines analytical recoveries from the sampling media by spiking the samples with surrogate standards and analysing a laboratory duplicate.

All analytical recoveries met the DQO.

4.4 Potential sources

4.4.1 Chemicals of interest (COIs)

This assessment was limited to volatile organic compounds (VOCs), with a focus on PCE, TCE and its degradation products cis-1,2-dichloroethene (cis-1,2-DCE), trans-1,2-dichloroethene (trans-1,2-DCE) and vinyl chloride.

4.4.2 Potentially contaminating activities

Previous investigations have primarily been based around the former appliance manufacturer site; however, historical groundwater investigation results suggest the presence of more than one source of contamination. The presence of numerous small industrial businesses in the Assessment Area, including various crash repairers, rug cleaners and manufacturing facilities, suggests that there is potential for multiple contaminant source sites to be present within the Assessment Area. Additional potential source zones for TCE are inferred from historic and recent data to exist to the east of Port Road and also from industrial properties to the west of the former appliance manufacturer property. A detailed assessment of all potential contaminant sources is beyond the scope of the current assessment.

In addition to current industrial activities, a number of locations in the Beverley area were historically excavated for clay, which was used for brick-making. The subsequent excavations also referred to as ‘clay pits’ or ‘pug holes’ were sometimes backfilled. If waste material containing TCE was used to backfill the pug holes, or waste liquids disposed within the pits, they may act as a source of TCE contamination in groundwater. One known pug hole is located in the eastern portion of the Assessment Area on the southern side of West Street, the location of which is illustrated on Figure 2.

4.5 Contaminated media

Elevated concentrations of volatile chlorinated hydrocarbons have been identified within groundwater and soil gas within the Assessment Area. In addition, elevated volatile chlorinated hydrocarbon concentrations have been identified within sub-floor areas and indoor air within selected residential properties.

4.5.1 Groundwater

4.5.1.1 Lateral extent of impacts

The recent and historical investigations have identified elevated concentrations of volatile chlorinated compounds (primarily TCE) in areas to both the east and west of the former appliance manufacturer site on Pope Street.

During the 2016 JBS&G Assessment, groundwater samples were collected from 20 locations including the previously installed groundwater wells (MW01-MW07, XMW02 and XMW03) and 11 groundwater wells installed by JBS&G (MW08-MW18). The locations of these groundwater wells and the corresponding TCE results are presented in Appendix C.

The lateral extent of COIs in groundwater has not been determined by the recent investigations, however Figure 4 of the JBS&G report (2016) (Appendix C) highlights the potential for several sources associated with three separate TCE plumes within the assessment area:

- **Primary groundwater plume:** The TCE impacts associated with the plume approximately located at the intersection of West Street and William Street is considered to be delineated laterally with the exception of to the north west, south west and north east.
- **Secondary groundwater plume:** The TCE impacts associated with the plume located generally to the east of Wodonga Street and to the south of Woolginga Street is considered to be laterally delineated with the exception of to the east and north east.
- **Tertiary groundwater plume:** A tertiary plume associated with a single monitoring well on the north-west boundary of the Assessment Area (MW12) is not delineated in any direction.

Notable concentrations of COIs in groundwater are discussed in the following sections.

4.5.1.1.1 PCE

Detectable concentrations of PCE were reported in the 2016 JBS&G Assessment in monitoring wells MW10 (0.3 µg/L) and MW11 (0.4 µg/L), located along the southwest boundary of the Assessment area, as well as MW17 (0.2 µg/L), located approximately 50 m south of the pug-hole. Concentrations of PCE were reported below the laboratory LOR (<0.1 µg/L) in other wells sampled.

Minor variability in PCE concentrations was reported between the 2015 Golder Assessment and 2016 JBS&G Assessment, however, reported concentrations were in the same order of magnitude and there were no general increasing or decreasing trend present across the well locations.

4.5.1.1.2 TCE

Detectable concentrations of TCE were reported in the 2016 JBS&G Assessment at all wells sampled, with concentrations ranging from 0.5 µg/L immediately south of the Assessment Area (MW09) to 2,900 µg/L at the intersection of West Street and Charles Road (MW03). This is generally consistent with previous investigations.

The lowest concentrations of TCE, ranging from 0.5 to 78 µg/L, were reported in monitoring wells MW06-MW11 and MW13-MW18, located on the periphery of the Assessment Area, as well as at XMW03, located on Charles Road approximately 150 m south of the intersection with West Street.

The highest concentrations of TCE, ranging from 230 to 2,900 µg/L, were reported in monitoring wells MW01-MW05 and MW12, located in the central portions of the three groundwater plumes described in Section 4.4.1.1.

4.5.1.1.3 1,2-DCE

Detectable concentrations of cis-1,2-DCE were reported in the 2016 JBS&G Assessment at 12 monitoring wells in the central portion of the three groundwater plumes described in Section 4.4.1.1, as well as along the north-west and south-west boundaries of the Assessment Area, with concentrations ranging from 0.1 µg/L (XMW02) to 42µg/L (MW04). This is generally consistent with previous investigations.

Based on this data, low concentrations of cis-1,2-DCE appear to be present throughout the majority of the Assessment Area. Concentrations of trans-1,2-DCE were reported below the laboratory LOR in in the monitoring wells sampled.

4.5.1.1.4 Vinyl chloride

Concentrations of vinyl chloride were reported below the laboratory LOR (<0.3 or <0.4 µg/L) for the samples analysed as part of the 2016 JBS&G Assessment with the exception of MW11 (1 µg/L). This is generally consistent with previous investigations.

4.5.1.2 Vertical extent of impacts

Chemical results reported by historic investigations (URS 2012) indicate the concentration of TCE detected in a sample collected from GW80, installed within the Q2 aquifer (322 µg/L in August 2011), was lower than the concentrations detected in adjacent wells installed within the Q1 aquifer (GW10 – 730 µg/L , GW99 – 1680 µg/L). No investigation of the Q2 aquifer was undertaken as part of the 2015 or 2016 Assessments, and no assessment of the lateral extent of impacts within the Q2 aquifer has been historically undertaken.

One groundwater sample has previously been collected from a deep bore within the T1 tertiary aquifer located on the former appliance manufacturer site. No chlorinated hydrocarbons were detected in this sample (URS 2008).

The vertical extent of TCE impacts throughout the Assessment Area is not known.

4.5.1.3 Potential for contamination attenuation

Table 10 below presents TCE and cis-1,2-DCE concentrations in groundwater reported in the latest round of monitoring (JBS&G 2016) against historical concentrations reported in the same or similar location.

Table 10: Summary of Historical TCE and Cis-1,2-DCE Concentrations (µg/L) in Groundwater

Original Bore	Contaminant	Jun-07	Nov-07	May-08	New Bore in similar location	Nov-13	May- 15	April 2016
GW93	**TCE** **cis-1,2-DCE**			4,070 <LOR	**MW02**		2,000 <LOR	2,500 1.4
GW65	**TCE** **cis-1,2-DCE**	1,820 <LOR		1,980 <LOR	**XMW02**	529 <LOR	700	760 2.4
GW66	**TCE** **cis-1,2-DCE**	324 <LOR		341 <LOR	**XMW03**	49 <LOR	73 <LOR	78 0.1
GW71	**TCE** **cis-1,2-DCE**	1390 <LOR	1140 18		**MW05**		2,000 20	1,000 17
GW75	**TCE** **cis-1,2-DCE**	6320 <LOR	5320 36		**MW06**		29 0.2	75 0.8

Historically, the highest concentration of TCE recorded in the Assessment Area was reported in monitoring well GW75 in June 2007 (6,320 µg/L). This well was located in the western portion of the Assessment Area, in the general vicinity of monitoring well MW06, installed during the 2015 Golder Assessment. Groundwater sampled from this well recorded a TCE concentration in May 2016 of only 75 µg/L. This is generally consistent with the results of the 2015 Golder Assessment, and is supported by subsequent soil vapour data. It is therefore is considered to be reliable for the purpose of the current assessment of vapour intrusion.

The reason for this dramatic reduction in recorded TCE concentrations in this location is unknown; however it is noted that the newly installed well is shallower and has a shorter well screen than the historical well. It is possible that the historical well intersected a lens of more highly contaminated material below the depth of the newly installed well; however there is no evidence of such a lens identified within the historical well bore log. It is also possible that a fresh water lens could be present at shallower depth, and the lower salinity of groundwater reported in this well supports this possibility.

Generally, previous and recent groundwater investigations within the Assessment Area indicate a decrease in TCE concentrations since 2008. The notable historic exception to this trend is MW5, which reported a TCE concentration of 2,000 µg/L in May 2015, compared to 1,140 µg/L at GW71 (formerly located in close proximity to where MW5 was installed) in June 2007. The reported TCE concentration for MW5 in April 2016 was 1,000 µg/L, generally consistent with 2015 results.

A slight increase in the TCE concentrations was also noted between the November 2013 and May 2015 monitoring events in wells XMW02 and XMW03; however it is noted that the long-term trend within groundwater in the vicinity of these wells has been a decrease from concentrations reported in 2007.

Overall, chlorinated hydrocarbon impacts in groundwater reported within the Assessment Area in 2015 and 2016 are generally lower in comparison to historical concentrations. There has not been a corresponding increase in degradation products cis-1,2-DCE or VC concentrations over the monitoring period, therefore there is no evidence that the reduction in TCE concentrations is associated with biodegradation of TCE.

4.5.2 Soil vapour

Notable concentrations of COIs detected during soil vapour sampling are discussed in the following sections. Soil vapour concentrations have been compared with the interim soil vapour health investigation levels (HILs) for volatile organic chlorinated compounds as published in the National Environment Protection (assessment of site contamination) Measure (ASC NEPM), 1999 (as amended in 2013). The HILs are stated in the NEPM as being based on shallow soil vapour measurements (to a depth of 1 metre below a building). Application of the HILs for assessment of soil vapour measurements deeper than 1 metre is likely to be conservative due to additional attenuation anticipated to occur through the soil profile. In the absence of soil vapour screening guidelines for deeper samples, the HIL values have been adopted as an initial conservative screening approach for all soil vapour sample depths.

4.5.2.1 PCE

Concentrations of PCE above the LOR were reported in 19 of 57 soil vapour samples at depths of between 0.85 and 3.85 m bgl, at the following locations:

- along the west side of Main Street, approximately 40 m south of West Street
- along both the north and south side of the central portion of West Street, from the pug-hole to Williams Street, as well as on residential properties on the south side of West Street in this area
- along the south portion of Williams Street and Charles Road, approximately 90 m south of West Street, as well as on a residential property on the west side of Williams Street in this area
- on residential properties on the east side of Wodonga Street, approximately 50 to 100 m south of Woolgina Street.

Reported concentrations of PCE at these locations ranged between 6.1 µg/m^3 (SV51-S) and 179 µg/m^3 (SV21-S). These concentrations do not exceed the interim soil vapour HIL of 2,000 µg/m^3 for residential land use published in the ASC NEPM.

Concentrations of PCE were reported below the laboratory LOR (<2 µg/m^3) in other soil vapour samples.

4.5.2.2 TCE

Concentrations of TCE were reported above the LOR in all of the 57 sampling locations analysed, with reported concentrations ranging between 11 (SV46-S) and 150,000 µg/m^3 (SV02-M). In general, the highest concentrations of TCE were reported along Main Street, north of West Street, along West Street between Main Street and Williams Street, and along Williams Street, up to 50 m south of West Street. These concentrations generally exceed the interim soil vapour HIL of 20 µg/m^3 for residential land use published in the ASC NEPM.

4.5.2.3 1,2-DCE

Concentrations of cis-1,2-DCE above the LOR were reported in 10 of 57 soil vapour samples at depths of between 0.85 and 3.85 m bgl, at the following locations:

- along the west side of William Street, approximately 70 m south of West Street.
- along the south side of West street, between Main Street and Williams Street

Reported concentrations of cis-1,2-DCE ranged between 4.4 µg/m^3 (SV26-S) and 390 µg/m^3 (SV04-M). The concentration at SV04, on the south side of West Street, exceeded the interim soil vapour HIL of 80 µg/m^3 for residential land use published in the ASC NEPM. As noted above, this HIL is intended to be used to a depth of 1 m bgl, and application of the HIL below this depth is a conservative approach.

Concentrations of cis-1,2-DCE were reported below the laboratory LOR in other soil vapour samples.

Concentrations of trans-1,2-DCE were reported below the laboratory LOR for the samples analysed.

4.5.2.4 Vinyl chloride

Concentrations of vinyl chloride were reported below the laboratory LOR for the samples analysed.

4.5.2.5 Lateral extent of impacts

Soil vapour bores located along Main Street (north of West Street), along with the bores along the south side of West Street and north portions of William Street and Charles Street, recorded significantly greater concentrations of soil vapour than those sampled elsewhere throughout the Assessment Area. Soil vapour bores installed within the base of the pug-hole adjacent West Street generally recorded lower TCE concentrations than nearby bores along West Street. Similarly, lower concentrations were reported within properties on the north side of West Street and within properties south of West Street than samples collected from the south side of West Street itself. These results indicate a primary area of impact along West Street between Main Street and Charles Street, including some properties along Port Road, Main Street and William Street, and are generally correlated with the primary plume of groundwater impacts as discussed in Section 4.4.1.1.

A second area of soil vapour impacts, of lower magnitude, has been identified in the vicinity of Howards Road and Wodonga Street, and is generally correlated with the secondary plume of groundwater impacts. Soil vapour bores installed within this area reported higher concentrations of TCE within residential properties between these two streets than on nearby bores on either Howards Road or Wodonga Street.

The lateral extent of soil vapour impacts was previously assessed by a passive soil vapour (PSV) survey as part of the 2015 Golder Assessment, to qualitatively assess relative soil vapour concentrations within the Assessment Area. Installation and sampling of multiple soil vapour bores was subsequently conducted to confirm the outcomes of the PSV survey and quantitatively assess the magnitude of soil vapour impacts. In general, the lateral extent of soil vapour impacts interpreted from the 2016 Golder Assessment appears reasonably consistent with results of the 2015 PSV survey and active sampling results.

4.5.2.6 Vertical extent of impacts

The vertical extent of soil vapour impacts has been assessed through the installation of 30 clustered soil vapour bores at 11 locations and three nested soil vapour bores at one location within the Assessment Area. In clustered/nested soil vapour bore locations the TCE concentrations reported generally increased with depth, as shown on Image 3 below. Soil vapour impacts were observed to exist throughout the vadose zone.

The vertical profile of TCE concentrations in soil vapour generally suggests that groundwater is likely to be a primary source of the elevated TCE concentrations recorded in soil vapour. In general, with the exception of locations SV02 and SV51, the observed attenuation of TCE concentrations with depth is roughly linear, as would be expected for steady state diffusion with no biodegradation within a relatively homogeneous soil profile. These results are generally consistent with those observed in the Golder 2015 Assessment.

The TCE concentrations at locations SV02 and SV51 were greater within the mid depth sample than in the deeper samples from these locations. At location SV02 this may be associated with a possible preferential pathway within the unsaturated zone (such as the sandy lens present at approximately 4.1-4.2 m depth at this location). No preferential lithological pathways were observed at location SV51, however it is possible that the sewer or stormwater pipe trenches beneath William Street could act as a preferential migration pathway in this area. The results from SV02 and SV51 may also suggest contributions from sources within the soil closer to the surface in these areas, in addition to underlying groundwater.

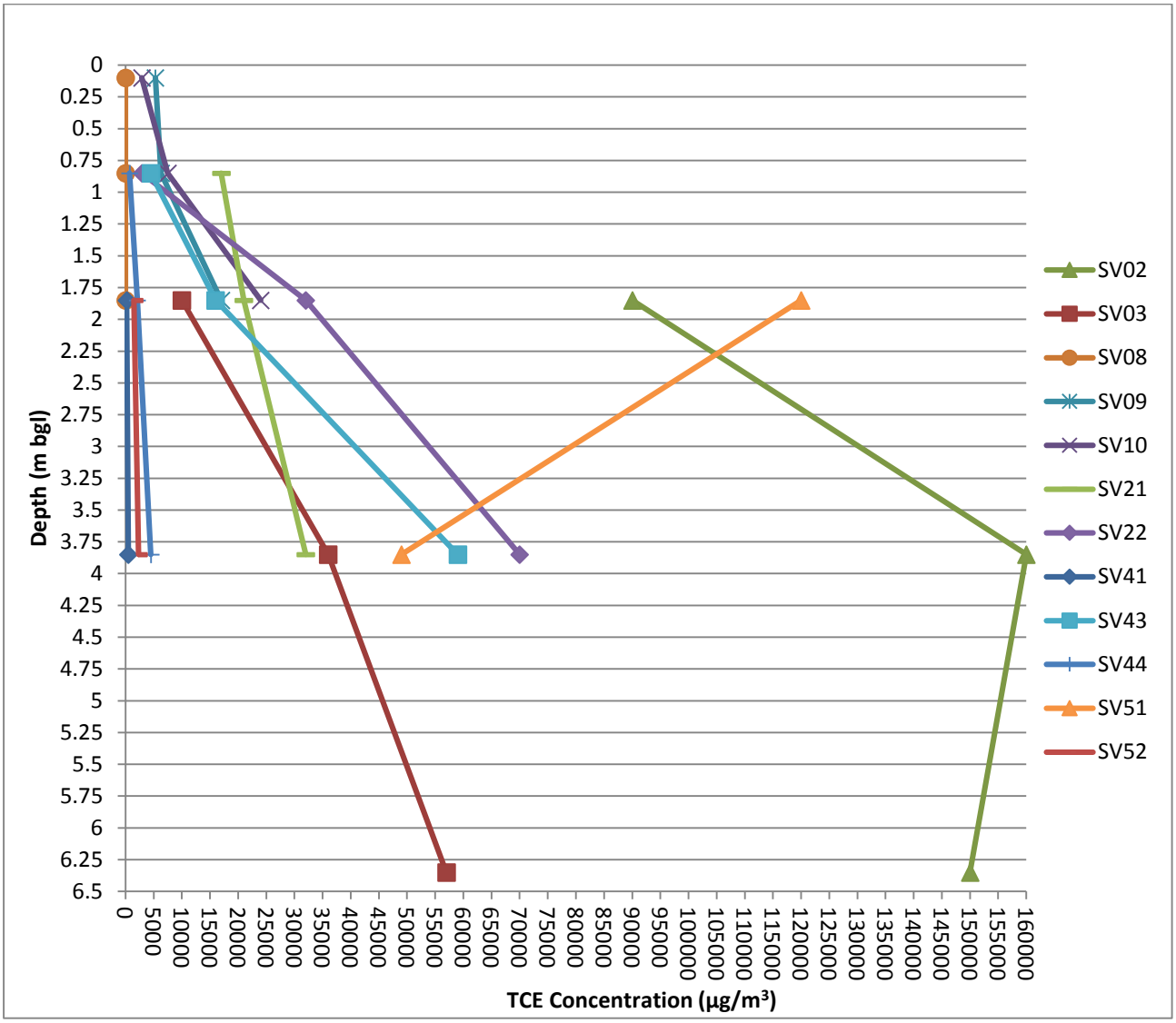


Image 3: TCE Soil Vapour Depth Variation

4.5.2.7 Temporal variation in soil gas concentrations

Soil vapour bores sampled on more than one occasion have been compared to assess the potential for temporal variations in soil gas concentrations. The most recent Golder sampling event was undertaken between March and April 2016, while the JBS&G sampling event was undertaken between January and February 2016. The variations in TCE concentrations are summarised in Table 11 and presented in Images 4-7 below.

Table 11: Temporal Variations in Soil Gas TCE Concentrations*

	Depth (m)	April 2015 (Golder) (TCE(µg/m^3))	June-August 2015 (Golder) (TCE(µg/m^3))	January-February 2016 (JBS&G) (TCE(µg/m^3))*	March-April 2016 (Golder) (TCE(µg/m^3))
SV01-M	3.85	78,000	120,000	-	86,000
SV02-S	1.85	42,000	36,000	-	82,000
SV02-M	3.85	93,000	-	-	150,000
SV02-D	6.35	97,000	-	-	140,000#
SV03-S	1.85	7,000	5,800	-	9,400
SV03-M	3.85	< LOR	-	-	33,000
SV03-D	6.35	57,000	-	-	52,000
SV04-M	3.85	3,100	2,800	-	8,400
SV05-M	3.85	5,600	5,500	6,300	-
SV06-S	1.85	530	490	570	-
SV06-M	3.85	1,100	-	1,500	-
SV06-D	6.35	33	-	3,300	-
SV07-S	1.85	69	68	71	-
SV07-M	3.85	290	-	290	-
SV08-S	0.85	240	220	-	410
SV08-M	1.85	< LOR			1,300
SV08-D	3.85	< LOR			5,800
SV09-S	0.85	2,400	1,600	-	4,900
SV09-M	1.85	3,600	-	-	5,800
SV09-D	3.85	5,500	-	-	16,000
SV10-S	0.85	3,100	2,700	-	2,700
SV10-M	1.85	6,000	-	-	6,900
SV10-D	3.85	17,000	-	-	22,000
SV18-S	0.85	-	140	150	-
SV19-S	0.85		1,800	2,900	-
SV19-M	1.85	-	4,500	5,000	-
SV19-D	3.85	-	25,000#	19,000	-
SV20-S	0.85	-	330	430	-
SV20-M	1.85	-	290#	420	-
SV20-D	3.85	-	1,000	1,600	-
SV21-S	0.85	-	12,000#	-	16,000
SV21-M	1.85	-	20,000	-	19,000

	Depth (m)	April 2015 (Golder) (TCE(µg/m^3))	June-August 2015 (Golder) (TCE(µg/m^3))	January-February 2016 (JBS&G) (TCE(µg/m^3))*	March-April 2016 (Golder) (TCE(µg/m^3))
SV21-D	3.85	-	35,000	-	29,000
SV22-S	0.85	-	17,000	-	2,700
SV22-M	1.85	-	17,000	-	29,000
SV22-D	3.85	-	48,000	-	64,000
SV25-S	0.85	-	18,000	-	28,000
SV26-S	0.85	-	95	-	180
SV27-S	0.85	-	73	-	860
SV28-S	0.85	-	23,000	-	42,000
SV29-S	0.85	-	460	-	1,200
SV30-S	0.85	-	570	-	870
SV31-S	0.85	-	2,800	-	2,300
SV32-S	0.85	-	<7	-	150
SV33-S	0.85	-	1,300	-	980
SV34-S	0.85	-	76	-	26
SV38-S	0.85	-	15	-	44
SV39-S	0.85	-	1,500	-	1,100
SV40-S	0.85	-	810	-	710

Where primary and replicate samples taken, the highest concentration has been reported.

* Concentrations expressed at 25°C and 101.3kPa.

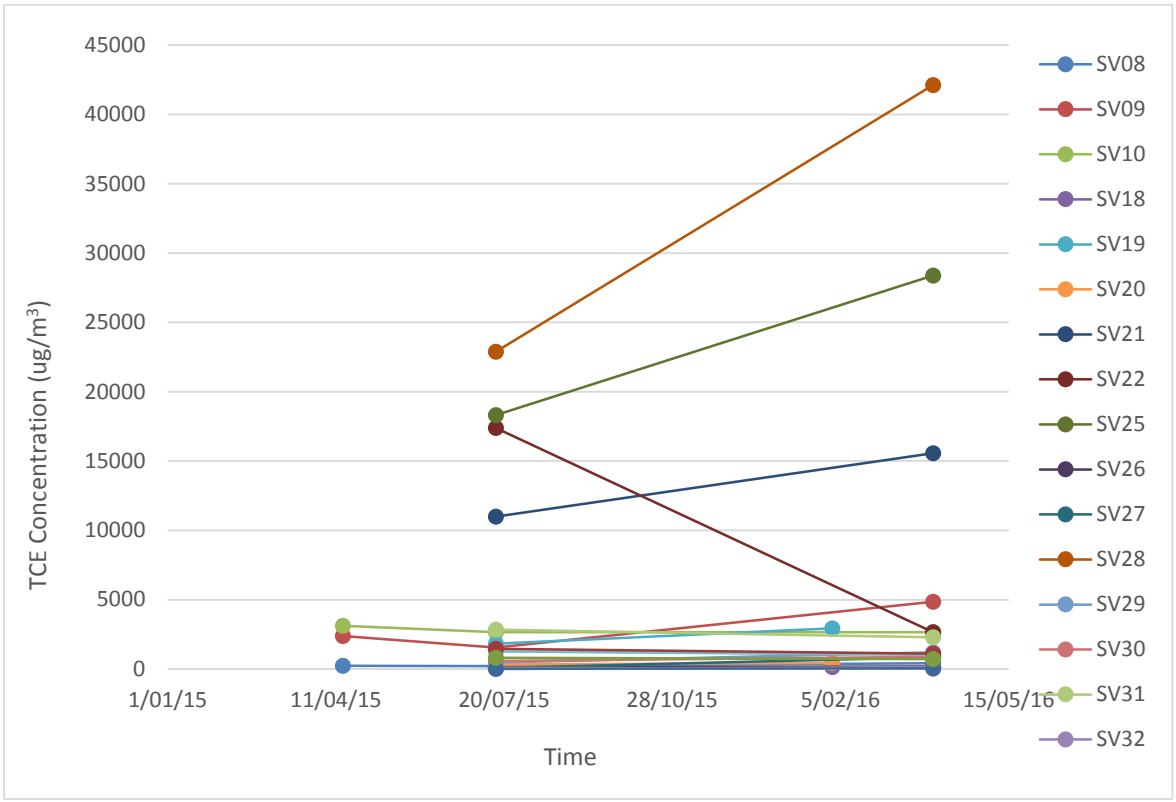


Image 4: Temporal Variation in TCE Concentrations in Soil Vapour, 0.85 m Depth

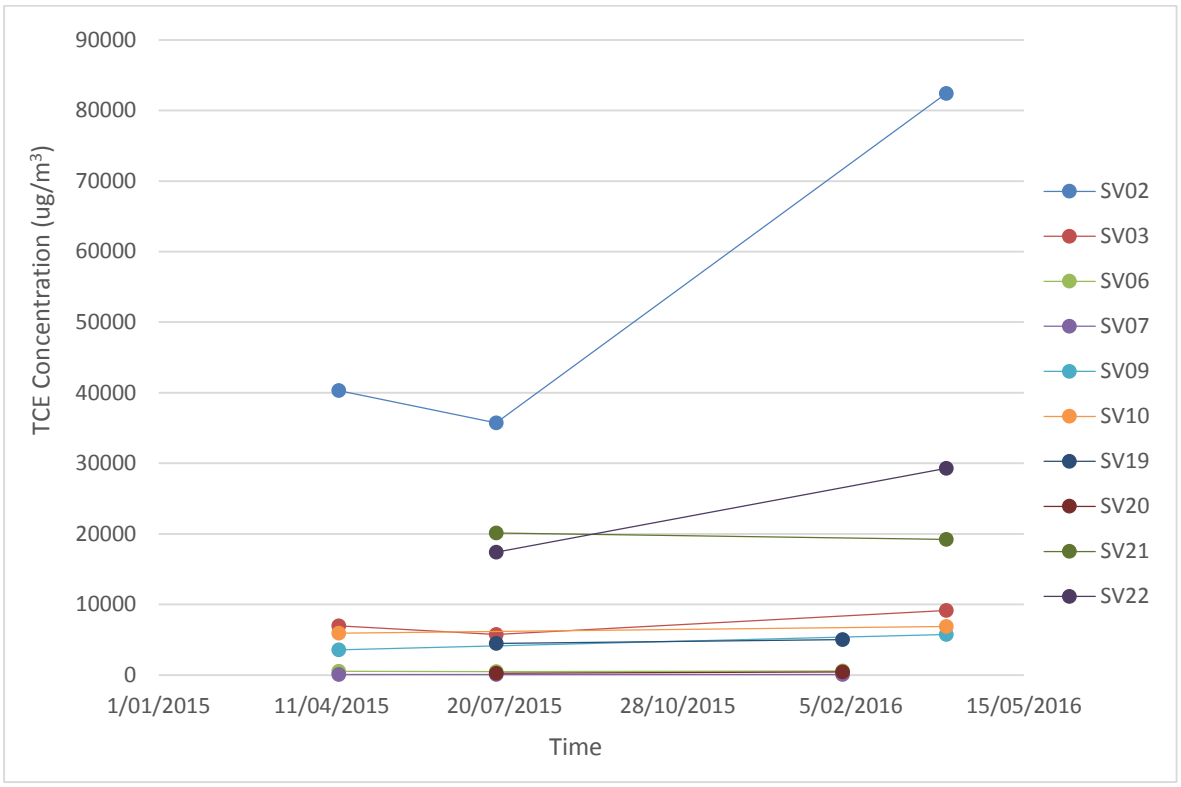


Image 5: Temporal Variation in TCE Concentrations in Soil Vapour, 1.85 m Depth

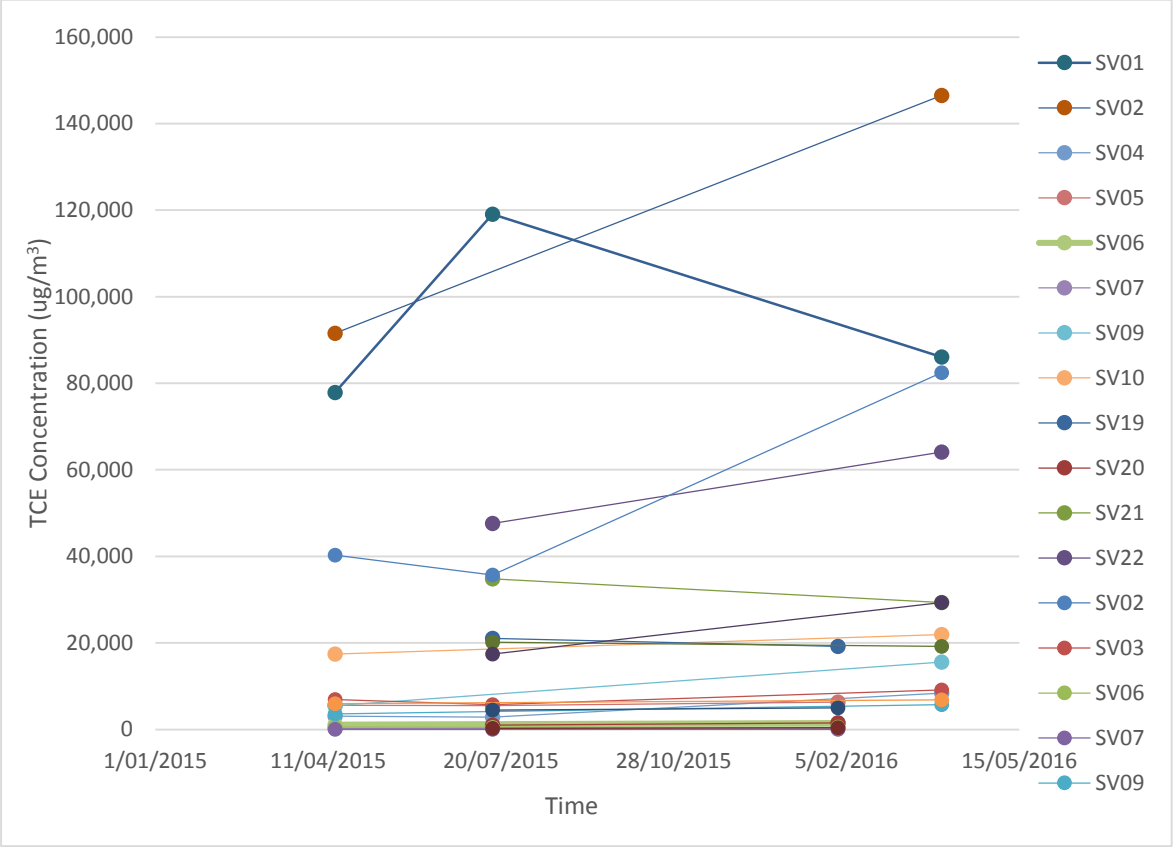


Image 6: Temporal Variation in TCE Concentrations in Soil Vapour, 3.85 m Depth

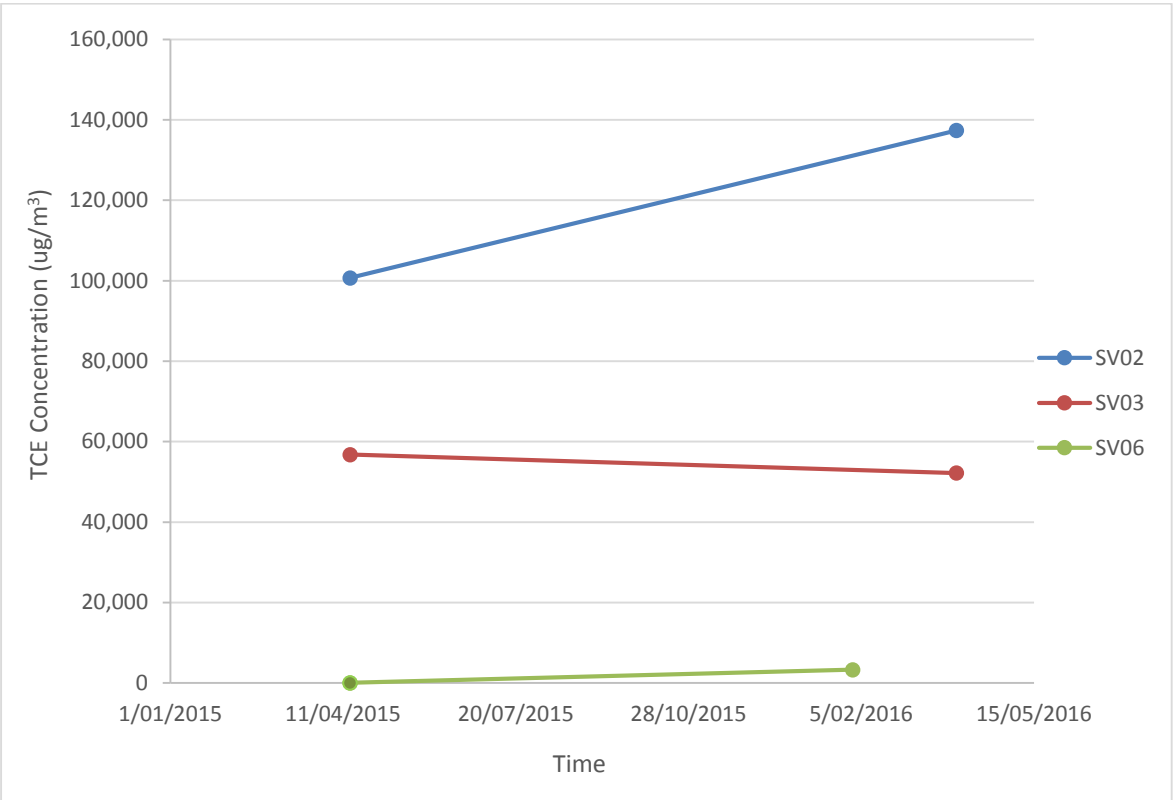


Image 7: Temporal Variation in TCE Concentrations in Soil Vapour, 6.35 m Depth

Based on this data it is apparent that soil gas TCE concentrations were relatively similar (within one order of magnitude) during the four sampling events, with the greatest variance in reported concentrations noted between samples collected during the 2015 Golder Assessment and 2016 Golder Assessment. It is noted that the 2015 Assessment was conducted in winter, while the 2016 Assessment was conducted in autumn. The increased concentrations reported in the 2016 Golder Assessment may therefore represent seasonal variations in vapour migration due to increased temperatures and decreased soil moisture relative to the winter 2015 event.

Notable discrepancies in reported TCE concentrations were observed at sample locations SV03-M, SV08-M, and SV08-D. The reported concentrations at these locations were below LOR in 2015 and 36,000 µg/m^3, 1,400 µg/m^3, and 6,300 µg/m^3, respectively, in 2016. Reported concentrations at shallower and deeper sampling probes at these locations (SV03-S, SV03-D, and SV08-S) have remained generally consistent, suggesting that either the 2015 or 2016 data may be erroneous.

It was noted during the 2015 event that vapour samples were drawn at a faster rate than expected at these locations. When assessing the 2015 data, it was considered most likely that the flow controllers had been incorrectly set at a higher flow rate by the laboratory. Although the fault was not present during the initial leak test of the equipment prior to 2015 sampling, in light of the 2016 data, it is now considered likely that the increased flow rate may have resulted from a leak in the flow controller, allowing the infiltration of atmospheric air. No similar occurrences were noted during the 2016 sampling event, and as such the results of the 2016 sampling event at these locations are considered to be of higher confidence than those of 2015.

As shallow soil vapour data existed for both locations (SV03 and SV08), the deeper soil vapour data was not utilised in the 2015 calculation of estimated indoor air concentrations near these soil vapour points. No similar occurrences were noted at other locations sampled in 2015. The potential invalidation of the 2015 data at SV-03M, SV-08M, and SV-08D therefore does not influence the outcomes of either the 2015 or current assessments.

4.5.3 Outdoor air

An ambient outdoor air sample was collected from one location at the south side of West Street, approximately 80 m east of William Street. A detectable concentration of TCE was reported; however this concentration was reported at a level (0.33 µg/m^3) which is considered unlikely to have significantly contributed to soil vapour, sub-floor, or indoor air sampling results.

Concentrations of other COIs were below the LOR. A summary of the ambient outdoor air concentrations is presented in Appendix F.

4.5.4 Residential sub-floor samples

Air samples were collected from the sub-floor areas of 19 residential properties (three sub-slab and 16 crawl space locations) during the Golder 2016 soil vapour assessment program at the following locations:

- several locations along either side of West Street, between Williams Street and Main Street
- several locations along either side of Williams Street, north and south of West Street
- several locations along either side of Wodonga Street, south of Woolgina Street
- a single location at the intersection of Ledger Road and Woolgina Street.

Depending on floor construction types sub-floor samples were collected using sub-slab vapour pins for concrete slab floors (over a 20 minute sampling period) and active sampling with passivated steel canisters (over a 24 hour sampling period) for timber floors with a sub-floor void (crawl space).

The results of sub-slab and crawl space samples are discussed below. The TCE concentrations in sub-floor samples for each property sampled is summarised in Appendix F.

4.5.4.1 Crawl space samples

Notable concentrations of COIs identified in crawl space air samples are presented in the following sections.

4.5.4.1.1 PCE

Concentrations of PCE were not reported in excess of the laboratory LOR (<6 to <0.16 µg/m^3) in indoor crawl space air samples.

4.5.4.1.2 TCE

Elevated TCE concentrations were detected in majority of the crawl spaces sampled, with maximum recorded concentrations at each property ranging from 6.8 µg/m^3 (Property 4) to 170 µg/m^3 (Property 17). TCE concentrations were reported below the LOR in both samples collected from the crawl spaces of Properties 22 and 23.

4.5.4.1.3 1,2-DCE

Concentrations of cis-1,2-DCE or trans-1,2-DCE were not reported in excess of the laboratory LOR (<4 to <4.8 µg/m^3) in indoor crawl space air samples.

4.5.4.1.4 Vinyl chloride

Concentrations of vinyl chloride were not reported in excess of the laboratory LOR (2 to 3 µg/m^3) in indoor crawl space air samples.

4.5.4.1.5 Temporal variation in crawl space concentrations

A comparison of the data collected in the crawl space of buildings in the Golder 2016 Assessment with the Golder 2015 Assessment provides an indication of temporal trends in TCE concentration within the crawl space of selected buildings that were monitored during both of these sampling events. This comparison is presented in Table 12.

The TCE concentrations recorded in both events were relatively similar (within one order of magnitude), indicating relatively stable sub-floor conditions during these periods.

Table 12: Temporal Variations in Crawlspace TCE Concentrations

Sample location	2015 Golder Assessment	2016 Golder Assessment
1-1C-7/04/16	36	21
1-2C-7/04/16	13	20
2-1C-7/04/16	12	<2
2-2C-7/04/16	22	17
4-1C-7/04/16	10	6.1
4-2C-7/04/16	16	6.8
5-1C-3/03/16	22	31
5-2C-3/03/16	10	19
7-1C-3/03/16	35	22
9-1C-18/03/16	14	46

4.5.4.2 Sub-slab samples

Notable concentrations of COIs identified in sub-slab vapour samples are presented in the following sections.

4.5.4.2.1 PCE

Concentrations of PCE were not reported in excess of the laboratory LOR (<0.16 to <0.6 µg/m^3) in sub-slab vapour samples.

4.5.4.2.2 TCE

Elevated TCE concentrations were detected at the three sub-slab locations sampled, with maximum recorded concentrations ranging from 14,000 µg/m^3 (Property 8) to 20,000 µg/m^3 (Property 5).

4.5.4.2.3 Cis- and trans-1,2-DCE

Concentrations of cis-1,2-DCE or trans-1,2-DCE were not reported in excess of the laboratory LOR in sub-slab vapour samples.

4.5.4.2.4 Vinyl chloride

Concentrations of VC were not reported in excess of the laboratory LOR (2.2 to 4.5 µg/m^3) in sub-slab vapour samples.

4.5.4.2.5 Temporal variation in sub-slab samples

A comparison of the data collected for sub-slab vapour in the Golder 2016 Assessment with the Golder 2015 Assessment provides an indication of temporal trends in TCE concentration beneath the sub-slab of selected buildings that were monitored during both of these sampling events. This comparison is presented in Table 13.

The TCE concentrations recorded in both events were relatively similar (within one order of magnitude), indicating relatively stable sub-slab conditions during these periods. A general increase in sub-slab TCE concentrations during the 2016 Assessment may be attributable to seasonal weather differences associated with the respective time of sampling for each event (i.e. 2015 in April through June and 2016 in March through April).

A notable decrease in the concentration of sub-slab TCE vapours was reported at Property 8 (8-1P and 8-2P), located at the southern side of West Street. This elevated temporal variation may be associated with property-specific construction details associated with fill and services located beneath the slab.

Table 13: Temporal Variation in Sub-Slab TCE Concentrations

Sample location	TCE (µg/m^3) (2015)	TCE (µg/m^3) (2016)
5-3P-3/03/2016	18,000	20,000
7-2P-11/03/2016	26,000	19,000
8-1P-23/03/2016	27,000	14,000
8-2P-23/03/2016	15,000	9,500

4.5.5 Indoor air

Indoor air sampling was undertaken at nine properties as detailed in Section 3.1. Sampling conducted at most properties was undertaken while occupied by the property residents, under normal ventilation conditions. Replicate sampling was also undertaken at Properties 7 and 17 under unoccupied conditions anticipated to result in minimal ventilation. In general, with the exception of the unoccupied condition at Properties 7 and 17, sampling was conducted using passivated Summa canisters over a 72 hour period, and also using passive Radiello samplers over a one week period. Unoccupied sampling was completed using passivated Summa canisters only, over a 72 hour period. The maximum indoor air concentrations of TCE recorded at each property using each sampling method are summarised in Table 14.

Table 14: Indoor Air Maximum TCE Concentrations

Location	Sample Type	Sampling Date	Condition	Maximum TCE Concentration (µg/m^3)
Property 1	Radiello	1/04/2016 – 8/04/2016	Occupied	2.3
	SUMMA canister	1/04/2016 – 4/04/2016	Occupied	2.3
Property 2	Radiello	1/04/2016 – 8/04/2016	Occupied	0.81
	SUMMA canister	1/04/2016 – 8/04/2016	Occupied	<2
Property 5	Radiello	26/02/2016 – 4/03/2016	Occupied	4.9
	SUMMA canister	26/02/2016 – 29/02/2016	Occupied	8.2
Property 7	Radiello	26/02/2016- 4/03/2016	Occupied	4.8
	SUMMA canister	26/02/2016 – 29/02/2016	Occupied	3.1
		11/03/2016 – 14/03/2016	Unoccupied	40
Property 8	Radiello	16/03/2016 – 23/03/2016	Occupied	1.8
	SUMMA canister	16/03/2016 – 19/03/2016	Occupied	<2
Property 9	Radiello	16/03/2016 – 23/03/2016	Occupied	6.2
	SUMMA canister	16/03/2016 – 19/03/2016	Occupied	17
Property 17	Radiello	4/03/2016 – 11/03/2016	Occupied	41
	SUMMA canister	4/03/2016 – 7/03/2016	Occupied	60
		22/04/2016 – 25/04/2016	Unoccupied	55
Property 18	Radiello	1/04/2016 – 8/04/2016	Occupied	0.71
	SUMMA canister	1/04/2016 – 4/04/2016	Occupied	<2
Property 20 (excluding basement)	Radiello	4/03/2016 – 14/03/2016	Occupied	0.47
	SUMMA canister	4/03/2016 – 7/03/2016	Occupied	<2

Location	Sample Type	Sampling Date	Condition	Maximum TCE Concentration (µg/m^3)
Property 20 basement	Radiello	4/03/2016 – 14/03/2016	Occupied	3.3
	SUMMA canister	4/03/2016 – 7/03/2016	Occupied	4.4

Notable concentrations of COIs identified in indoor air samples are presented in the following sections.

4.5.5.1 PCE

Concentrations of PCE were not reported in excess of the laboratory LOR (<0.16 to <0.6 µg/m^3) in indoor air samples.

4.5.5.2 TCE

Elevated TCE concentrations above 2 µg/m^3 were detected at seven of nine properties, with concentrations of TCE in indoor air exceeding the laboratory LOR reported in all properties assessed. The highest concentrations of TCE in indoor air were generally reported at properties located on West Street and William Street.

Replicate sampling at Properties 7 and 17 was conducted under unoccupied conditions, simulating a high-risk scenario where doors and windows are kept closed during the sampling period. Reported unoccupied concentrations at Property 17 were generally similar to occupied conditions, while unoccupied concentrations at Property 7 were approximately one order of magnitude greater. Variances associated with these comparisons may be attributable to differences in the structural condition and design of the respective properties.

4.5.5.3 1,2-DCE

Concentrations of cis-1,2-DCE or trans-1,2-DCE were not reported in excess of the laboratory LOR (<4 to <4.8 µg/m^3) in indoor air samples.

4.5.5.4 Vinyl chloride

Concentrations of vinyl chloride were not reported in excess of the laboratory LOR (<2.2 to <4.5 µg/m^3) in indoor air samples.

4.5.5.5 Temporal variation in indoor air samples

A comparison of the data collected for indoor air in the Golder 2016 Assessment with the Golder 2015 Assessment provides an indication of temporal trends in TCE concentrations within residential properties. This comparison is presented in Table 15.

Table 15: Comparison of Indoor TCE concentrations, Golder 2015 and 2016 sampling events

Property	TCE Concentration (µg/m^3)		
	Golder 2015 (Occupied)	Golder 2016 (Occupied)	Golder 2016 (Unoccupied)
Property 5	<3 -13	<2 - 8.2	NA
Property 7	12 – 38	<2 - 4.8	20 – 40
Property 8	<3 - 8.6	1.0 – 1.8	NA
Property 17	11 – 29	12 - 60	20 - 55
Property 18	<2 - 2.2	0.49 - 0.71	NA

NA – no unoccupied sample collected from this property

Considering occupied data only, reported 2016 concentrations of TCE were slightly decreased from those under occupied conditions in 2015 at Properties 5 and 18, generally similar at Property 8, and displayed conflicting trends in Property 17 (reported concentrations slightly increased in one room, slightly decreased in a second, and were generally similar in other rooms). Reported occupied 2016 TCE concentrations in Property 7 were generally an order of magnitude lower than those reported in 2015. This suggests that temporal variation in concentrations may be greater at some locations within the Assessment Area than others, and may be influenced by the construction details of each property.

As discussed in Section 4.5.5.2, replicate sampling was undertaken at Properties 7 and 17 under unoccupied conditions. Reported unoccupied concentrations at Property 17 were generally similar to occupied conditions, while unoccupied concentrations at Property 7 were approximately one order of magnitude greater. The degree of variance observed at Property 7 suggests that the structural condition and design of this property make indoor air concentrations of COIs responsive to changes in ventilation conditions. It is therefore possible that small differences in occupant activity between the two occupied sampling events at Property 7 (i.e. greater ventilation during the 2016 event) may have contributed to the temporal variance reported at this property.

4.6 Potential receptors and pathways

4.6.1 Receptors

Potential human receptors within the Assessment Area include residential property occupants, workers within commercial and industrial properties and maintenance and construction workers.

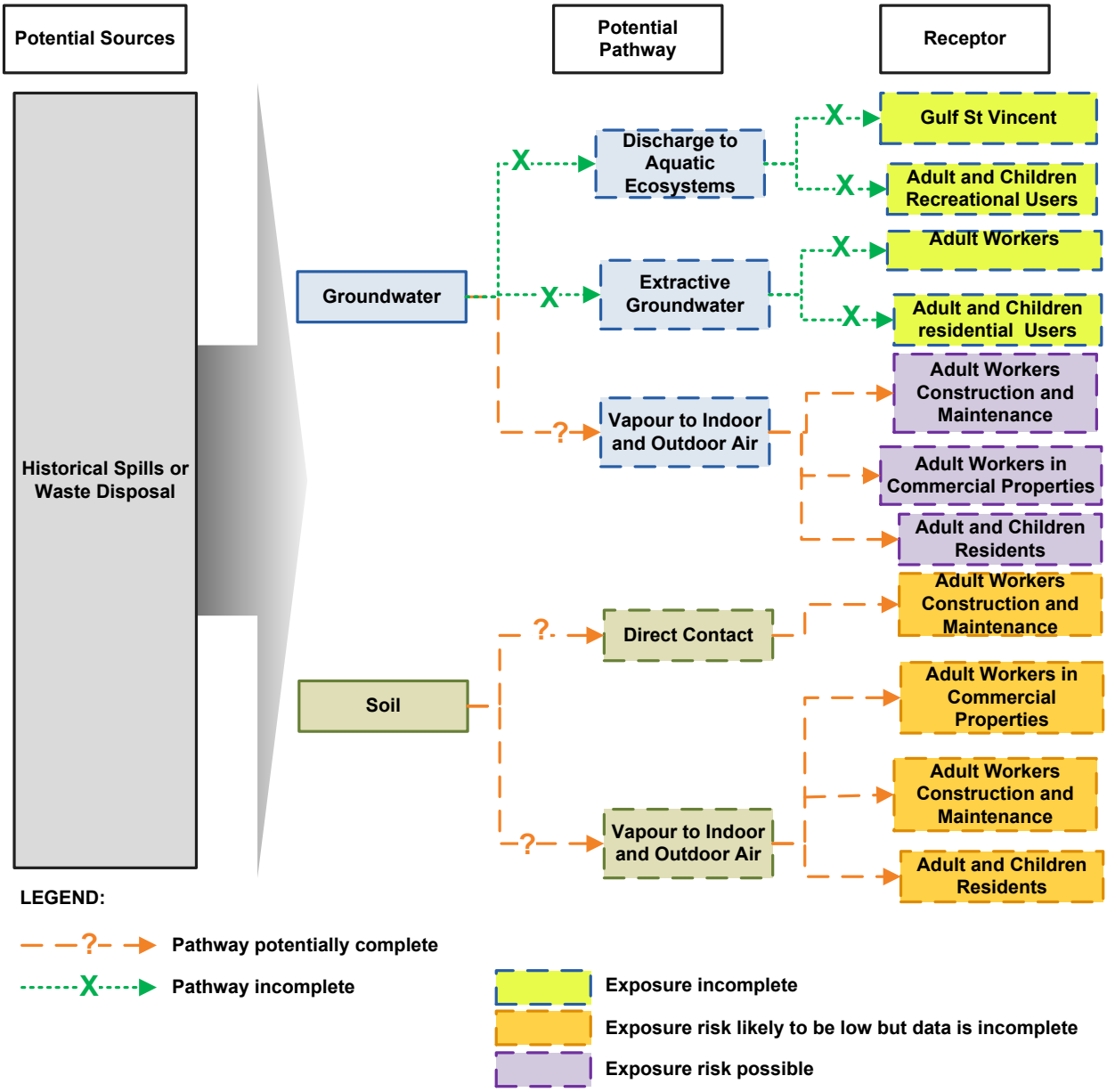
The closest potential ecological receptor for groundwater is likely to be the aquatic ecosystem of Gulf St Vincent, located approximately 4 km west of the site. Terrestrial organisms within soil (e.g. earthworms and burrowing animals) may also be present within residential gardens and landscaped areas within the Assessment Area and may be receptors for soil gas impacts.

4.6.2 Exposure pathways

A pathway is a means by which the identified receptors may come in contact with the identified contaminants of interest, in this case volatile chlorinated hydrocarbons. The primary exposure pathways for the identified receptors are as follows:

- inhalation of vapours generated from soil and groundwater
- ingestion or dermal contact with contaminated groundwater extracted from within the Assessment Area
- migration of contaminants in groundwater to down hydraulic gradient receiving water bodies (Gulf St Vincent).

A summary of potential sources and exposure pathways is presented below.



The exposure pathway from extractive groundwater use is considered incomplete based on the previous advice provided to landowners in the Assessment Area not to utilise groundwater and the availability of reticulated mains water.

Due to the significant distance from the site to Gulf St Vincent it is not considered that groundwater contamination from the Assessment Area will migrate this distance in the short term, therefore this exposure pathway is also currently considered incomplete.

The primary contaminant pathway of concern is volatilisation to indoor air, where vapours may accumulate and present a health risk from inhalation. Volatilisation to outdoor air is not considered to be a significant concern due to the rapid dilution of contaminant concentrations in the open air environment.

Although volatile chlorinated hydrocarbon contamination of soil has not been identified by the assessment undertaken, there is limited information available regarding specific contaminants source areas, therefore the presence of residual soil contamination in some portions of the Assessment Area cannot be ruled out.

4.6.2.1 Groundwater contaminant migration

It is expected that dissolved phase chlorinated hydrocarbons in groundwater will migrate in the direction of the hydraulic gradient (i.e. in a general westerly direction) from the source area. The contaminant concentrations may decline with distance from the source based on factors such as dispersion, source characteristics (i.e. constant or finite), and degradation of the chlorinated hydrocarbons.

The 2016 JBS&G Assessment included development of a steady state groundwater fate and transport model to assess the long-term migration of TCE-impacted groundwater. This model incorporated several assumptions, including the absence of dense, non-aqueous phase liquids (DNAPL), that no active dehalogenation of TCE was occurring, and that key factors determining TCE concentrations with time were limited to advection and dispersion processes. As the likely contaminant sources were unknown, plume distribution within the model was calibrated using reported groundwater concentrations from 2008, 2015, and 2016.

The model was run over a 100 year period, and predicted that current TCE plumes would continue to migrate to the west and northwest approximately 450 m beyond the extent of the current Assessment Area. It is noted that the limited time series data available may pose a limitation to model accuracy. Should data on source zone characteristics or additional temporal data become available in the future, additional modelling should be undertaken to refine migration estimates.

4.6.2.2 Potential preferential pathways

The key potential preferential pathways for soil vapour migration identified within the Assessment Area include trenched services, in particular stormwater and sewer, and sand lenses within the predominantly clayey soil stratigraphy.

As the Assessment Area is within an urban environment, there is a high potential that trenched services are intersecting areas impacted with TCE in the groundwater and/or soil vapour, thus providing potential preferential pathways for soil vapour to migrate. Stormwater and sewer plans within the Assessment Area have been previously presented in the Golder 2015 Assessment Report. The sewer depth within the Eastern portion of the Assessment Area is known to typically be in the order of 1.5 to 3.1 m deep along West Street, around 4 m deep along Main Street and between 2.6 and 3.1 m deep along William Street. It is noted that the sewer along Main Street is not reported to be connected to the sewer beneath West Street. The sewers along West and William Street are understood to have been constructed in approximately 1934, and therefore are most likely made from vitreous clay construction.

Given the depth to groundwater and the sewer depth within the Assessment Area, it is considered unlikely that service trenches provide preferential pathways for migration of contaminants within groundwater; however they may act as conduits for vapour migration. It is also possible that historic disposal of industrial waste to sewer, and subsequent sewer leakage, could potentially have led to the sewer lines being secondary sources of soil vapour and/or groundwater contamination. However, there is currently no evidence available to confirm whether this has occurred. No vapour sampling within the sewer lines has been undertaken to date, therefore there remains a potential that sewer lines could form preferential migration pathways.

The limited data collected from sampling of telecommunications pits and stormwater drain pits within the Assessment Area (Golder 2015b) has not identified any significant preferential vapour migration pathways within these services. It is possible, however, that service penetrations into buildings may provide a preferential vapour migration pathway from sub-surface soil into the buildings.

Although the subsurface lithology between the Q1 aquifer and ground surface is predominantly fine grained clay and sandy clay materials, some sand and clayey sand lenses have been observed within recent and historical boreholes. Sand and clayey sand lenses identified within cores samples from the 2015 and 2016 assessments are illustrated in Figures 4A and 4B. Those identified in the 2016 Golder Assessment are also detailed in the bore logs provided as Appendix A. Sand lenses may present localised preferential migration pathways for contaminant migration, and sandy soil at a depth of approximately 4.1 to 4.5 m bgl was encountered in the eastern portion of the Assessment Area, correlating to the area of highest reported TCE concentrations in soil vapour. The southern and northern extent of this sand layer has not been assessed and it is not known if this sand layer is acting as a preferential migration pathway for TCE vapour.

4.7 Summary and data gaps

4.7.1 Lateral delineation of groundwater and soil vapour impacts

Historical groundwater investigations (URS 2012) have identified elevated TCE concentrations within shallow groundwater in two portions of the Assessment Area, as indicated on the historic plume figure presented in Appendix D. One plume was located to the north east of the former appliance manufacturer site (centred around West Street) [the primary plume] and the other was located to the west of Howards Road [the secondary plume]. Recent assessments (JBS&G 2016 and Golder 2015) have identified that both plumes remain present. The southern and western extents of the primary plume are well-characterised; however this plume remains un-delineated to the north-east and north-west. The northern, southern, and western extents of the secondary plume have been reasonably delineated to the west by wells on Wodonga Street and Ledger Road; however the eastern extent of this plume remains un-delineated. The zero boundary of TCE concentrations in groundwater has not been delineated in any direction for these plumes; however it is considered that the TCE concentrations in groundwater are reasonably delineated for the purposes of assessing vapour intrusion risks within the Assessment Area.

A tertiary plume is located at the intersection of Fife Street and Haynes Crescent, and was identified based on data from a single monitoring well reported in the JBS&G Assessment Report. These impacts may be associated with the secondary plume; however based on soil vapour data it appears more likely that a tertiary source is present at an unknown location east of Haynes Crescent. This plume has not been delineated in any direction, and was not included within the scope of the 2016 Golder Assessment.

In general, the extent of soil vapour impacts is consistent with that of groundwater impacts. Soil vapour assessments undertaken by Golder in 2015 and 2016 have reasonably delineated the lateral extent of significantly elevated TCE concentrations in shallow soil vapour within the Assessment Area, with the exception of the following areas:

- the industrial area west of Charles Road and east of Howards Road (associated with the primary groundwater plume)
- the northern portion of the area between Wodonga Street and Howards Road, immediately south of Woolgina Street, and the southern portion of the area between Ledger Street and Wodonga Street, immediately north of the south boundary of the Assessment area (associated with the secondary groundwater plume)
- the north-west portion of the Assessment Area, in the vicinity of the intersection of Fife Street and Haynes Crescent (associated with the tertiary groundwater plume).

The lateral extent of elevated soil vapour outside the Assessment Area to the north–east and north-west is unknown, and is considered to present a significant data gap.

4.7.2 Vertical delineation of groundwater impacts

The TCE concentrations observed in GW80 (installed in the deeper Q2 aquifer) during historical investigations (URS 2012) suggest that TCE contamination has migrated vertically into the Q2 aquifer. Historical sampling of groundwater from the deeper tertiary aquifer has not identified any TCE within this aquifer (URS 2012). No further assessment of the vertical extent of chlorinated hydrocarbon contamination within the Assessment Area has been undertaken.

The extent of chlorinated hydrocarbon impacts within the Q2 aquifer and the presence and extent of impacts in the deeper quaternary aquifers is not known.

4.7.3 Contaminant sources

The locations of greatest identified TCE soil vapour impacts in the Assessment Area are concentrated along the following locations:

- three locations associated with the primary groundwater plume
  - the south side of West Street, between Charles Road and Main Street
  - Main Street, north of West Street
  - William Street, between West Street and approximately 50 m to the south
- one location associated with the secondary groundwater plume
  - between Wodonga Street and Howards Road, approximately 60 m south of Woolgina Street.

Based on this distribution it is inferred that at least two, and likely more, sources of impact exist within or hydraulically up-gradient of the Assessment Area. Given the generally lower concentrations of TCE identified by 2016 groundwater monitoring (JBS&G 2016) compared with historic monitoring (URS 2012), it is likely that the primary sources are historic in nature, and unlikely to be ongoing. Identification of specific source sites is beyond the scope of the investigations completed, however based on the works undertaken possible source zones could include:

- industrial properties to the North-East of Port Road
- current or former industrial properties within the north-eastern portion of the Assessment Area
- several small industrial properties within the Assessment Area, including manufacturing facilities, crash repairers and rug cleaners
- industrial properties between Pope Street and Wodonga Street
- the former appliance manufacturer site on Pope street (however considered unlikely based on the DRA Report for this property (URS 2012)
- the ‘pughole’ area on West Street (although soil vapour investigations within the central and eastern portions of this pughole have identified lower TCE soil vapour concentrations than recorded beneath West Street, suggesting that the pughole may not be a significant source area).

The relatively linear nature of impacts along West Street suggests the possible influence of the sewer or other historic underground infrastructure along this street as a potential secondary source, and/or migration pathway for TCE impacts from possible sources to the north-east.

4.7.4 Contaminant migration and concentration trends

Temporal data with which to assess contaminant concentration trends is limited to a small number of groundwater wells from 2007-2016 and soil vapour data from 2015 to 2016.

Concentrations of TCE in groundwater appear to have generally decreased between 2007 and 2015. Minor variability in groundwater TCE concentrations has been recorded between 2015 and 2016, within the same order of magnitude, with no significant increasing or decreasing trends identified across the Assessment Area. Groundwater fate and transport modelling was presented in the JBS&G Assessment Report. This model predicted that over a 100 year period, the TCE plumes would continue to migrate to the west and northwest approximately 450 m beyond the extent of the current Assessment Area. It is noted that due to the limited time series data available, the contaminant migration model is considered to be of low-confidence and may be overly conservative. Further time series data of groundwater concentrations is required to allow a more refined assessment of future migration or degradation of the identified TCE plumes in groundwater.

Concentrations of soil vapour have also reported minor variability but remained within the same order of magnitude. In general, concentrations of soil vapour reported in the JBS&G Assessment Report were generally similar to those in the Golder 2015 Assessment, while soil vapour data from the Golder 2016 Assessment was generally elevated from that of 2015 across most sampling locations. It is noted that the 2015 Assessment was conducted in winter, while the 2016 Assessment was conducted in autumn. The increased concentrations reported in the 2016 Golder Assessment may therefore represent seasonal variations in vapour migration due to increased temperatures and decreased soil moisture relative to the winter 2015 event. Additional soil vapour monitoring during warmer and drier periods would be beneficial to assess this possible variation.

Indoor air samples were collected from five occupied residences previously sampled in the Golder 2015 Assessment. Reported 2016 concentrations of TCE were slightly decreased from those in 2015 at two residences, generally similar in the third, and displayed conflicting trends in the fourth (reported concentrations slightly increased in one room, slightly decreased in a second, and were generally similar in other rooms). Reported 2016 TCE concentrations in the fifth residence (Property 7) were generally an order of magnitude lower than those reported in 2015. This suggests that temporal variation in concentrations may be greater at some locations within the Assessment Area than others, and is likely influenced by the construction details of each property.

Replicate indoor air sampling was conducted under unoccupied conditions at two residences (Property 7 and Property 17) which had reported concentrations of TCE in indoor air exceeding 20 $\mu g/m^3$ under occupied conditions. Reported unoccupied TCE concentrations at Property 17 were generally similar to occupied conditions, while unoccupied concentrations at Property 7 were approximately one order of magnitude greater. It is anticipated that the magnification effect to vapour concentrations within unoccupied buildings will be highly variable and dependent upon the construction details of each property. It is also possible that the variation observed at Property 7 may be partially attributable to temporal variation between sampling events, which has been found to be high at this residence. Additional replicate indoor air sampling at unoccupied properties would be beneficial to assess the variation in the vapour concentrations attributed to reduced building ventilation (i.e unoccupied vs occupied condition).

4.7.5 Pathways for vapour migration into buildings

The assessment carried out to date has identified elevated concentrations of TCE within sub-slab and crawl space vapour beneath 16 of the 18 residences within the Assessment Area for which sub-floor sampling was conducted. Indoor air sampling has also identified elevated concentrations of TCE within the nine residential properties for which indoor air was assessed.

Further field investigation of vapour migration from the sub-floor areas into buildings is required to characterise vapour migration from the sub-floor to indoor air. It is possible that preferential pathways between the sub-floor areas and indoor air may exist through cracks in the floor or through floor penetrations for services. It is anticipated that vapour migration will be dependent on specific building construction as well as these preferential migration pathways.

4.8 Conceptual site model summary

Based on the investigations completed at least two plumes of chlorinated hydrocarbon (predominantly TCE) contamination of shallow groundwater exist within the Assessment Area, with a third potential plume identified on the northwest boundary of the Assessment Area:

- The primary plume is located in the north-eastern portion of the Assessment Area. The source this plume has not been established; however it appears likely that at least two sources have contributed to the plume. One source appears to originate to the north-east of Port Road or near the north-eastern boundary of the Assessment Area, while a second appears to originate near the intersection of West Street and Williams Street.
- A secondary plume is located in the western portion of the Assessment Area. The source of this plume has not been established; however it appears likely to originate in or near the industrial area between Pope Street and Wodonga Street.
- A tertiary plume is located at the intersection of Fife Street and Haynes Crescent, and was identified based on data from a single monitoring well reported in the JBS&G Assessment Report. These impacts may be associated with the secondary plume; however based on soil vapour data it appears more likely that a tertiary source is present at an unknown location east of Haynes Crescent. Investigation of soil vapour in the vicinity of the tertiary plume was not included within the scope of the 2016 Golder Assessment.

The lateral extent of groundwater impacts within the Assessment Area has not been fully defined, particular to the north-east and northwest of the primary plume, to the east of the secondary plume, and in all directions around the tertiary plume. TCE impacts within the Assessment area have previously been identified in deeper groundwater (the inferred Q2 aquifer); however the deep tertiary aquifer has not recorded elevated TCE concentrations at the one location sampled (URS 2012). The vertical extent of TCE impacts in deeper quaternary aquifers has not been defined.

Soil vapour impacts from TCE, inferred to be associated with the groundwater impacts, have been recorded in portions of the Assessment Area and have been reasonably well defined, with the exception of the following areas:

- One area associated with the primary plume: the industrial area west of Charles Road and east of Howards Road
- Two areas associated with the secondary plume: the northern portion of the area between Wodonga Street and Howards Road, immediately south of Woolgina Street, and the southern portion of the area between Ledger Street and Wodonga Street, immediately north of the south boundary of the Assessment area
- One area associated with the tertiary plume: the northwest portion of the Assessment Area, in the vicinity of the intersection of Fife Street and Haynes Crescent.

Attenuation of vapour from underlying groundwater to shallow soil has been shown to be relatively minor, therefore elevated TCE concentrations have been recorded in shallow soil vapour, sub-slab, crawl space, and indoor air samples collected from selected residential properties.

As assessment of potential contaminant exposure pathways in the Assessment Area indicates that the vapour intrusion pathway for workers and residents within the Assessment Area is complete and requires further evaluation. In addition, the lateral extent of TCE impacts in the areas identified above have not been fully delineated; therefore consideration of further evaluation of potential exposure risks in these areas is warranted.

It is considered that the previously issued advice to not extract and utilise groundwater from the Assessment Area remains valid. Given the potential for contaminant plume migration in a westerly direction with the direction of groundwater flow, the precise westerly extent of the area for which this advice should apply has not been confirmed. Further temporal monitoring of groundwater is required to enable refinement of the contaminant migration model.

5.0 VAPOUR INTRUSION RISK ASSESSMENT

5.1 Scope of works

The VIA scope of works included the following:

- review of environmental investigation data including the observations and results of samples of groundwater, soil, soil vapour, crawl-space air, ambient (surface) air and indoor air
- review of observations regarding building types and land uses present within the Assessment Area and in particular the building foundation types
- identification of COI requiring assessment based on the results of environmental sampling works
- preparation of vapour migration and intrusion models in consideration of the site conditions (geology and hydrogeology) and in consideration of residential building types indicated to be present in the Assessment Area
- estimation of an attenuation factor (α) for the adopted COI for assessment of each vapour migration and intrusion pathway from soil vapour
- verification of estimated vapour attenuation factors against attenuation indicated by vapour concentrations reported during environmental investigation works and revision and adjustment of the proposed vapour attenuation factors based on the results of the environmental investigation works
- estimation of vapour attenuation factors, in consideration of model results, site sample data and published generic attenuation factors, for application in the HHRA and assessment of the potential for vapour concentrations to exceed management guidelines.

5.2 Assessment methodology

The VIA was undertaken following the general principles and methodology as provided in the National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPC, 2013) and with reference to other applicable Australian guidance including the Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth, 2012). Where data or assessment parameters were not available from site investigation works or from Australian sources, reference was made to guidance issued by the United States EPA.

The outline approach followed for the VIA is presented in Image 8 below.

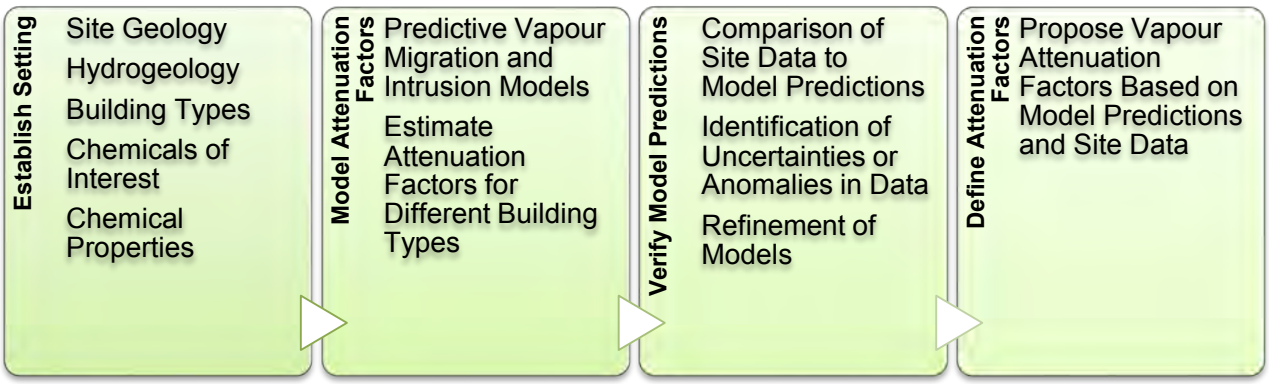


Image 8: Vapour Intrusion Assessment - Outline Approach

The site investigation data used to complete the VIA was sourced from reports prepared for previous stages of investigation and sampling works (Golder 2015a, 2015b, 2015c, 2015d, 2016), from the CSM compiled from these investigation works (Golder, 2015e), and from additional site investigation and sampling data obtained during verification works in 2016 (refer to Section 4).

In order to estimate the potential indoor air concentration of a volatile chemical identified in groundwater or soil vapour, an attenuation factor (designated "α") is required. The attenuation factor represents the change in concentration between the measured environmental location (such as a deep soil vapour sample) and the indoor air environment. The attenuation factor represents a number of different processes that may occur to reduce the concentration of the chemical, including biological degradation, dispersion, dilution and adsorption to soil particles. The routinely adopted approaches available to estimate the degree of attenuation are:

- application of published generic attenuation factors derived from databases of site sampling results collated from a range of chemicals, geology and building types
- modelling of vapour migration using measured or estimated site specific soil and building parameters
- collection and analysis of groundwater, soil vapour and ambient air samples and estimation of attenuation factors based on inferred changes in measured concentrations at different points in the vapour migration pathway.

The methodology adopted for the VIA has included consideration of each of the three approaches noted above.

Based on the CSM, identified COI and property (building) types, predictive vapour intrusion models were prepared to estimate attenuation (migration) of volatile chemicals from soil vapour at different depths and from ambient air samples immediately below building structures (crawl space samples), into overlying buildings. Whilst attenuation factors from groundwater were considered during review of site sampling data, they were not applied in the VIA or HHRA as soil vapour and ambient air samples were adopted as being more representative of site conditions and potential for health risk.

The estimated attenuation factors were then reviewed against the results of vapour sample analysis to assess the accuracy of the models.

The attenuation factors estimated by modelling and the attenuation factors inferred from the results of vapour sample analysis were then reviewed against published generic attenuation factors (obtained from multi-site databases), to assess consistency with conclusions from international data.

Proposed attenuation factors were then selected for use in the HHRA based on the review of the complete modelling and site investigation data set.

Whilst a multiple lines of evidence approach was used, the primary data used for the VIA and HHRA were the sample analysis results from shallow and medium depth soil vapour including sub slab samples (obtained from soil material immediately below the foundation concrete) and crawl space samples. These sample results represent the concentrations in closest proximity to receptors (overlying buildings) with a lower degree of uncertainty due to partitioning from groundwater and from migration through deeper soil profiles.

5.3 Vapour intrusion setting

5.3.1 Identification of COI drivers of health risk

The COI targeted for consideration within the Beverly Assessment Area were based upon the original scope request and included "*TCE and other chlorinated hydrocarbons*". Review of the available results of soil, groundwater and soil vapour sampling (Golder, 2015e) indicated detection of the volatile chlorinated hydrocarbons (referred to as volatile halogenated compounds or VHC), as summarised in Table 16:

Table 16: Summary of Volatile Halogenated Compounds Detected in Media at Assessment Area

Volatile Halogenated Compounds	Groundwater	Soil	Active Soil Vapour
Tetrachloroethene (PCE)	☑	☐	☑
Trichloroethene (TCE)	☑	☐	☑
cis-1,2-dichloroethene	☑	☐	☑
trans-1,2-dichloroethene	☑	☐	☐
1,1-dichloroethene	☑	☐	☐
Vinyl chloride	☐	☐	☐
Chloroform	☑	☐	☑
1,1,2-trichloroethane	☑	☐	☐
1,2-dichloroethane	☑	☐	☐
1,2-dichloropropane	☑	☐	☐
Freon 11 (trichlorofluoromethane)	☐	☐	☑

☑ - Detected in Media; ☐ - Not Detected

Sample analysis results are presented in the 2015 Conceptual Site Model report (Golder, 2015e)

Passive soil vapour (PSV) samples were also obtained from shallow soil within the Assessment Area during the Stage 2 assessment works (Golder, 2015b).The objective of the PSV sampling was to assess the potential extent and spatial distribution of chemicals in soil vapour and to assist in the selection of future active soil vapour (ASV) sample locations. PSV sampling devices rely on understanding of the rate at which chemicals are adsorbed into the device and the assumption that absorption is continuous over the sampling duration. For soil vapour sampling, the area around the device may become 'starved' of vapour where the absorption rate is higher than the rate at which vapour is replenished or reduced absorption may occur due to obstruction by soil particles or soil moisture.

Note that passive air sampling devices were also used in sampling crawl space and indoor air for comparison with ASV methods. For ambient air (indoor, outdoor or crawl space) the passive sampling methodologies adopted for the Assessment Area are considered appropriate.

Golder considers the PSV data to be semi-quantitative due to potential for variability in absorption rates and efficiency, with a higher degree of uncertainty in reported concentrations in comparison with ASV data. Therefore the PSV data has not been used to define COI or concentrations of COI for the assessment.

Whilst a number of chlorinated hydrocarbons were detected in environmental samples, TCE represented the majority of detected VHC in any sample. TCE accounted for greater than 98% of total VHC reported in groundwater samples with the exception of well MW04 where it accounted for 88% of total VHC and cis-1,2-dichloroethene accounted for approximately 11% of total VHC.

In soil vapour, TCE typically accounted for greater than 97% of total VHC reported in ASV samples. With the exception of one ASV sample during 2015 monitoring (from location SV26-S) and one ASV sample during 2016 monitoring (from location SV50-S), TCE accounted for greater than 87% of total VHC reported in all ASV samples and concentrations of TCE were typically more than one order of magnitude (factor of 10) higher than any other reported VHC. At location SV26-S in 2015 sampling, TCE accounted for 67% of total reported VHC. The only other VHC reported at location SV26-S was chloroform. Location SV26-S is inferred to be at the southern margin of the impacted area and the reported concentration of TCE was low relative to other ASV samples through the Assessment Area. At location SV50-S in 2016 sampling, TCE accounted for 81% of the total chlorinated ethenes with PCE accounting for approximately 15% of the total. The reported concentration of TCE at SV50-S was low relative to other ASV samples throughout the Assessment Area and PCE is less volatile and of lower toxicity than TCE.

In consideration of the relative toxicity and volatility of the VHC reported in groundwater and soil vapour, and of the relative proportion of each VHC reported in environmental samples, TCE was indicated to be the primary driver of health risk for the Assessment Area. TCE was adopted as the COI for the VIA and HHRA. Golder anticipate that potential health risks due to other reported VHC will be lower than for TCE and, in consideration of the lower concentrations of other VHC, that assessment of TCE will also be sufficient to assess potential health risks due to the combined VHC mixture.

5.3.2 Review of property (building) types

Review of the local land use patterns and building structures indicated the Assessment Area is comprised of a mixture of commercial/industrial and residential property (Golder, 2015e). The primary land use of interest for the VIA and HHRA was residential dwellings as these are anticipated to provide the most sensitive human health receptors based on age of occupants (i.e. young children), occupancy times (hours per day) and occupancy duration (years present within the Assessment Area).

The review indicated that residential buildings within the Assessment Area were typically single storey of between 40 to 100 years age. Predominantly brick and masonry construction buildings were observed although some timber or fibre/cement sheeting buildings were also present. Inspection of a selection of properties within the Assessment Area indicated timber suspended floors (crawl space) and concrete slab on grade foundations. Combination foundations with older crawl space constructions and newer slab on grade foundations as part of the same building were also reported. Two properties were identified where small basement or cellar levels were present. The frequency of basement levels at property within the Assessment Area is not known.

A detailed inspection and review of the relative proportion (frequency) of building types in the Assessment Area was not undertaken. However, the primary construction types as noted in the review and adopted for the VIA and HHRA were:

- suspended timber floor with crawl space
- concrete slab on grade foundation
- combination foundation with both suspended timber floor and concrete slab on grade sections.

Consideration was also made for a basement or cellar level within residential property during the HHRA.

5.3.3 Adopted soil properties for vapour intrusion modelling

The moisture content of soil samples obtained in February 2016 was generally within the range of values reported during previous works but lower (drier) than the averages of previous data. The February 2016 data may be representative of drier seasonal conditions in comparison with the previous data from May 2015. As the February 2016 data was based on a small number of locations (two soil boreholes) the February 2016 data may not be as representative of the Assessment Area vapour intrusion conceptual model in comparison with the larger data set available from May 2015 sampling. However, the average moisture content data from both the February 2016 sampling and the May 2015 sampling were considered for use in the vapour intrusion model.

Adopted soil properties for vapour intrusion modelling were selected following review of the results from geotechnical testing of soil samples. The results of geotechnical testing indicated soil material at shallower depths (0 to 2 m bgl) to have (broadly) higher total porosity and lower moisture content than deeper soil. Near-surface soil vapour samples are anticipated to provide a more reliable estimate of vapour risks than deeper soil vapour samples and the near-surface soil profile is anticipated to be a primary controlling factor for migration and risk due to vapour arising from groundwater impacts. Adopted soil properties were therefore based on the results of geotechnical testing at depths from 0 to 1 m bgl and from 1 to 2 m bgl.

The soil moisture content was adopted as the lowest (conservative) value from either (a) the average moisture content reported from May 2015 data, or (b) the average moisture content reported from February 2016 data. The average moisture content values from February 2016 data were lower (conservative) for both soil profile depth ranges and were therefore adopted for the vapour intrusion model.

The dry bulk density and particle density were adopted from the data applicable to the adopted moisture content. The adopted soil properties are summarised in Table 17.

Table 17: Adopted Soil Properties for Vapour Intrusion Modelling

Adopted Soil Profile Depth Range (m bgl)	Lowest of 2015 Average and 2016 Average Moisture Contents (% mass)	Adopted Moisture Content (% volume)	Dry Bulk Density (tonnes/m^3)	APD 2.36 (g/cm^3)	Estimated Porosity (unitless)
0 - 1	6.8	10.1	1.44	2.67	0.46
> 1	12.1	17.9	1.44	2.71	0.47

In Table 17, the volumetric moisture content was estimated from the adopted minimum moisture content from sample testing (% moisture by mass) and assuming a dry density of 1.44 tonnes/m^3 based on soil testing results from 1 to 2 metres depth. The soil porosity was estimated from the dry bulk density and apparent particle density from soil testing results of samples from 0 to 1 and from 1 to 2 metres depth. The adopted porosity value is anticipated to be conservative for deeper soil profiles with estimated values, based on testing results for soil from 2 to 7 metres depth ranging from 0.38 to 0.45.

5.4 Vapour intrusion model

5.4.1 Model used

Estimation of vapour attenuation factors for TCE was completed using the model prepared by the US EPA (2004). The US EPA vapour intrusion model was developed from the one-dimensional analytical solution to convective and diffusion movement of vapour published by Johnson and Ettinger (1991). The Johnson and Ettinger model has been widely reviewed and adopted by international agencies and was used in the development of petroleum hydrocarbon health screening levels (HSL) adopted in the ASC NEPM.

Review of the Johnson and Ettinger model was undertaken by CRC CARE (2009) and by Hers et al. (2003), and noted the model was (broadly) conservative with a potential to over-estimate vapour levels. Whilst the CRC CARE (2009) review principally concerned petroleum hydrocarbon vapour, Golder consider the conclusions and the Hers et al. (2003) review to be applicable to other volatile organic chemicals including the VHC identified in the Assessment Area.

The model (US EPA, 2004), provides an estimate of the vapour attenuation factor (α), being the ratio of predicted vapour concentration in an overlying building to the vapour concentration in underlying soil.

5.4.2 Model parameters adopted

In addition to the soil properties noted in Section 5.3.3, a range of building-specific model parameters were adopted. Models were developed for the two primary building construction types observed in the Assessment Area, concrete slab on grade foundation and timber suspended floor with crawl space. For buildings with combinations of the two foundation types, the respective models would be applicable to each section of the building.

Golder note the Johnson and Ettinger model does not include the facility to directly model a crawl space foundation. The model was modified by selection of parameters to simulate the effects of a crawl space, including a foundation thickness of zero and assumption that the entire floor area was comprised of open 'crack'. Some of the resulting parameters calculated by the model (Appendix F) are not realistic (such as soil vapour flow rate into the building). However, these parameters do not influence the resulting estimated attenuation factors. Further assessment of the vapour migration pathway for crawl space buildings was undertaken by reference to site sampling and analysis data (Section 5.5.2).

The building and other parameters adopted for the two model scenario are summarised in Table 18.

Table 18: Summary of Vapour Intrusion Model Parameters

Model Parameter	Adopted Value Slab on Grade Building	Adopted Value Crawl Space Building	Source
Building Length (m)	15	15	Within range for average floor areas, houses and other residential buildings (enHealth, 2012), and consistent with observations of buildings within the Assessment Area.
Building Width (m)	10	10	
Building Ceiling Height (m)	2.4	2.4	enHealth (2012) and consistent with or conservative (low) based on observations of buildings within the Assessment Area.
Foundation Slab Thickness (m)	0.1	0	AS 2870-2011 (2011) and consistent with CRC CARE (2011)
Foundation Depth Below Ground Surface (m)	0.1	0	Foundation slab thickness.
Air Exchange Rate (per hour)	0.6	0.6	enHealth (2012) and anticipated to be conservative (low) for older residential structures observed within the Assessment Area.
Foundation Crack Width (cm)	0.3	300	Wall to floor seam crack width. For slab on grade, adopted as 0.1% of total foundation area. For crawl space, adopted as 100% of foundation area.
Q_{SOIL} : $Q_{BUILDING}$ (unitless)	0.0027	1	Ratio of vapour flow rate through foundation to air flow rate through building. For slab on grade, adopted value based on 50th percentile sub slab to indoor air attenuation factor from US EPA (2012) database considering all residential buildings. The 50th percentile value from the US EPA database was adopted in consideration of the results of sub slab and indoor air sampling data from the Assessment Area that indicated attenuation factors in the order of 0.00015 to 0.0011 based on combined 2015 and 2016 data (Refer Section 5.5.1). For crawl space, adopted on the assumption that crawl space and indoor air are in equilibrium and consistent with the 95th percentile attenuation factor of 0.9 for crawl space buildings from US EPA (2012). The results of crawl space and associated indoor air sampling from the Assessment Area indicated an attenuation factor of 1 may be conservative for the majority of buildings sampled (Refer Section 5.5.2)

As noted in Section 5.3.3, a detailed review of all buildings within the Assessment Area has not been completed. Residential buildings with basements or other below-ground accessible spaces (such as cellars) were noted during environmental investigation works (two properties) but such buildings were not inferred to be representative of the majority of buildings within the Assessment Area. Vapour intrusion models for basement-type structures are anticipated to be highly property-specific and a generic scenario model would require a number of additional assumptions regarding construction and occupancy. Basement-type structures have been considered with reference to the available site data in the VIA (Section **5.5.3**) and a property specific assessment is provided in the HHRA based on the results of indoor air sampling.

The adopted COI for the VIA and HHRA is TCE in consideration of toxicity, volatility and reported concentrations in soil, groundwater, soil vapour and ambient air in the Assessment Area in comparison with other chlorinated hydrocarbons.

The adopted properties of TCE for the vapour intrusion model are summarised in Table 19.

Table 19: Summary of Chemical Properties for Vapour Intrusion Model

Property	Adopted Value	Source
Chemical of Interest	TCE	Section 5.3.1
Molecular Weight (g/mol)	131.39	RAIS (2015)
Diffusivity in Air (cm^2/s)	6.87E-02	RAIS (2015)
Diffusivity in Water (cm^2/s)	1.02E-05	RAIS (2015)
Henry's Law Constant (atm m^3/mol)	9.85E-03	RAIS (2015) at 25 degrees C
Henry's Law Constant (unitless)	0.403	RAIS (2015) at 25 degrees C

The vapour intrusion model was developed for both concrete slab on grade foundation building type and for a timber suspended floor with crawl space building type. For each building type, the depth of the soil vapour 'source' was modelled to correspond with the approximate depths at which soil vapour samples had been obtained during site investigation works. Vapour intrusion models were developed for each of the following building types and depths below ground surface:

- Slab on Grade Building: Sub Slab (0 m); 0.85 m; 1.85 m; 3.85 m; 6.35m.
- Crawl Space Building: 0.85 m; 1.85 m; 3.85 m; 6.35m.

A vapour intrusion model was not developed for basement rooms. Such a model would be highly dependent upon site specific construction parameters (including as floor and wall materials and integrity, room dimensions, presence of ventilation and presence of house infrastructure such as a heating systems); the degree of connection to the overlying house (open stairway, door or trapdoor); and the frequency of usage of the room. A generic vapour intrusion model for a theoretical basement room is anticipated to be highly conservative for the majority of properties and not representative of potential risk. Golder consider that property-specific review and assessment is an appropriate process for identifying and managing potential vapour risks for basement rooms.

The results of the model for each building and depth scenario are presented in the following section.

5.4.3 Model results

The model input parameters and estimated vapour attenuation factor ("α") for each building type and depth scenario are provided in Appendix F.

A summary of the estimated vapour attenuation factor for each model scenario is provided in Table 20.

Table 20: Summary of Vapour Intrusion Model – Estimated Attenuation Factors

Soil Vapour Source Depth (m)	Estimated Vapour Attenuation Factor "α" - Concrete Slab on Grade (unitless)	Estimated Vapour Attenuation Factor "α" - Timber Suspended Floor, Crawl Space (unitless)
0 (Sub Slab)	2.7 E-03	See Note Below
0.85	1.5 E-03	3.1 E-03
1.85	7.3 E-04	9.6 E-04
3.85	3.4 E-04	3.8 E-04
6.35	2.0 E-04	2.2 E-04

Note – An attenuation factor was not estimated for vapour from within a crawl space to overlying indoor air. The scenario assumed that crawl space and indoor air were in equilibrium and that limited attenuation occurs (effectively α=1) through the suspended floor. In reality, a degree of attenuation is anticipated to occur. However, this will be subject to the specific condition of the suspended floor and nature of any floor covering or sealing.

The estimated attenuation factors for slab on grade and for crawl space buildings for deeper soil vapour (1.85 metres and deeper) are of similar magnitude (Table 20). The higher vapour permeability of a suspended timber floor is partially balanced by the increased air exchange between the crawl space and ambient (outdoor) air. As the depth below ground increases (distance between the soil vapour source and the building) diffusion through the soil becomes the more dominant factor in the attenuation process, with the building foundation type becoming less important.

5.5 Validation of vapour intrusion model

5.5.1 Consideration of soil vapour sampling data

The estimated vapour attenuation factors provided by the model (Table 20) indicate approximately double the magnitude of attenuation from soil vapour at each successive depth compared with soil vapour at sub-slab depths as follows:

- 0.85 m depth: factor of 1.8
- 1.85 m depth: factor of 2.1
- 3.85 m depth: factor of 2.1
- 6.35 m depth: factor of 1.7

Figures I1, I2 and I3 in Appendix I provide a summary of reported soil vapour concentrations at different sample depths in the Assessment Area and Figures I4 (2015 data) and I6 (2016 data) provide a summary of reported sub slab soil vapour concentrations and associated indoor air concentrations. The methodology and results of the sampling works have been reported under separate cover for 2015 works (Golder 2015a, 2015b, 2015c, 2015d, 2016) and are reported in Section 3 for the 2016 Assessment. For clarity, where a sub slab sampling location did not have an associated deeper soil vapour sample, the sub slab sampling location has been excluded from Figures I1, I2 and I3.

Of five sub slab samples obtained during 2016 Assessment with associated deeper soil vapour sample data, four samples reported concentrations approximately consistent with or higher than associated deeper soil vapour samples; and therefore indicated an attenuation factor equal to or greater than one.

Table 21 provides a summary of the approximate attenuation between soil vapour at different depths, based upon both the modelled attenuation factors (from Table 20), and the results of soil vapour sample analysis (from Figures I1, I2, I3, I4, and I6, Appendix I).

Table 21: Attenuation Factors with Depth – Vapour Intrusion Model and Soil Vapour Sample Results

Soil Vapour Depth Range (m)	Attenuation Between Soil Depths From Modelled "α" Values (unitless)	Attenuation Between Soil Depths From 2015 and 2016 Soil Vapour Sample Results			
		No. of Data Pairs 2015 Data	Minimum 2015 Data (unitless)	Maximum 2015 Data (unitless)	Average 2015 Data (unitless)
Sub Slab to Indoor	0.0027	6	0.00018	0.0011	0.00055
0.85m to Sub Slab	0.56	11	0.03	0.68	0.37
1.85m to 0.85m	0.49	4	0.41	0.67	0.53
3.85m to 1.85m	0.47	9	0.21	0.65	0.40
6.35m to 3.85m	0.59	2	0.10	0.96	0.53
		No. of Data Pairs 2016 Data	**Minimum 2016 Data** (unitless)	**Maximum 2016 Data** (unitless)	**Average 2016 Data** (unitless)
Sub Slab to Indoor	0.0027	6	0.00015	0.00088	0.00031
0.85m to Sub Slab	0.56	1	NA	NA	0.71
1.85m to 0.85m	0.49	20	0.0009	0.84	0.31
3.85m to 1.85m	0.47	10	0.22	0.67	0.42
6.35m to 3.85m	0.59	0	NA	NA	NA

Modelled attenuation factors between soil layers taken as the difference between modelled "α" values at different soil source depths for the concrete slab on grade building type.

Attenuation values equal to 1 or greater in soil vapour sample results (12 data points) have been excluded from the listed values.

Review of soil vapour sampling data obtained from different depths indicated that:

- The degree of attenuation indicated by field sampling results range by up to three orders of magnitude (i.e. between minimum and maximum values).
- The estimated attenuation between sub slab and indoor air as indicated from the vapour intrusion model was higher (more conservative) than the range of values reported from 2015 and 2016 sampling. Whilst the attenuation factor estimated by the vapour intrusion model was approximately one order of magnitude higher than the average of 2015 or 2016 data, the estimated attenuation factor (0.0027) was consistent with the maximum individual sample attenuation factor (40 $\mu g/m^3$ indoor air compared with 16,000 $\mu g/m^3$ sub slab, α = 0.0025).
- The estimated attenuation between soil depths as indicated from the vapour intrusion model were comparable with the average attenuation values indicated by the results of soil vapour sampling as follows:
  - The estimated attenuation between 0.85 m depth and sub slab from the soil vapour model (0.56) was higher than the average attenuation indicated by soil vapour samples over the same depth range from 2015 data (0.37) and lower than the average from 2016 data (0.71). However, it is noted the 2016 data was based on only one sample result.

- 1.85 m to 0.85 m depth range: 2015 data (0.54 average) and 2016 data (average of 0.31) were broadly comparable with modelled attenuation factor (0.49). Whilst the 2016 data was less comparable with the modelled attenuation factor than 2015 data, the 2016 data also included the largest data set (20 sample pairs) and reported the widest range of inferred attenuation factors (3 orders of magnitude between minimum and maximum values).
- 3.85 m to 1.85 m depth range: 2015 data (average 0.40) and 2016 data (average 0.42) consistent with modelled attenuation factor (0.47).
- 6.35 m to 3.85 m depth range: 2015 data (average 0.53) consistent with modelled attenuation factor (0.59). However, it is noted the 2015 data was based on only two sample results.

- Whilst the estimated attenuation between 0.85 m depth and sub slab from the soil vapour model (0.56) was higher than the average attenuation indicated from 2015 data (0.37) it was within the range of values indicated from the soil vapour samples (0.03 to 0.71 including both 2015 and 2016 data) and was considered appropriate to reflect the degree of attenuation observed in field samples.

5.5.2 Consideration of crawl space and associated soil vapour and indoor sampling data

The results of crawl space and associated soil vapour and indoor air sampling works were reviewed in comparison with the vapour attenuation factors estimated from modelling. Where appropriately located samples were available, the following data sets were reviewed:

- Soil vapour sampling results from 0.85 m bgl (and 1.05 m bgl in 2015 data) were compared against crawl space air sampling results. Crawl space air sample results, obtained by active methods (SUMMA canister) and by passive methods (sorbent media), were compared separately. Crawl space sampling during 2016 works was undertaken by active methods (SUMMA canister) only.
- Crawl space air sampling results were compared against associated indoor air sampling results where an association between the crawl space and the indoor air space could be made, i.e. where the indoor air sample location had a crawl space sample location below the room.

Property-specific sampling data (crawl space and associated soil vapour and indoor air), was only available from a selection of residential buildings (three properties during the 2015 Assessment and 13 during the 2016 Assessment), within the Assessment Area. Therefore, data may not be representative of all building types and vapour conditions present within the Assessment Area. However, Golder consider the selected buildings to provide a representative sample of the vapour intrusion scenario in the area where the potential for vapour impacts was indicated by the results of groundwater sampling (Golder, 2015a) and a passive soil vapour assessment (Golder, 2015b).

Figure I4 (2015 data) and Figure I5 (2016 data) in Appendix I provide a summary of reported crawl space concentrations (for suspended timber floor buildings), and associated soil vapour concentrations. Figure I7 (2016 data) in Appendix I provides a summary of reported crawl space concentrations (for suspended timber floors) and associated indoor air concentrations in an overlying room. The estimated degree of attenuation between the respective subsurface (soil vapour) concentrations and air (crawl space) concentrations or between crawl space air and overlying indoor air is noted in each figure and summarised in Table 22.

Table 22: Attenuation Factors, Crawl Space Buildings – Comparison of Model Estimates and Site Sampling Results

Source of Attenuation Factors	Estimated Attenuation Factors	
	Soil Vapour (0.85m Depth) to Crawl Space Air	Crawl Space Air to Indoor Air
Model Estimated (Section 5.4.3)	3.1E-03 [A]	1 [B]
Inferred from 2015 Sample Data (Active Air Sampler)	6.0E-03 to 2.2E-02 (Avg. 1.4E-02)	NA, No paired crawl space and indoor air data
Inferred from 2015 Sample Data (Passive Air Sampler)	4.0E-03 to 1.9E-02 (Avg. 1.0E-02)	NA, No paired crawl space and indoor air data
Inferred from 2016 Sample Data (Active Air Sampler Data)	1.0E-03 to 1.1E-01 (Avg. 2.3E-02)	0.04 to 0.91 (Avg. 0.37)
Inferred from 2016 Sample Data (Passive Air Sampler Data)	NA, All data via active sampling	0.05 to 0.43 (Avg. 0.19)

Note – All attenuation factors are unitless.

A – An attenuation factor from soil vapour to a crawl space air was not modelled. For modelling purposes, the attenuation factor from crawl space air to indoor air is assumed to be 1, therefore the model soil vapour to indoor air attenuation factor (3.1E-03) has been adopted to estimate attenuation to both the crawl space air and indoor air.

B – A crawl space air to indoor air attenuation factor was not modelled. Based on data from international studies (Section 5.5.4) a conservative attenuation factor of 1 was adopted on the assumption that crawl space and indoor air would be in equilibrium.

Review of crawl space and associated indoor air sampling data indicated that:

- The inferred attenuation factor between crawl space and indoor air ranged from 0.04 to 0.91 with an average of 0.30 (combined active and passive samples) based on data from 6 properties.

Review of soil vapour, crawl space and indoor air sampling data indicated that:

- The model estimated attenuation factor for soil vapour from 0.85 m depth to crawl space air was consistent with the range of attenuation factors observed in sample results. However, the modelled attenuation factor was adopted from the soil vapour to indoor air model assuming an attenuation factor between crawl space and indoor air of 1.0. The adopted factor was approximately one order of magnitude (factor of 10) lower (less conservative) than the average values observed in sample results.
- The adopted attenuation factor from crawl space to indoor air (1.0) was conservative in comparison with the average attenuation factor inferred from the results of 2016 sample works (0.3). However, the adopted attenuation factor (1.0) was consistent with the highest values inferred from the results of sampling works (0.91).

The results of soil vapour, crawl space and indoor air sampling indicated the ‘modelled’ attenuation factor for soil vapour to a crawl space (3.1E-03) was not conservative and was lower than the observed attenuation in the Assessment Area.

However, when the observed average attenuation between crawl space air and indoor air (0.3) is applied to the observed average attenuation between soil vapour and crawl space air (values between 1.0E-02 and 2.3E-02, Table 22), the resulting range of attenuation factor values (3.0E-03 to 6.9E-03) were consistent with the attenuation factor for soil vapour to indoor air at a crawl space building as indicated by the vapour intrusion model (3.1E-03).

In summary:

- The soil vapour to crawl space attenuation factor indicated by the vapour intrusion model (3.1E-03) was not appropriate for application to the Assessment Area. However, assessment of this pathway was unlikely to be required and an attenuation was not adopted for this assessment.
- The soil vapour to indoor air (for a crawl space building) attenuation factor indicated by the vapour intrusion model (3.1E-03) was consistent with attenuation factors indicated by site sampling data and was adopted for this assessment.
- The crawl space air to indoor air attenuation factor (1.0) indicated from international studies (Section 5.5.4) was conservative in comparison with the average attenuation factors indicated by site sampling data and was consistent with the maximum attenuation factors indicated by site sampling data. The conservative attenuation factor of 1.0 was considered appropriate and was adopted for this assessment.

5.5.3 Consideration of basement level and associated soil vapour and other indoor air sampling data

Two properties were identified within the Assessment Area where below ground rooms were present, Property 4 and Property 20. For simplification, these rooms are referenced as 'basements' although the specific usage of such rooms will vary between buildings and between owners/occupants.

The basement room at Property 4 was sampled during August 2015 by passive sampler (Radiello). This sample replaced a planned sub-slab sample at this location which could not be installed due to deficiencies in the concrete floor, and as such a Radiello sampler was located within a depression in the basement floor. The sample was considered to be qualitative and was not quantitatively representative of either an indoor air sample or a sub slab soil vapour sample.

The basement room at Property 20 was sampled during May 2016 by both passive sampler (Radiello) and active sampler (SUMMA canister) with duplicate samples obtained from each method.

Table 23 provides a summary of the results of basement room samples and associated indoor air and soil vapour sample results where available.

Table 23: Review of Inferred Attenuation Factors – Basement Room Sample Results

Sample Locations	Property 4			Inferred AF	Property 20		Inferred AF
Indoor Air – Active	-	-	-	NA	<2	<2	0.11
Indoor Air – Passive	-	-	-		0.47	0.36	
Basement – Active	-	-	-	0.07	4.4	4.4 (dup.)	0.03
Basement – Passive	7.2	-	-		3.3	3.2 (dup.)	
Soil Vapour – 0.85 m	100	180 [A]	910 [A]	NA	110	-	NA
Soil Vapour – 1.85 m	1400 [A]	-	-		-	-	
Soil Vapour – 3.85 m	2100 [A]	1800 [A] (dup.)	-		-	-	

Note – All sample result in micrograms per cubic metre. All attenuation factors are unitless.

A – Indicates sample data from 2016 associated with Property 4. Other sample data associated with Property 4 obtained in 2015.

Soil vapour sample data associated with Property 4 was obtained during July 2015 and April 2016 whilst basement indoor air sample data was obtained during August 2015. Attenuation factors for Property 4 have been based on July 2015 soil vapour data only, are considered qualitative and are provided for comparison with Property 20 data.

Inferred attenuation factors between soil vapour, basement rooms and overlying indoor air are indicated in Table 23. The review inferred attenuation factors in the order of 0.03 to 0.07 between soil vapour and basement rooms. However, soil vapour data for both Property 4 and Property 20 were obtained from 0.85 m sample depths. As basement rooms may be influenced by soil vapour at a range of depths (depending on the depth of the room below ground level), soil vapour data from shallow depths (i.e. 0.85 m) may underestimate source vapour concentrations. The actual site attenuation factors may therefore be lower (greater attenuation) than those inferred by reference to shallow soil vapour data.

Due to the limited available data and the highly site-specific nature of vapour intrusion into basement spaces, the calculated attenuation factors should be treated with caution and may not be suitable for broad application across the Assessment Area.

5.5.4 Consideration of published (generic) vapour attenuation factors

The US EPA has collated a database of soil vapour intrusion data including sample analysis results for soil vapour, sub slab, crawl space, basement and indoor air; petroleum hydrocarbons and chlorinated hydrocarbons; and for a range of building types. Review of the database indicated potential generic attenuation factors for migration of chlorinated hydrocarbons from soil vapour, sub slab vapour and crawl space air to indoor air (US EPA, 2012). Table 24 provides a summary of the 95th and 50th percentile attenuation factors from the US EPA database, and comparison with the attenuation factors estimated from the vapour intrusion model. Note that soil vapour data in the US EPA database is not classified according to depth below ground surface. A single attenuation factor is therefore presented for soil vapour at all depths (e.g. 0.85 m bgl, 1.85 m bgl etc.)

Table 24: Attenuation Factors – Comparison of Model Estimates and US EPA Database

Soil Vapour Source Depth (m)	Estimated Attenuation Factor (Slab on Ground)	Estimated Attenuation Factor (Crawl Space)	US EPA Database 95th Percentile	US EPA Database 50th Percentile
Crawl Space	Not Applicable	1	0.9	0.39
0 (Sub Slab)	2.7E-03	Not Applicable	3.0E-02	2.7E-03
0.85	1.5E-03	3.1E-03	3.0E-02 [A]	3.8E-03
1.85	7.3E-04	9.6E-04		
3.85	3.4E-04	3.8E-04		
6.35	2.0E-04	2.2E-04		

Note – All attenuation factors are unitless. Crawl space building type assumed except for sub slab pathway.

Note – All attenuation factors are unitless. Estimated attenuation factors adopted from the vapour intrusion model with consideration of results from site sampling data.

A – US EPA (2012) note the 95th percentile value for attenuation of soil vapour other than sub slab samples (i.e. deeper soil vapour) was higher (less attenuation) than the value for sub slab samples. The reason for the higher soil vapour value was inferred to include the variability in the soil vapour database, which was significantly greater than the data for other vapour sources and potential variability in the soil vapour sampling methodology. The sub slab attenuation factor (3.0E-02) was therefore adopted for soil vapour at all depths (US EPA, 2015).

Review of the US EPA vapour intrusion database and comparison with the results of vapour intrusion modelling, indicated:

- The estimated crawl space to indoor air attenuation factor was consistent with 95th percentile value from the US EPA database.
- The estimated sub slab to indoor air attenuation factor was consistent with the 50th percentile value from the US EPA database.

- The estimated 0.85 m depth soil vapour to indoor air attenuation factors were approximately one order of magnitude (factor of 10) lower (more attenuation) than the proposed US EPA value for soil vapour, which is based on the sub slab attenuation factor.
- The estimated soil vapour to indoor air attenuation factors for other depths (1.85 m, 3.85 m, 6.35 m) were approximately one to two orders of magnitude (factor of 10 or 100) lower (more attenuation) than the proposed US EPA value for soil vapour.
- The estimated soil vapour to indoor air attenuation factors (depth of 0.85m, 1.85 m, 3.85 m, 6.35 m) were approximately consistent with or one order of magnitude (factor of 10) lower (more attenuation) than the 50th percentile value for soil vapour from the US EPA database.

Whilst the modelled attenuation factors for soil vapour to indoor air at depths of 0.85 m and greater were lower (more attenuation) than both the proposed US EPA attenuation factor for soil vapour the 50th percentile value for soil vapour from the US EPA database, the US EPA database does not account for the depth below ground of samples and the data set was noted to incorporate a larger range of variability than that of other vapour sources (groundwater, sub slab and crawl space).

The modelled attenuation factors for soil vapour at depths of 0.85 m and greater were consistent with the range of attenuation factors reported in the US EPA database (25th percentile of 6.0E-04 to 75th percentile of 2.7E-02).

As discussed in Section 5.5.1, the results of soil vapour sampling and analysis within the Assessment Area inferred the modelled soil vapour attenuation factors for depths of 0.85 m bgl and greater were consistent with the attenuation observed in samples.

Based on the review of the modelled soil vapour attenuation factors; results of soil vapour sampling within the Assessment Area; and the US EPA vapour intrusion database, Golder considered that no adjustment to the estimated attenuation factors was necessary.

5.6 Uncertainty and sensitivity assessment

All environmental sampling, modelling and assessment activities include a degree of uncertainty. The objective of any assessment process includes the understanding and minimisation of uncertainty in order to allow robust and defensible conclusions to be made.

Two primary areas of uncertainty are relevant to the VIA:

- The degree to which the field data is representative of conditions in the Assessment Area.
- The performance and accuracy of the vapour intrusion model.

5.6.1 Uncertainty in field data

Field sampling and assessment of geological parameters, including selection of samples, sampling methodology and recording of field observations was undertaken by experienced environmental scientist and engineering personnel. Over 110 soil samples were obtained for assessment of moisture content and 31 samples were obtained for assessment of geotechnical properties relevant to the vapour intrusion model.

Analysis of geotechnical parameters was undertaken by facilities holding NATA accreditation for the testing methods where available.

Field sampling and assessment of soil vapour, crawl space and indoor air was undertaken by experienced air sampling specialists and in accordance with NATA accreditation held for the sampling methods. Analysis of vapour and air sampling was undertaken by recognised local and international laboratory facilities

The location of soil vapour, sub slab, crawl space and indoor air samples was guided by:

- The results of groundwater investigation and sampling which indicated the approximate location of VHC compounds with the potential to generate a vapour intrusion risk.

- The results of a passive soil vapour survey (Golder, 2015b), undertaken to detect the presence of VHC in shallow soil and to infer the potential extent and position of higher concentrations of VHC. The results of the passive soil vapour survey were used to guide further targeted sampling works.
- The results of successive stages of assessment works (Golder 2015a, 2015b, 2015c, 2015d, 2015f, 2015h, 2016), which refined the understanding of the vapour intrusion conceptual site model and assisted in definition of the scope of successive stages of works.

Environmental conditions, including soil vapour, crawl space and indoor air conditions can change with time. Atmospheric conditions, including temperate, air pressure and wind can influence the migration of vapour.

Soil vapour and ambient air samples were obtained using a variety of methodologies including sampling over different durations. Crawl space samples were obtained using vacuum canisters over a period of approximately 24 hours and also (during 2015 works) by using passive sorbent samplers over a period of 7 or 8 days. The reported concentrations of TCE between the two sampling methods were comparable (Golder 2015b, 2015c). The comparison of sampling methods indicated that the adopted concentrations from either method were anticipated to be representative of the potential exposure conditions over periods of up to one week.
Repeat sampling of crawl space and indoor air locations from 2015 works was undertaken in 2016. The reported crawl space concentrations of TCE in 2016 were broadly comparable with those from 2015 sampling and the indoor air concentrations of TCE in 2016 were comparable or lower than those from 2015 sampling, where results from the same property were available for comparison.

Repeat sampling of four indoor air locations from 2016 works (17-1S, 17-2S, 17-3S and 17-4S), reported consistent concentrations of TCE between March and April sampling. Repeat sampling of four other indoor air location during 2016 works (7-1S, 7-2S, 7-3S and 7-4S) reported higher concentrations of TCE (by approximately one order of magnitude) during the March 2016 sampling than during February 2016 sampling.

Potential variability of indoor air vapour concentrations over shorter time periods (e.g. weekly or monthly variation) on an individual property basis or over the wider Assessment Area is unknown.

Repeat sampling of soil vapour and sub slab locations during the 2015 and 2016 works reported generally consistent concentrations of TCE, as discussed in Sections 4.5.2.7 and 4.5.4.2.5, respectively. The results of the available repeat sampling indicate that the degree of variability over time for soil vapour and sub slab concentrations of TCE was generally low.

5.6.2 Uncertainty in vapour intrusion model

The vapour intrusion model adopted for the VIA (Johnson and Ettinger, 1991), has been widely applied to vapour assessments in Australia and internationally, including by regulatory agencies such as US EPA. Performance and sensitivity of the Johnson and Ettinger model has been reviewed on a number of occasions including by Johnson (2002), Hers et al. (2003) and CRC CARE (2009). The primary limitation of any model is the validity of the parameters used. Where possible, site-specific parameter values were adopted from the results of environmental and geotechnical investigation works. Where a range of potential parameter values were indicated, or where a parameter value was not known, either average or conservative values were adopted for the VIA.

Some of the critical parameters influencing the sensitivity of the Johnson and Ettinger model are the soil moisture content and the building air exchange rate (Johnson, 2002). In addition to the model being sensitive to these parameters, they are also factors that are anticipated to vary within the Assessment Area spatially and over time as follows:

- Soil moisture conditions will vary with depth, with soil type, with surface covering and (for near-surface soil layers) will also vary seasonally and over shorter time periods with rainfall events.
- Building air exchange rates will vary with building construction type, with resident occupancy patterns (such as whether present at home during the day), and with climate conditions (such as the use of open doors and windows during warmer weather and the use of air conditioning or heating systems).

The parameter values adopted for the VIA were based on conservative or average values inferred from geotechnical sampling data (soil moisture content) or conservative recommended guideline values based on studies of a range of building types (air exchange rate).

Whilst the adopted values for the VIA are considered to be both conservative and appropriate for the Assessment Area, a sensitivity assessment was completed during the previous VIA in 2015 (Golder 2015h), to understand the potential effect of variability in these parameters. For the sensitivity assessment, the selected parameters were adjusted to higher and lower values from those adopted for the Assessment Area.

The vapour intrusion model for soil vapour from 1.85 m depth to indoor air (slab on grade foundation) was used for the sensitivity assessment as this scenario incorporates both soil and building properties. The adjusted vapour intrusion models were presented in the previous VIA (Appendix C of Golder, 2015h) and a summary of the model reference identifications, adjusted parameters and resulting vapour attenuation factors is provided in Table 25.

Table 25: Sensitivity Assessment – Model Parameters and Adjusted Parameter Values

Vapour Intrusion Model Reference ID	Sensitivity Parameter Value	Change in Parameter Value from Baseline	Attenuation Factor	Change in Attenuation Factor
A3-	0.03	- 76 %	1.16E-03	+ 27.3 %
A2-	0.05	- 60 %	1.12E-03	+ 22.9 %
A1-	0.1	- 19 %	9.88E-04	+ 8.5 %
Baseline	Soil Moisture (0.124)	0	9.11E-04	0
A1+	0.148	+ 19 %	8.23E-04	- 9.7 %
A2+	0.198	+ 60 %	6.10E-04	- 33.0 %
A3+	0.218	+ 76 %	5.19E-04	- 43.0 %
B4-	0.1	- 83 %	4.74E-03	+ 420 %
B3-	0.2	- 67 %	2.58E-03	+ 183 %
B2-	0.3	- 50 %	1.77E-03	+ 94.3 %
B1-	0.45	- 25 %	1.20E-03	+ 31.7 %
Baseline	Air Exchange Rate (0.6)	0	9.11E-04	0
B1+	0.75	+ 25 %	7.33E-04	- 19.5 %
B2+	1	+ 67 %	5.53E-04	- 39.3 %
B3+	1.2	+ 100 %	4.62E-04	- 49.3 %

Note – All attenuation factors are unitless. Crawl space building type assumed except for sub slab pathway.

The sensitivity assessment indicated that the vapour attenuation factor was sensitive to both soil moisture content and to building air exchange rate. The relationship between soil moisture and attenuation factor was approximately linear over the range of values assessed. Moderate (approximately 50%) change to the moisture content resulted in approximately 20% to 30% changes in the estimated attenuation factor. The range of moisture content anticipated for natural, near-surface soil in the Assessment Area was not expected to result in significant (order of magnitude) influences on the results of the vapour intrusion modelling.

The relationship between building air exchange rate and attenuation factor was indicated to be exponential with attenuation factor being more sensitive to lower air exchange rates over the range of values assessed. The adopted air exchange rate (0.6 per hour) was anticipated to be conservative (low) for the occupied residential buildings indicated in the Assessment Area. A conservative air exchange rate value is considered appropriate for the VIA in order to account for the potential future construction of new buildings with higher degree of energy efficiency and therefore lower natural ventilation.

The adoption of conservative assumptions and parameters within various aspects of the VIA process can potentially lead to the effect where cumulative ‘factors of safety’ result in assessment outcomes that are unrealistic. However, for the assessment of environmental conditions, a higher level of cumulative conservatism is considered appropriate to address the uncertainties and variability within the Assessment Area.

5.7 VIA conclusions and proposed vapour attenuation factors

The results of environmental investigation works reported the presence of volatile chlorinated compounds, principally TCE, in groundwater, soil vapour, crawl space air and indoor air within the Assessment Area.

The soil vapour to crawl space air and soil vapour to indoor air attenuation factors, estimated by use of an analytical model (US EPA, 2004) were consistent with the results of soil vapour and ambient air sampling from a selection of properties within the Assessment Area.

In consideration of the results of the vapour intrusion modelling and review of environmental sampling data, estimated soil vapour attenuation factors proposed for application within the Assessment Area are presented in Table 26. The proposed attenuation factors adopt the more conservative (higher values) from each of the two building foundation types. Adoption of the more conservative attenuation factor is also appropriate for buildings where a combination of slab on grade and crawl space foundations are present in the same building.

An attenuation factor for crawl space air to indoor air is also proposed based on review of published international data (US EPA, 2012) and the results of sampling works within the Assessment Area.

Table 26: Proposed Vapour Attenuation Factors, Beverley Assessment Area

Vapour Source Location or Depth (m)	Proposed Vapour Attenuation Factor "α" (unitless)	
	Concrete Slab on Grade Foundation	Timber Suspended Floor, Crawl Space
Crawl Space	Not Applicable	1
0 (Sub Slab)	2.7E-03	Not Applicable
0.85	3.1E-03	3.1E-03
1.85	9.6E-04	9.6E-04
3.85	3.8E-04	3.8E-04
6.35	2.2E-04	2.2E-04

Preliminary calculation of vapour attenuation factors for soil vapour to a basement space were calculated based on limited data from two properties. Due to the limited nature of the available data and the fact that vapour intrusion into basement rooms will be highly dependent on basement depth and site-specific construction parameters (floor and wall materials and integrity, room dimensions, ventilation, connectivity to overlying house, etc.) it is not recommended that these attenuation factors be generally applied in the Assessment Area. Where basement rooms are present, use of generic attenuation factors for such buildings is not recommended and property-specific assessment should be considered.

6.0 HUMAN HEALTH RISK ASSESSMENT

6.1 Scope of works

Golder recognise that HHRAs have been completed on behalf of SA EPA for a number of locations in South Australia involving similar COI (chlorinated ethenes), geological conditions (sediments of the Adelaide Plains), and human health receptors (residential dwellings). A preferred toxicity assessment and risk management approach has been previously determined by SA Government including SA EPA and SA Health. The scope of works for the VIA and the HHRA therefore sought to remain consistent with the methodology adopted at other assessment areas. The scope of works for the HHRA included the following:

- adoption of vapour attenuation factors (α) estimated from the VIA for TCE and for each vapour migration and intrusion pathway
- estimation of indoor air concentrations of TCE from reported concentrations of TCE in soil vapour and in crawl space air
- assessment of the potential for vapour concentrations to pose a risk to health by comparison with adopted TCE response ranges
- consideration of other (short-term) implications of the estimated exposure concentrations.

6.2 HHRA methodology

The HHRA was undertaken following the general principles and methodology as provided in the ASC NEPM and with reference to other applicable Australian guidance including the Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth, 2012).

The process adopted for the HHRA was as follows:

- Reported concentrations of TCE in soil vapour at depth below surface, sub slab soil vapour and crawl space air were multiplied by the relevant attenuation factor as estimated in the VIA.
- The resulting estimated indoor air concentration was compared with the TCE response ranges (as developed by Government of South Australia (2014) (discussed further below), to identify the significance of the results and the level of action required.
- Reported concentrations of TCE in outdoor air, indoor air and subsurface utilities and services were compared directly with the response ranges to identify the significance of the results and the level of action required.

The concentrations of TCE in soil vapour, sub slab soil vapour, crawl space air, outdoor air and indoor air used for assessment of risk were sourced from reports prepared for previous stages of investigation and sampling works in 2015 (Golder 2015a, 2015b, 2015c, 2015d, 2016); from the conceptual site model compiled from these investigation works (Golder, 2015e); and from the results of additional verification sampling undertaken in 2016 (refer to Section 4).

Whilst a multiple lines of evidence approach was used, the primary data used for the HHRA were the sample analysis results from shallow and medium depth soil vapour including sub-slab, crawl-space, and indoor air samples. These sample results represent the concentrations in closest proximity to receptors (overlying buildings) with a lower degree of uncertainty due to partitioning from groundwater and from migration through deeper soil profiles.

The attenuation factors for soil vapour or crawl space air to indoor air, as estimated from the VIA, are summarised in Table 27.

Table 27: Adopted Vapour Attenuation Factors, Beverley Assessment Area

Vapour Source Location or Depth (m)	Adopted Vapour Attenuation Factor "α" to indoor air (unitless)	
	Concrete Slab on Grade Foundation	Timber Suspended Floor, Crawl Space
Crawl Space	Not Applicable	1
0 (Sub Slab)	2.7E-03	Not Applicable
0.85	3.1E-03	3.1E-03
1.85	9.6E-04	9.6E-04
3.85	3.8E-04	3.8E-04
6.35	2.2E-04	2.2E-04

Response ranges (concentrations) of TCE in air had previously been developed and adopted for assessment of vapour migration and potential health risk for the Clovelly Park Mitchell Park Environmental Management Project (Government of South Australia, 2014). Golder understands that SA EPA has adopted the same response ranges for the Beverley Assessment Area and these response ranges were applied during the previous HHRA in 2015 (Golder, 2015f).

The TCE response ranges (concentrations) have been established for direct comparison with modelled or measured air concentrations from vapour intrusion. Therefore a Hazard Identification and Dose-Response Assessment, as per NEPC (2013) and enHealth (2012) guidance, was not required.

The TCE response ranges incorporate an order of magnitude (factors of 10) approach to establish the significance of an air concentration and the indicated level of response. For example, a concentration 10 times higher than the "Investigation" response range would indicate a higher potential health concern and more urgent response timeframe. The response ranges therefore incorporate a measure of the 'significance' of the air concentration and a Risk Characterisation process was not required.

The approach used in establishment of the response ranges is outlined in Government of South Australia (2014) and a relevant discussion from this document is presented below:

The indoor air level response range was developed following a review of international standards and research for TCE.

A joint workshop between SA Health, EPA, the Clovelly Park Mitchell Park Project Team, and the consultants undertaking the environmental investigations and human health/vapour intrusion risk assessment, was held to develop this indoor air level response range.

The workshop considered the scientific evidence for health effects from TCE exposure and reviewed various guidance on TCE action levels from around the world.

Agreement was reached at the workshop to establish ranges using levels prescribed by the US EPA as the lower limit and those of the World Health Organisation (WHO) as the upper limit for the ranges.

The basis of the agreement was taking a sensible balance between the highly conservative approach of the US EPA with the widely validated approach of the WHO.

These guidance levels are intended to be protective against cancer and other health risks over the course of a lifetime of continuous TCE exposure (70 years).

This approach is also consistent with Australian approaches to chemical assessment and regulation where the WHO is identified as a preferred source of guidance, in an absence of national regulatory standards.

While there is international consensus around the reference concentration of 2 µg/m^3 of TCE in indoor air as the trigger for further investigation, decision making frameworks for levels above this vary considerably and are the subject of ongoing scientific and public debate.

For the purposes of this investigation, 2 µg/m^3 of TCE in indoor air has been adopted as the level above which further action is necessary.

The ranges adopted above this level to determine differences in the nature and timing of the actions are based on increasing levels of health risk between levels such as 2 µg/m^3, 20 µg/m^3 and 200 µg/m^3.

Within the designated ranges it is very difficult to scientifically determine the differences in possible health risks within the particular action level ranges (eg between 3 µg/m^3 and 17 µg/m^3).

It is also important to note the science and understanding of the health effects of TCE are constantly evolving. Adjustments to the response levels may be appropriate as new information comes to hand.

The response ranges (TCE concentrations), and explanation of each range are provided in Image 9 below, extracted from Government of South Australia (2014).

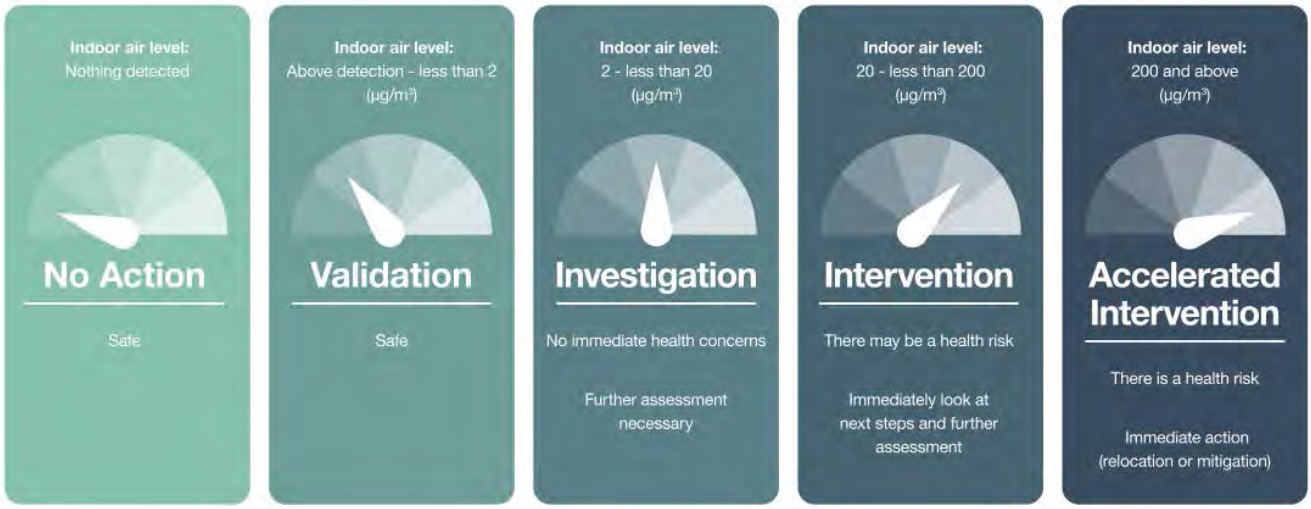


Image 9: TCE Indoor Air Response Ranges (Government of South Australia, 2014)

No adjustment was made to the response ranges to account for different sampling or potential exposure duration. Review of results from crawl space samples from 2015 works (Golder, 2015e) inferred that TCE concentrations obtained over a 24 hour sampling period (using vacuum canister methods) were consistent with TCE concentrations obtained over a 7 to 8 day sampling period (using passive sorbent methods). Review of results from indoor air samples from the 2016 Assessment (Section 4) inferred that TCE concentrations obtained over a 72 hour sampling period (using vacuum canister methods) were consistent with TCE concentrations obtained over a 7 to 10 day sampling period (using passive sorbent methods).

As the response ranges were adopted on the assumption of continuous exposure and the crawl space sample results did not infer significant variability in concentrations between 24 hour, 72 hour and 7 to 10 day durations, no adjustment was required.

6.3 Estimated vapour concentrations

The assessment program included sampling of indoor air, crawl space air and sub slab soil vapour at properties within the Assessment Area during 2015 and 2016 and reported ranges of TCE concentrations as depicted in Image 10 at these properties.

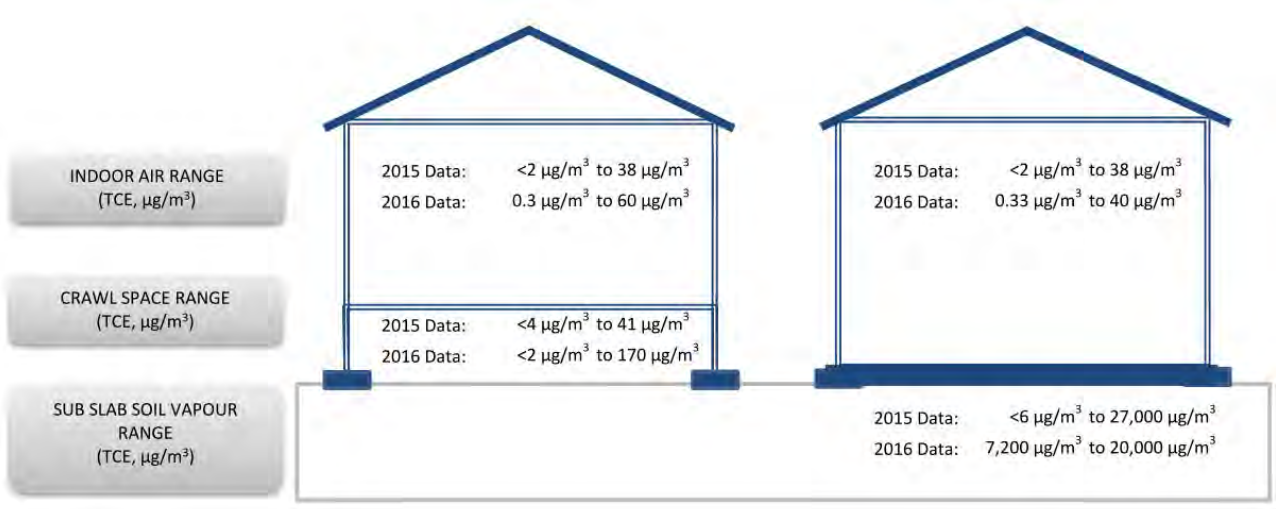


Image 10: Range of Sub Slab, Crawl Space and Indoor Air TCE Concentrations Reported in Assessment Area

Property-specific environmental sampling results were available for 26 properties within the Assessment Area. Sampling was undertaken over several stages of works and a summary of the data available for each property is provided in Table 28.

Table 28: Summary of Property-Specific Environmental Sampling Data

Property ID	Deep Soil Vapour Data >0.85m	Shallow Soil Vapour Data ≤0.85m	Sub Slab Data	Crawl Space Data	Indoor Air Data
Property 1 (2015)	☑	☑	☑	☑	☐
(2016)	☑	☑	☐	☑	☑
Property 2 (2015)	☑	☑	☑	☑	☐
(2016)	☑	☑	☐	☑	☑
Property 3 (2015)	☐	☐	☐	☑	☐
Property 4 (2015)	☐	☐	☑	☑	☑
(2016)	☑	☑	☐	☑	☐
Property 5 (2015)	☐	☐	☑	☑	☑
(2016)	☑	☑	☑	☑	☑
Property 6 (2015)	☐	☐	☑	☐	☑
Property 7 (2015)	☐	☐	☑	☑	☑
(2016)	☑	☑	☑	☑	☑
Property 8 (2015)	☐	☑	☑	☐	☑
(2016)	☑	☑	☑	☐	☑
Property 9 (2015)	☐	☑	☐	☑	☐
(2016)	☑	☑	☐	☑	☑
Property 10 (2015)	☐	☐	☐	☑	☐
Property 11 (2015)	☑	☑	☑	☐	☐
Property 11 (2016)	☑	☑	☐	☑	☐
Property 12 (2016)	☐	☑	☐	☑	☐
Property 13 (2016)	☑	☑	☐	☐	☐
Property 14 (2015)	☐	☑	☐	☐	☐
Property 15 (2016)	☐	☑	☐	☐	☐
Property 16 (2016)	☑	☑	☐	☐	☐
Property 17 (2016)	☑	☑	☐	☑	☑
Property 18 (2016)	☑	☑	☐	☐	☑
Property 19 (2016)	☐	☑	☐	☑	☐
Property 20 (2016)	☐	☑	☐	☐	☑
Property 21 (2016)	☐	☑	☐	☑	☐
Property 22 (2016)	☐	☐	☐	☑	☐
Property 23 (2016)	☐	☐	☐	☑	☐
Property 24 (2016)	☐	☑	☐	☑	☐
Property 25 (2016)	☐	☑	☐	☑	☐
Property 26 (2016)	☐	☐	☐	☑	☐

Indoor air concentrations for consideration in the HHRA were either:

- adopted from the results of samples obtained from indoor air at each property, or
- estimated from the results of samples obtained from soil vapour, sub slab soil vapour or crawl space air by applying the relevant attenuation factors (for the sample media) as reported in the VIA (Table 20).

The measured or estimated (calculated) indoor air concentrations from the 2016 Assessment are presented in Appendix J as Table J1 (Indoor Air Data), Table J2 (Crawl Space Air Data), Figure J3 (Sub-Slab Data), and Table J4 (Soil Vapour Data).

For the results of 2016 Assessment, where an indoor air sample or sub slab soil vapour sample was available and associated with deeper soil vapour data (0.85 m or 1.85 m depth samples), the indoor air concentration was not estimated from the deeper soil vapour data. It was anticipated that indoor air or sub slab soil vapour would provide a more representative assessment of potential vapour intrusion and risk than assessment of migration from deeper soil vapour to indoor air.

6.4 Assessment of potential health risk

For the assessment of potential health risk to residential property within the Assessment Area, comparison was made between measured or estimated indoor air concentrations and the adopted response ranges.

Where a potential for health risk was indicated (Investigation and higher response ranges), the level of action and priority for action were indicated by the specific response range for the concentration.

6.4.1 Chronic, intermediate, and acute health implications

With the exception of the “No Action” and “Validation” concentrations, the response ranges are not directly based on consideration of acceptable or unacceptable human health risk. The “Investigation”, “Intervention” and “Accelerated Intervention” response ranges are scaled (upwards by an order of magnitude at each level) from the “Validation” range. The response ranges are management action guidelines for use in assessing the need for action and priority with which that action is implemented. They are not intended to define or assess a ‘safe’ or ‘acceptable’ duration of exposure.

The “Validation” response range was based on the reference concentration (RfC) of 2 µg/m^3 adopted by the US EPA. The RfC is defined as:

> *An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.*

The “No Action” and “Validation” response ranges may therefore be considered to represent concentrations at which continuous, long-term exposure (‘chronic exposure’) is not anticipated to result in health risks.

The review and establishment of the chronic toxicological reference value for TCE also included consideration of a wide range of exposure durations (‘sub-chronic’ or ‘intermediate’) and effects. The effects included those relevant to sensitive subpopulations such as immune toxicity, developmental and reproductive toxicity. The studies documenting these effects involve short term or intermediate exposure durations.

Golder notes the draft revision to the ATSDR toxicological profile for TCE (ATSDR, 2014) adopts the 2 µg/m^3 reference concentration from US EPA as both a chronic (long term) Minimum Risk Level (MRL) and as an intermediate (sub chronic) MRL. ATSDR defines an intermediate duration as a period greater than 14 days and less than 1 year.

Because the acute health effects of TCE occur at higher concentrations than intermediate or chronic effects the chronic reference value is protective against acute health effects.

6.4.2 Subsurface construction and maintenance workers

As noted in Section 6.4.1 the adopted chronic reference value for TCE is also anticipated to be protective against acute health effects. However, adoption of a chronic reference concentration for assessment of short-term or incidental exposures may also be overly conservative and may infer the need for excessive management controls that are not justified by the length of exposure.

For personnel engaged in construction or maintenance works where exposure to subsurface conditions may occur (e.g. trenches and utility pits) a screening assessment was also undertaken with reference to guidelines for occupational exposure standards and guidelines for acute (short-term effect) health hazards.

Table 29 provides a summary of maximum reported concentrations of TCE in soil vapour to a depth of 1.85 m (including sub slab samples data) and comparison against occupational and acute effects screening guidelines. A depth of 1.85 m was considered to represent the likely range of most services and utilities and the depth of incidental excavation activities such as for building foundations and landscape tree planting.

Field assessment of existing utilities was undertaken as part of the 2015 Golder Assessment (Golder, 2015b) and included sampling of eight service pits within the Assessment Area using passive samplers over an 8 day sampling period. The assessment reported concentrations of TCE ranging from <0.2 to 18 $\mu g/m^3$. All reported concentrations within service pits were below the adopted occupational or acute screening guidelines (Table 29).

Table 29: Review of Soil Vapour Concentrations - Occupational and Acute Screening Guidelines

Maximum Reported TCE Concentrations 2015 and 2016 Data		TWA (NOHSC, 1995)	AEGL 1 (US EPA, 2008)	AEGL 2 (US EPA, 2008)	10% LEL
Service Pits:	18	54,000	413,000	1,288,000	42,960,000
Sub Slab Data:	27,000	54,000	413,000	1,288,000	42,960,000
0.85 m Depth Data:	42,000	54,000	413,000	1,288,000	42,960,000
1.85 m Depth Data:	110,000	**54,000**	413,000	1,288,000	42,960,000

All concentrations in micrograms per cubic metre. Bold and underlined indicates screening guideline exceeded by maximum reporting TCE concentration.

(NOHSC, 1995) – 8 hour Time Weighted Average (TWA), Worksafe Australia, National Occupational Health and Safety Commission, Occupational Atmospheric Exposure Standards.

(US EPA, 2008) - 8 hour Acute Exposure Guideline Levels (AEGL), United States Environmental Protection Agency

LEL – Lower Explosive Limit, adopted 10% of LEL as a screening level indicative of the potential for explosive atmospheres to exist.

Review of reported subsurface concentrations of TCE indicated that the maximum reported concentration of TCE in soil vapour at a depth of 1.85 m bgl was higher than the Australia occupational exposure standard (8 hour TWA). This maximum reported concentration of TCE soil vapour (SV51-M, March 2016) was the only sample to 1.85 m depth which reported a concentration higher than the adopted occupational and acute screening guidelines.

6.5 HHRA Uncertainty and Sensitivity Assessment

For the HHRA, the primary sources of uncertainty are:

- the environmental sampling data from the Assessment Area, including soil vapour, crawl space air and indoor air samples
- the estimated attenuation factors and whether they are representative of the building and exposure conditions in the Assessment Area
- the SA Government response ranges and whether they are relevant and protective for the Assessment Area.

Review of uncertainty was undertaken for the environmental sampling data within the environmental assessment reports (Golder, 2015a, 2015b, 2015d, 2015e and Section 3.2 of this report) and within the VIA (Section 5.6 of this report). A sensitivity assessment was undertaken for the vapour intrusion models and estimated attenuation factors within the VIA (Section 5.6). For further information regarding the uncertainty and sensitivity of the assessment, reference should be made to these previous reports (Golder 2015a, 2015b, 2015c, 2015d, 2015g) and the Section 3.2 of this report.

The basis of the response ranges is discussed in Section 6.2 and consideration of relevance to intermediate and acute health effects is provided in Section 6.4.

6.6 Conclusions and assessment of health risk

The measured indoor air and estimated (from soil vapour, sub slab vapour and crawl space air samples) indoor air concentrations of TCE were compared with the SA Government response ranges adopted for the Assessment Area. The background to the response ranges is discussed in Section 6.1, and for presentation purposes have been assigned colour codes as follows:

<Detection [A]	< 2 µg/m^3	2 to <20 µg/m^3	20 to <200 µg/m^3	200+ µg/m^3
No Action	Validation	Investigation	Intervention	Accelerated Intervention

A – See discussion below regarding sample results below detection limits.

Comparison between measured (indoor air), or estimated (from soil vapour or crawl space air) concentrations of TCE and the response ranges has been provided in Tables 1, 2, 3, and 4 in Appendix J. Property-specific data considered in these calculations is provided in Figure 7.

For the purposes of the risk assessment, where a crawl space air sample reported a result less than the laboratory detection limit, but that detection limit was higher than 2 µg/m^3 the result was classified as "Validation".

Where a soil vapour sample reported a result less than the laboratory detection limit, but that detection limit was higher than 2 µg/m^3 the result was classified as "No Action" in consideration of the expected degree of attenuation between soil vapour samples and indoor air.

The results of the 2016 Golder Assessment generally confirmed the general conclusions about the Assessment Area and individual properties developed from the 2015 Golder Assessment. Of the 10 additional properties assessed in 2016 (Properties 17 to 26), three were categorised as within the "Intervention" response category, four within the "Investigation" category, two within the "Validation" category, and two within the "No Action" category.

Table 30 provides a summary of the classification, with reference to the response ranges, for the individual properties targeted within the Assessment Area, with consideration of both Golder 2015 and 2016 assessment data.

Table 30: Summary of Property Classification – Response Ranges

Property ID	Soil Vapour Data >0.85m	Soil Vapour Data <0.85m	Sub Slab Data	Crawl Space Data	Indoor Air Data
Data Priority ➔	5	4	3	2	1
Increasing Confidence in Data Source ➔					
Property 1	Intervention	Intervention	Investigation*	Intervention	Investigation
Property 2	Investigation	Investigation	Investigation*	Investigation*	Validation
Property 3	NA	NA	NA	Validation*	NA
Property 4	Validation	Validation	Investigation	Investigation	NA
Property 4 (Basement)	NA	NA	NA	NA	Investigation*
Property 5	Intervention	Intervention	Intervention	Intervention	Investigation
Property 6	NA	NA	Intervention*	NA	Validation*
Property 7	Investigation	Investigation	Intervention	Intervention	Intervention
Property 8	Validation	Validation	Intervention	NA	Validation
Property 9	Investigation	Validation	NA	Intervention	Investigation
Property 10	NA	NA	NA	Intervention*	NA
Property 11	Validation	Validation	Validation*	Investigation	NA
Property 12	NA	Investigation	NA	Intervention	NA
Property 13	NA	Validation	NA	NA	NA
Property 14	NA	No Action*	NA	NA	NA
Property 15	NA	Validation	NA	NA	NA
Property 16	Investigation	Investigation*	NA	NA	NA
Property 17	Intervention	Intervention	NA	Intervention	Intervention
Property 18	Investigation	Intervention	NA	NA	Validation
Property 19	NA	Validation	NA	Investigation	NA
Property 20	NA	Validation	NA	NA	Validation
Property 20 (Basement)	NA	NA	NA	NA	Investigation
Property 21	NA	Investigation	NA	Investigation	NA
Property 22	NA	NA	NA	No Action	NA
Property 23	NA	NA	NA	No Action	NA
Property 24	NA	Validation	NA	Investigation	NA
Property 25	NA	Validation	NA	Intervention	NA
Property 26	NA	NA	NA	Intervention	NA

NA – Not Assessed. Indicates that no data was available of the given type for the property.
Note – colour coding 'faded' for classifications where a higher priority data source is available. i.e. Property 9, crawl space data is displayed as a stronger colour than lower priority soil vapour data.
* Not assessed in 2016 Golder Assessment. Response Range classification based on data from 2015 Golder Assessment.
** Response range classification conservatively based on data from 2015 Golder Assessment.
Basement data for Property 4 (2015 sampling) was considered qualitative due to difficulties in obtaining representative samples.

Data sources are listed in reverse order of priority, such that the response range indicated by indoor air data should be given greater weighting than the response range indicated by soil vapour data.

Assessment of reported concentrations of TCE in soil vapour to a depth of 1.85 m and concentrations of TCE reported in service pits (Section 6.4.2) did not indicate the presence of a health concern for personnel engaged in excavation or in maintenance works on services and utilities within the Assessment Area. One soil vapour sampling location reported a concentration of TCE higher than the Australian occupational exposure standard (8 hour TWA value). However, it is unlikely the concentration reported in a soil vapour sample would occur within an open excavation (due to atmospheric dispersion and dilution), or that personnel would be exposed to the reported concentration on a continuous basis for an entire working day (i.e. it is unlikely a maintenance task would require personnel to remain within a subsurface utility or excavation for an extended period).

The screening assessment of potential occupational or acute exposure risks to utility maintenance or excavation personnel was considered conservative. However, as a precautionary measure the presence of measured concentrations of TCE in soil vapour at depth exceeding Australian occupational exposure standards should be notified to relevant organisations responsible for operation and maintenance of utilities within the Assessment Area.

6.6.1 Residential "Zones"

No property-specific data has been collected for many properties within the Assessment Area. To allow consideration of areas beyond those where property-specific investigations have been conducted, the Assessment Area has been divided into "Residential Zones" based on the estimated (theoretical) indoor air concentration of TCE estimated from active soil vapour data. It is noted that each Zone may also contain a number of non-residential properties. Each Residential Zone comprises a contiguous series of properties for which an identical response range classification has been assigned.

A summary of the properties within each Residential Zone and the corresponding Response Range Classification is provided in Table 31. As site-specific assessments of many residential properties based on sub-slab vapour, crawl space air, or indoor air have already been conducted within several Residential Zones as part of the 2015 and/or 2016 assessment works, the results of these assessments have also been summarized in Table 31. Residential Zone boundaries are presented in Figure 8.

The boundary of each Residential Zone has been interpreted based on available soil vapour data within each zone and near the boundaries of adjacent zones, as well as the current understanding of the conceptual site model for the Assessment Area. It is acknowledged the data for spatial distribution of soil vapour data is limited throughout many Residential Zones, and uncertainty exists regarding the appropriate classification of properties which are more distant from sample data.

Where such uncertainty exists, properties have been classified conservatively. Further assessment would be required to provide greater certainty and allow for less conservative classification of these properties.

Table 31: Summary of Response Range Classifications for Residential Zones (From Soil Vapour Data)

Residential Zone	Estimated Number of Residential Properties Within Zone	Associated Active Soil Vapour Data Points	Investigation Priority Classification Based on Soil Vapour Data	Response Range Classification of Investigated Individual Properties within Zone
1	21	SV-16, SV-23, SV 37, SV-17, SV 110	No Action	1 Property: No Action
2	44	SV-07, SV-08, SV 16, SV-17, SV 20, SV-24, SV 50, SV-101, SV 106, SV-107, SV-109, SV-110, SV-111	Validation	1 Property: Investigation
3	33	SV-108, SV-109, SV-111	Validation	1 Property: Intervention
4	24	SV-03, SV-04, SV-05, SV-07, SV-09, SV-10, SV-18, SV-19, SV-31, SV-47, SV-49, SV-51, SV-101, SV-102, SV-106,	Investigation	2 Properties: Intervention 3 Properties: Investigation 2 Properties: Validation* 1 Property: No Action
5	5	SV-02, SV-03, SV-22. SV-25, SV-51	Intervention	1 Property: Intervention 2 Properties: Investigation
6	35	SV-22, SV-26, SV-32, SV-33, SV-34, SV-37, SV-41, SV-46, SV-50, SV-52	Validation	1 Property: Investigation
7	12	SV-12, SV-15, SV-21, SV-27, SV-29, SV-30, SV-33, SV-35, SV-36, SV-39, SV-40, SV-41, SV-43, SV-44, SV-45	Investigation	1 Property: Intervention 1 Property: Investigation 3 Properties: Validation*
8	3	SV-01, SV-21, SV-28, SV42	Intervention	1 Property: Intervention* 1 Property: Validation
9	4	SV-11, SV-48	Validation	No Properties Assessed

* Includes response range classifications based on data from 2015 Golder Assessment for one property not assessed in 2016 Golder Assessment.

7.0 RECOMMENDATIONS

Further assessment of potential health risks is recommended based on the level of modelled vapour intrusion and priority classification within each Residential Zone. Based on the results of the 2016 Golder Assessment, the Vapour Mitigation Strategy (Golder 2015g) developed for the Assessment Area is considered to remain appropriate for guiding the decision process and providing recommendations for further investigation. A copy of the Decision Flow Chart from the Vapour Mitigation Strategy is provided in Appendix K. The recommended next phase of investigation in each zone is described in Table 32.

Table 32: Recommended Investigation Actions for Residential Zones

Zone	Preliminary Action Category	Recommended Action	Estimated Number of Residential Properties
1	No Action	No further investigation recommended.	21
2	Validation	Where not already completed as part of the 2016 Golder or JBS&G Assessments, confirm active soil vapour results within this zone by re-sampling existing soil vapour probes. It is recommended that the additional active soil sampling be undertaken during the summer period to allow assessment of potential seasonal variations.	44
3	Validation	Based on limited soil vapour data within this area and elevated crawl space air concentrations reported at Property 26 within this Zone, undertake a further area-wide screening assessment. This assessment should focus on additional active shallow soil vapour sampling to assess soil vapour in the vicinity of groundwater monitoring well MW12 and soil vapour probes SV108 and SV111. Also confirm active soil vapour results within this zone by re-sampling existing soil vapour probes. Based on the outcomes of the area-wide soil vapour assessment, property-specific investigation may be required in focused properties within this Zone, as described for Zone 5. Undertake indoor air sampling at Property 26.	33
4	Investigation	Refinement of area wide screening assessment by additional shallow active soil vapour sampling in private properties in the west portion of this Zone. Based on the outcomes of this soil vapour assessment, as well as property specific investigations already undertaken in eight properties, further property-specific investigation is required in focused properties within this Zone, as described for Zone 5.	24

Zone	Preliminary Action Category	Recommended Action	Estimated Number of Residential Properties
5	Intervention	Implement property-specific investigations in accordance with the Vapour Mitigation Strategy, including: • building construction survey • crawl space sampling and/or sub-slab sampling (dependent on building construction) • soil gas sampling • property-specific vapour intrusion assessment. It is noted that these investigations have been undertaken in three of the residential properties throughout this Zone as part of the 2016 Golder Assessment. Where indoor air sampling has confirmed the Intervention classification, consider implementing mitigation measures as per the *SA EPA Vapour Mitigation Strategy (2015).*	5
6	Validation	Confirm active soil vapour results within these zones by re-sampling existing soil vapour probes. It is recommended that the additional active soil sampling be undertaken during the summer period to allow assessment of potential seasonal variations. Undertake confirmatory crawl space sampling at Property 19.	35
7	Investigation	As further area-wide screening in these Zones would be impractical, due to the level of existing area-wide assessment completed to date, as well as property specific investigations already undertaken on five properties, implement further property-specific investigations as described above for Zone 5. Where indoor air sampling has confirmed the Intervention classification, consider implementing mitigation measures as per the *SA EPA Vapour Mitigation Strategy (2015).*	12
8	Intervention	Implement property-specific investigations as described above for Zone 5. It is noted that these investigations have been commenced in two of the three residential properties within this Zone as part of the 2016 Golder Assessment.	3*
9	Validation	Where not already completed as part of the 2016 Golder or JBS&G Assessments, confirm active soil vapour results within this zone by re-sampling existing soil vapour probes. It is recommended that the additional active soil sampling be undertaken during the summer period to allow assessment of potential seasonal variations.	4

*Zone includes one or more properties identified as commercial based on South Australian Government land use data (July 2015) but which appear to be used for residential purposes based on aerial photographs and/or observations from the property boundary.

As set out in the Decision Flow Chart within Appendix K, the need for installation of vapour mitigation systems in properties will be dependent on property-specific vapour intrusion assessment.

Basement spaces were identified at two properties during property-specific sampling works. As the presence of basement levels poses a potential for higher concentrations of TCE within indoor air than in overlying buildings, the following actions are recommended to address the potential for additional health risks to occur within the Assessment Area:

- Undertake a building survey for all properties within Residential Zones (Table 31) where a response range classification of 'Investigation' or higher is indicated. The survey should seek to identify the presence, construction type and usage of basement structures within zone.
- Assessment of TCE concentrations in indoor (basement) air where basement rooms are identified. Assessment priority should be based upon the response range classification of the zone in which the property is located with consideration for the sensitivity of the individual basement usage indicated by the building survey (i.e. a sensitive occupancy or usage of a basement level may justify a higher priority for assessment than indicated by the zone classification).

In addition to the recommended actions as set out in Table 32 and above for investigation of potential human health concerns, the following investigations are also recommended to address key data gaps within the conceptual site model:

- Assessment of the potential for preferential contaminant migration along West Street within the sewer line or unknown (potentially redundant) subsurface utilities. Sampling of vapour within the sewer and a ground penetrating radar (GPR) survey across West Street are recommended.
- Further assessment of the lateral extent of soil vapour impacts in the north-eastern portion of the assessment area (to further assist in source identification).
- Further assessment of groundwater to confirm likely contaminant source areas and allow future migration of TCE impacted groundwater to be assessed.

8.0 IMPORTANT INFORMATION

Your attention is drawn to the document titled - “Important Information Relating to this Report”, which is included in Appendix L of this report. The statements presented in that document are intended to inform a reader of the report about its proper use. There are important limitations as to who can use the report and how it can be used. It is important that a reader of the report understands and has realistic expectations about those matters. The Important Information document does not alter the obligations Golder Associates has under the contract between it and its client.

9.0 REFERENCES

AS 2870-2011 (2011). Australian Standard 2870-2011, Residential Slabs and Footings. Standards Australia, 2011.

ASTM (1995). American Society for Testing and Materials. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites. E1739-95.

ATSDR (2014). DRAFT Toxicological Profile for Trichloroethylene. Agency for Toxic Substances and Disease Registry, US Department of Health and Human Services, October 2014.

CRC CARE (2009). Petroleum Vapour Model Comparison. Davis, G.B., Trefry, M.G., Patterson, B.M. CRC for Contamination Assessment and Remediation of the Environment, Technical Report No. 9, March 2009.

CRC CARE (2011). Health Screening Levels for Petroleum Hydrocarbons in Soil and Groundwater. CRC for Contamination Assessment and Remediation of the Environment, Technical Report No.10, September 2011.

enHealth (2004). Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards. Department of Health and Ageing and enHealth Council. Commonwealth of Australia.

enHealth (2012). Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards. Department of Health and Ageing and enHealth Council. Commonwealth of Australia. September 2012.

Falta, RW, Basu, N, Suresh Rao, P – Assessing impacts of partial mass depletion in DNAPL source zones: II. Coupling source strength functions to plume evolution, Journal of Contaminant Hydrology, Vol 79, Pages 45-66. May 2005.

Golder (2001), *Phase 2 Environmental Site Assessment, Pope Street, Beverley SA*, dated June 2001

Golder (2003), *Additional Groundwater Investigations and Monitoring Electrolux Washing Plant, 19 Pope Street, Beverley, South Australia*, June 2003

Golder (2015a). Groundwater and Soil Vapour Data Report – Beverley Assessment Area, South Australia. Golder Associates Pty Ltd (Reference 1418522-003-R-Rev1), 27 May 2015.

Golder (2015b). Beverley Assessment Area, South Australia, Stage 2 Vapour Monitoring Data Report (June 2015). Golder Associates Pty Ltd (Reference 1418522-010-R-Rev0), 7 July 2015.

Golder (2015c). Beverley Assessment Area, South Australia, Stage 3 Vapour Monitoring Data Report (July-August 2015). Golder Associates Pty Ltd (Reference 1418522-012-R-Rev0), 1 October 2015.

Golder (2015d). Beverley Assessment Area, South Australia, Stage 4 Indoor Air Data Report (August-September 2015). Golder Associates Pty Ltd (Reference 1418522-020-R-Rev0), 1 October 2015

Golder (2015e). Conceptual Site Model – Beverley Assessment Area, South Australia. Golder Associates Pty Ltd (Reference 1418522-002-R-Rev0), 1 October 2015.

Golder (2015f). Preliminary Human Health Risk Assessment – Beverley Assessment Area, South Australia. Golder Associates Pty Ltd. (Reference 1418522-022-R-Rev0), 1 October 2015.

Golder (2015g). Vapour Mitigation Strategy, Beverley Assessment Area. Golder Associates Pty Ltd (Reference 1418522-009-R-Rev1), 3 August 2015.

Golder (2015h). Preliminary Vapour Intrusion Assessment – Beverley Assessment Area, South Australia. Golder Associates Pty Ltd. (Reference 1418522-021-R-Rev0), 1 October 2015.

Golder (2015i). Assessment Work Summary (April to October 2015): Beverley EPA Assessment Area. Golder Associates Pty Ltd. (Reference 1418522-023-R-RevA), 1 October 2015.

Golder (2016). Beverley Assessment Area, South Australia, Stage 4B Indoor Air Data Report (September 2015). Golder Associates Pty Ltd (Reference 1418522-025-R-Rev0), 13 January 2016.

Government of South Australia (2014). Assessment Process and Next Steps, Clovelly Park Mitchell Park, Environmental Management Project. Government of South Australia, November 2014.

Hers et al. (2003). Evaluation of the Johnson and Ettinger Model for Prediction of Indoor Air Quality. Hers, I., Zapf-Gilje, R., Johnson, P.C., Li, L. Groundwater Monitoring and Remediation, 23(1), 62-76, 2003.

Johnson and Ettinger (1991). Heuristic model for predicting the intrusion rate of contaminant vapours in buildings. Johnson, P.C., Ettinger, R.A. Environ. Sci. Technol. 25: 1445-1452. 1991

Johnson (2002). Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapour Intrusion Model. Johnson, P.C. American Petroleum Institute Bulletin No. 17, Washington, DC. May 2002.

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

RAIS (2015). Risk Assessment Information System, Chemical Specific Parameters for Trichloroethylene. Oak Ridge National Laboratory, US Department of Energy. Accessed online September 2015.

URS (2007), *Groundwater Monitoring Event-September 2006, 19 Pope Street, Beverley, South Australia*, January 2007

URS (2008), *Electrolux Home Products Additional Environmental Site Assessment, 19 Pope Street, Beverley*, 21 May 2008

URS (2010), Additional *On-site and Off-site Environmental Assessment Report 19 Pope Street, Beverley, South Australia*, May 2010

URS (2012), *Groundwater and Soil Investigation and Detailed Risk Assessment for the Former Electrolux Washing Plant, 19 Pope Street, Beverley, South Australia*, August 2012

URS (2014), *Groundwater Well Installation and Monitoring, 19 Pope Street, Beverley, South Australia*, August 2014

US EPA (2004). User's Guide for Evaluating Subsurface Vapour Intrusion into Buildings. Prepared by Environmental Quality Management Inc., for United States Environmental Protection Agency, Office of Emergency and Remedial Response. Revised, February 2004.

US EPA (2012). EPA's Vapour Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings. United States Environmental Protection Agency, Office of Solid Waste and Emergency Response (publication EPA 530-R-10-002), March 2012.

US EPA (2015). OSWER Technical Guide for Assessing and Mitigating the Vapour Intrusion Pathways from Subsurface Vapour Sources to Indoor Air. United States Environmental Protection Agency, Office of Solid Waste and Emergency Response. (OSWER Publication 9200.2-154), June 2015.

Report Signature Page

GOLDER ASSOCIATES PTY LTD

Mark Peterson
Senior Environmental Scientist

Alex Blount
Senior GeoEnvironmental Engineer

MP:AB/JC:JF/sjm

A.B.N. 64 006 107 857

\\golder.gds\gap\adelaide\jobs\1. active\3. project\1546385 epa _stage 2 vapour_beverley\correspondence out\rev 0\hhra report\1546385-002-r-rev0.docx