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PARSONS BRINCKERHOFF
A BALFOUR BEATTY COMPANY

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Executive summary

Parsons Brinckerhoff was commissioned by the Environment Protection Authority (EPA) in February 2014 to undertake an additional Environmental Assessment of a nominated area of Hendon, South Australia, that included properties located in the general vicinity of 3–5 Philips Crescent. Previous investigations undertaken by Parsons Brinckerhoff within this area have identified elevated concentrations of metals (cadmium, cobalt, copper, nickel, zinc), nitrate, chloride, sulphate and volatile organic compounds (VOCs) (tetrachloroethene (PCE), trichloroethene (TCE), 1,1-dichloroethene (1,1-DCE), chloroform, 1,2-dichloroethane and vinyl chloride) in the shallow aquifer that exceed one or more of the adopted groundwater beneficial use criteria (i.e. marine ecosystem, potable, recreational and/or irrigation).

Objectives

The main objectives of this additional environmental assessment were:

- lateral delineation of VOC groundwater contamination in the Q1 aquifer in the areas to the north and south-east of the industrial area
- assess potential vapour intrusion risk to residents to the north of the industrial area associated with the designated VOC impacts (i.e. 1,1-DCE, *cis* and *trans* 1,2-DCE, TCE, PCE and vinyl chloride)
- obtain additional soil vapour and groundwater data from existing vapour bores and groundwater wells during the summer period
- obtain sub-slab and crawl space vapour data from beneath the child care centre
- utilise the additional data to update the risk assessment for sensitive land uses (i.e. residential properties and child care centre); and
- assess the potential for a preferential pathway for contaminant migration along West Lakes Boulevard and/or Tapleys Hill Road.

A secondary objective if the additional environmental assessment was to obtain data which can be used to assess likely source areas and plume configuration, including the degradation status of the identified plume(s).

Following the receipt initial crawl space vapour data, additional assessment of crawl space vapour and indoor and outdoor air at the First Steps Child Care Centre site was implemented to further assess potential vapour risks at this property.

Scope of work

The scope of work included further assessment of groundwater, soil vapour and ambient air, followed by the completion of a supplementary vapour risk assessment to update the previous risk assessment completed based on data obtained by Parsons Brinckerhoff in 2013. In addition, as assessment of geochemistry was completed to assist in the characterisation of the shallow Q1 aquifer and interpretation of potential contaminant source areas. Specific elements of the additional assessment works including the following:

Groundwater assessment

- Installation and development of five new groundwater monitoring wells (MW23 to MW27) to depths of between 5.5 and 6.0 mBGL.
- Collection and PID screening of soil samples from each soil bore.
- Analysis of selected soil samples for moisture content, TOC and SA EPA waste screens.
- Well gauging, and sampling of previously installed wells and new wells in the Investigation Area.

- Analysis of all groundwater samples for ultra-trace VOCs, natural attenuation parameters and major ions.

Soil vapour assessment

- Drilling of two soil vapour bores (SV16 and SV17), to depths of 2.1 mBGL.
- Soil vapour sampling from the two new bores and all previously installed soil vapour bores in the investigation area, with analysis for VOCs (including trichloroethene, tetrachloroethene, 1,1-dichloroethene, 1,2-dichloroethene (*cis*- and *trans*-), vinyl chloride) and general gases.

Sub-slab, crawl space and ambient air vapour assessment at First Steps Child Care Centre

- Collection of a sub-slab sample using a Vapour Pin^{tm} through the concrete slab within the Child Care Centre, with analysis of the sample for VOCs.
- Collection of an initial vapour sample within the crawl space using a silonite canister sampling over an eight hour period.
- Collection of additional crawl space samples from the initial location and three other locations using both summa canisters over a 24 hour period and Radiello passive samplers over a 10 day period, in addition to re-sampling the initial location with a summa canister over an 8 hour period.
- Collection of five indoor air samples (from within different rooms in the child care centre), and one outdoor air sample using summa canisters sampling over a 24 hour period.
- Collection of five indoor air samples (from the same rooms as the summa canister sampling) and one outdoor air sample using Radiello passive samplers).
- Collection of a vapour sample using a Radiello passive sampler within a grease trap pit located at the rear of the First Steps Child Care Centre.
- Performance of a (conservative) screening vapour risk assessment (VRA) based on the concentrations of designated VOCs (tetrachloroethene (PCE), trichloroethene (TCE), 1,1-dichloroethene (1-1-DCE), *cis*-1,2-dichloroethene (*cis*-DCE), *trans*-1,2-dichloroethene (*trans*-DCE), vinyl chloride and ethene) measured during the groundwater and soil vapour monitoring program.

Conclusions

Based on the available data, including data from the previous phases of assessment, and the results of a site-specific VRA, it is concluded that:

- Due to the presence of elevated concentrations of chloride, sulphate, nitrate, metals (cadmium, cobalt, copper, nickel, zinc) and VOCs within shallow groundwater beneath the investigation area, it is not suitable for a range of beneficial uses, including marine ecosystem protection, potable, recreational and irrigation uses.

- The lateral extent of groundwater VOC contamination has been reasonably delineated and includes the majority of the Hendon Industrial Area and residential areas to the north, south and west.

- Based on the observed concentrations of VOCs and an assessment of the geochemical data it is inferred that a number of contaminant sources are likely within the Hendon industrial area (i.e. the area bounded by Tapleys Hill Road to the west, West Lakes Boulevard to the south, Gordon Street to the east and Farman Avenue to the north. Potential source areas (and source chemicals) include:
    - the property at 3-5 Phillips Crescent (PCE/TCE/1,2-DCE)
    - a property to the south-east of 3-5 Phillips Crescent, north of West Lakes Boulevard (PCE/1,2-DCE)
    - a property within the north-eastern portion of the industrial area, between MW14 and MW23 (PCE/TCE)
    - possibly a property between well MW18 and Tapleys Hill Road (TCE).

- It is also considered possible that the deep sewer beneath Tapleys Hill Road, the western portion of Circuit Drive, Farman Avenue and possibly other portions of the investigation area could act as a preferential pathway for migration of chlorinated hydrocarbon impacts.
- A significant increase in TCE concentration was recorded in soil vapour bore SV10, to the north of the industrial area. The significant increase in recorded soil vapour concentrations in this area warrants further evaluation of the contamination and sub-surface conditions in the area.
- A supplementary vapour risk assessment was conducted to determine if the designated chlorinated compounds pose vapour risks to residential receptors, including those using the Child Care Centre and schools in the Investigation Area, based on the latest assessment results. The supplementary vapour risk assessment concluded that:
  - Based on the measured indoor air concentrations of the designated VOCs, the health risks associated with inhalation of the designated VOCs at the First Steps Child Care Centre are considered to be acceptable
  - The health risks associated with indoor vapour intrusion of the designated VOCs within the residential areas (based on consideration of slab on ground construction) are currently considered acceptable, and mitigated on the basis of the moisture content and geotechnical properties of the soil
  - The designated VOCs may pose vapour intrusion risks in the future, drawing on the findings of the sensitivity analysis, if increased vapour volatilisation due to changes in concentrations and soil conditions (particularly the reduction in soil moisture content) occurs.
- Additional targeted assessment to confirm geotechnical soil properties (including moisture content), variations in vapour and groundwater conditions, and housing construction details within the residential area should be considered to further verify the conclusions of the VRA for the wider area of investigation. Further assessment of temporal variation of VOCs within the Child Care Centre should also be considered.
- The source of the detectable concentrations of TCE within the Child Care Centre crawl space has not been confirmed. It is possible that the identified TCE could be associated with migration from underlying soil/groundwater, unidentified preferential migration pathways or source(s). Further assessment of soil gas concentrations from immediately below the Child care Centre would be required to determine if the elevated crawl space vapour is associated with a sub-surface source.

1. Introduction

1.1 Background information

Parsons Brinckerhoff was commissioned by the Environment Protection Authority (EPA) in February 2014 to undertake an additional Environmental Assessment of a nominated area of Hendon, South Australia, that included properties located in the general vicinity of 3–5 Philips Crescent. A locality map, showing the EPA Investigation Area, is presented as Figure 1 (Appendix A).

Previous investigations undertaken by Parsons Brinckerhoff within this area have identified elevated concentrations of metals (cadmium, cobalt, copper, nickel, zinc), nitrate, chloride, sulphate and volatile organic compounds (VOCs) (tetrachloroethene (PCE), trichloroethene (TCE), 1,1-dichloroethene (1,1-DCE),1,2- (cis & trans) dichloroethene chloroform, 1,2-dichloroethane and vinyl chloride) in the shallow aquifer that exceed one or more of the adopted groundwater beneficial use criteria (i.e. marine ecosystem, potable, recreational and/or irrigation). The results of these investigations are discussed further in Section 3 of this report.

Although the groundwater contaminants are considered likely to have derived, at least partly, from historical activities undertaken at the 3–5 Philips Crescent site, this site has not been confirmed as the source and other possible sources of groundwater contamination are likely to exist within the surrounding area.

This work was undertaken in accordance with our proposal (14-0024-00-RESMGTA929), dated 14 February 2014, and additional assessment works carried out in accordance with our variation proposal for Additional Assessment at the Hendon Child Care Centre dated 10 April 2014.

1.2 Objectives

The main objectives of this additional environmental assessment were to:

- delineate groundwater VOC contamination in the Q1 aquifer in the areas to the north and south-east of the industrial area (it is noted that vertical delineation of contaminants of concern is not included in the work scope)
- assess any potential vapour intrusion risk to residents to the north of the industrial area associated with the VOC impacts (i.e. 1,1-DCE, *cis* and *trans* 1,2-DCE, TCE, PCE and vinyl chloride)
- obtain additional soil vapour and groundwater data from existing vapour bores and groundwater wells during the summer period
- obtain sub-slab and crawl space vapour data from beneath the child care centre
- utilise the additional data to update the vapour risk assessment for sensitive land uses (i.e. residential properties and child care centre); and
- assess the potential for a preferential pathway for contaminant migration along West Lakes Boulevard and/or Tapleys Hill Road.

A secondary objective if the additional environmental assessment was to obtain data which can be used to assess likely source areas and plume configuration, including the degradation status of the identified plume(s).

Following the receipt initial crawl space vapour data, additional assessment of crawl space vapour and indoor and outdoor air at the First Steps Child Care Centre site was implemented to further assess potential vapour risks at this property.

2. Site characterisation

2.1 Regional geology

The Adelaide 1:250,000 geological map sheet (South Australian Department of Mines and Energy, 1969) indicates that the region is underlain by the Quaternary (Pleistocene) Pooraka Formation which is comprised of pale red-brown sandy clay containing carbonate of the Loveday soil.

According to the Australian Soil Resource Information System (ASRIS) website (http://www.asris.csiro.au/mapping/viewer.htm), the area of Adelaide that includes the site has an extremely low probability of containing acid sulphate soils (although this is based on limited data).

2.2 Regional hydrogeology

A total of six Quaternary aquifers (Q1 to Q6) have been identified in the Adelaide region and are underlain by a series of deeper Tertiary aged aquifers (T1 to T4), the latter considered to be essentially confined.

The aquifers identified within the Quaternary age sediments of the Adelaide Plains are typically found within the coarser interbedded silt, sand and gravel layers and vary greatly in thickness (typically from 1 to 18 m), lithology and hydraulic conductivity. The confining beds between the Quaternary aquifers consist of clay and silt and range in thickness from 1 to 20 m. These confining beds are absent in some areas, allowing hydraulic connection between the aquifers.

Table 2.1 details the main aquifers located beneath the Adelaide region (South Australian Department of Mines and Energy, 1992).

Table 2.1 Adelaide Plains aquifer geology

Aquifers	Rock Type	Geological Units	Age
Shallow aquifers	Sand and gravel in clay	Pooraka Formation Hindmarsh Clay	Quaternary
Deep aquifer T1	Sand, sandstone and limestone	Dry Creek Sands Hallett Cove Sandstone Port Willunga Formation	Tertiary
Confining bed	Clay with limestone layers	Munno Para Clay	
Deep aquifer T2	Limestone and sand	Port Willunga Formation	
Confining bed	Siltstone and claystone	Port Willunga Formation (Ruarung Member and Aldinga Member)	
Deep aquifer T3	Limestone and sandstone	Port Willunga Formation (Lower Aldinga Member and Chinaman Gully Formation)	
Confining bed	Siltstone	Blanche Point Formation Tortachilla Limestone	
Deep aquifer T4	Sand	South Maslin Sand	
Confining bed	Clay	Clinton Formation	
Fractured bedrock aquifer	Quartzite and siltstone	Adelaidean System	Precambrian

A summary of the Department of Environment, Water and Natural Resources (DEWNR, 2014) bore database for the area (Appendix B) indicates that there are 472 registered bores within a 2 km radius of the Tapleys Hill Road – West Lakes Boulevard intersection, 449 of which are groundwater bores. Of the groundwater bores, 40 were listed as backfilled, 36 were listed as operational, 11 as abandoned, six as unknown and two as plugged. The current status of the remaining 354 bores was not listed. In terms of their primary purpose, 119 bores were listed as being for investigation purposes, 66 bores were listed as being for domestic purposes, 49 bores for monitoring purposes, 45 bores for observation purposes, 15 bores for irrigation purposes, 14 bores for drainage purposes, three bores for industrial purposes, one bore for town water supply purposes, one bore for environmental and observation purposes, one bore for environmental and recreational purposes, one bore for investigation and observation purposes, and one bore for irrigation and observation purposes. The purpose/s of the remaining 133 bores were not listed.

Based on information contained in the database, the wells were drilled to depths of between 1.83 and 604.42 m between 1914 and 2014. Standing water levels (SWLs), recorded for 333 of the bores, ranged from approximately 0.91 to 32 m below ground level (mBGL). Groundwater salinity, recorded for 225 bores, ranged from 200 mg/L to 56,874 mg/L total dissolved solids (TDS), with the majority of bores recording salinity greater than 2,000 mg/L. Shallow wells drilled to depths of up to 12 m recorded standing water levels of 1.0 to 7.0 mBGL and salinity levels between 200 and 26,382 mg/L TDS.

The majority of the bores closest to the investigation area listed in the DEWNR bore database relate to shallow observation wells (drilled to 6 m depth) installed on and around the Philips Crescent site, observation wells (drilled to depths of up to 10 m) installed between Cedar Avenue and Tapleys Hill Road (north of Hendon Primary School) and investigation wells (drilled to depths of up to 7.5 m) installed south of Myrtle Street between Cedar Avenue and Tapleys Hill Road.

Table 2.2 lists wells recorded to be for domestic or irrigation purposes within the EPA Investigation Area.

Table 2.2 Registered domestic and irrigation bores within EPA investigation area

Well ID	Well depth (m)	rSWL (mAHD)	Purpose	Salinity (mg/L TDS)
6628-16431	12	1.82	Domestic	1552
6628-21134	13	0.39	Domestic	4479
6628-19312	12	0.9	Domestic	4465
6628-16955	16	–	Domestic	6062
6628-19364	12	0.96	Domestic	2171
6628-14240	10	2.6	Domestic	3482
6628-15679	6	3.05	Domestic	2756
6628-17495	15	–	Domestic	6338
6628-21109	10	ABANDONED	Domestic	5081
6628-19011	11.5	1.64	Domestic	6251
6628-15616	8	3.39	Domestic	–
6628-18862	12	-0.48	Domestic	7144
6628-18405	18	–	Domestic	8476
6628-12525	12.1	2	Domestic	3137
6628-15208	10	-2	Domestic	9873
6628-8635	128.93	-8.35	Irrigation	50540

3. Previous investigations

Previous investigations undertaken at the Philips Crescent site and surrounding area provided to Parsons Brinckerhoff by EPA are summarised below.

3.1 Environmental Site Assessment (Coffey Partners, 1992)

The results of an ESA previously undertaken for the site were detailed in the following report:

- Coffey Partners International Pty Ltd (1992a) *Delen Corporation Site, 3-5 Philips Crescent, Hendon Environmental Site Assessment Summary Report.* Report A2300/1-BD, dated August 1992 (two volumes).

Coffey Partners undertook an ESA at the site with the aim of identifying and characterising surface soil and groundwater contamination and initiating remediation of the site for proposed continued commercial/industrial land use. The program included some short term remediation (removal of liquid wastes and chemical residues), assessment of soil vapour and sampling of soil and groundwater.

The results were interpreted to indicate the following:

- soils at the site consisted of interbedded clays, sands and silts
- the depth to groundwater was approximately 3.5 mBGL with an interpreted flow direction towards the west, south-west and north-west at different locations on the site
- soil contained elevated concentrations of metals, boron and fluoride. It was concluded that deeper contamination may have also existed around some sumps and remediation of those areas was proposed.

Groundwater impacts were also identified, with elevated concentrations of metals, boron, fluoride, and VOCs detected. It was noted that arsenic and VOC contamination may have originated from off-site sources.

3.2 Second Stage Environmental Site Assessment and Site Remediation (Coffey Partners, 1992)

The results of the second stage of an ESA previously undertaken for the site were detailed in the following report:

- Coffey Partners International Pty Ltd (1992b) *Delen Corporation Site, Philips Crescent, Hendon, SA. Second Stage Environmental Site Assessment and Site Remediation,* report A2300/2-AQ, dated October 1992 (two volumes).

In the second stage ESA, Coffey Partners aimed to further assess the extent of soil contamination (particularly around the underground tanks), leachability of soil contaminants, quality of groundwater and the extent of groundwater impacts. To achieve these objectives, they undertook the collection of soil samples, installation of additional groundwater wells (two on-site and seven off-site), assessment of groundwater hydraulic parameters and surveying.

The results were interpreted to indicate the following:

- groundwater flow direction was inferred to be north-westerly, with shallow gradients noted and low permeability calculated for the shallow aquifer
- elevated soil metal concentrations were found in the vicinity of the sumps
- copper was found to be leachable from soil and was therefore inferred to have contributed to some of the on-site groundwater impacts, along with underground tank leakage and dispersion of contaminants
- elevated levels of metals and VOCs were detected within on-site groundwater and it was concluded that VOC impacts may have been due to both on-site and off-site sources. Although on-site sources may have included the surface dumping of solvents, specific source locations were not identified. It was also noted that high concentrations of VOCs were detected in groundwater from monitoring well GW10, comprising the most southerly located bore on West Lakes Boulevard.

It was stated that discussions with government agencies had resulted in the South Australian Health Commission (SAHC) not requiring the removal or covering of the shallow soil impacts, provided that the land use remained commercial/industrial.

3.3 Soil Gas Survey (Coffey Partners, 1992)

The results of a soil vapour survey previously undertaken for the site were detailed in the following report:

- Coffey Partners International Pty Ltd (1992c) *Delen Corporation Site, 3-5 Philips Crescent, Hendon, SA. Results of Soil Gas Survey and Preliminary Costings of Selected Site Remediation/Options*, report A2300/3-AD, dated December 1992.

This report presented the results of a soil vapour survey aimed at determining the source of identified volatile chlorinated hydrocarbon (VCH) impacts, as well as concepts and cost estimates for selected groundwater remediation options.

The methodology used was to assess soil gas using a photo-ionisation detector (PID) as a screening assessment and then to further assess high readings using a portable gas chromatograph (GC).

The results were interpreted to indicate the following:

- although no specific VOC leakage or dumping could be confirmed, soil gas concentrations of VOCs were widespread
- an unacceptable health risk may exist for site users and possible nearby residents. Further soil gas surveys and guidance from the SAHC was recommended
- preliminary modelling suggested that the use of interception drains may assist in the removal of contaminated groundwater beneath the site.

3.4 Environmental Site Assessment (Parsons Brinckerhoff, 2012)

The results of an ESA undertaken in the area surrounding the 3-5 Philips Crescent site were detailed in the following report:

- Parsons Brinckerhoff (2012) *Environmental Site Assessment Report, Hendon, SA*, report number 12-01-2171471A, dated 22 March 2013.

The investigation area included properties located in the general vicinity of the Philips Crescent site and the main aims of the investigation were to:

- provide updated groundwater contamination data for areas surrounding the Philips Crescent site
- provide preliminary soil vapour VOC concentrations in selected areas; and
- assess the potential vapour risk to residents and occupants of a nearby child care centre (*First Steps*) and the Hendon Primary School based on the concentrations of VOCs found in groundwater and soil vapour.

The scope of work undertaken in September 2012 included the following:

- drilling of ten soil bores to depths of 4.5 to 5.5 mBGL within sensitive land use areas to the south and west of the Philips Crescent site and analysis of selected soil samples for VOCs
- conversion of the soil bores to groundwater monitoring wells, followed by gauging and sampling of the wells (along with two existing wells) for total cyanide, metals, polychlorinated biphenyls (PCBs) and ultra-trace VOC analysis
- drilling of five soil vapour bores to depths of between 1.1 and 2.2 mBGL adjacent to five of the newly installed monitoring wells, followed by soil vapour and ambient air sampling for selected VOCs; and
- performance of a (conservative) screening vapour risk assessment (VRA) based on the concentrations of designated VOCs (tetrachloroethene (PCE), trichloroethene (TCE), 1,1-dichloroethene (1-1-DCE), *cis*-1,2-dichloroethene (*cis*-DCE), *trans*-1,2-dichloroethene (*trans*-DCE), vinyl chloride and ethene) measured during the groundwater and soil vapour monitoring program.

The results of the ESA undertaken in the Hendon investigation area indicated the following:

- The shallow (typically 3 to 4 mBGL) unconfined aquifer that underlies this area is located within interbedded sands and clays (with hydraulic conductivity values of up to 3.4 m/day), and inferred to flow in a westerly direction towards Boating Lake (West Lakes).

- Due to elevated concentrations of metals and VOCs within the shallow aquifer beneath the nominated investigation area, the groundwater is not suitable for a range of beneficial uses, including marine ecosystem protection, potable, recreational and irrigation uses. The extent and source(s) of the groundwater impacts have not yet been determined and the status of the underlying aquifer(s) has not been investigated.

- The VRA identified PCE and TCE in groundwater as the chemicals of concern which triggered soil vapour investigations to assess the potential vapour risk to the local residents or the occupants of the First Steps Child Care Centre and Hendon Primary School.

- The results of the VRA indicated that vapour risks associated with the measured soil vapour concentrations within the residential area and at the First Steps Child Care Centre as well as Hendon Primary School, using the site-specific geotechnical data are below the assessment criteria and considered to be tolerable.

- A sensitivity analysis was conducted to account for the uncertainties associated with elevated saturation identified in the geotechnical analysis. The sensitivity analysis indicated the soil vapour concentration of TCE marginally exceeded the assessment criteria when soil with lower water content was adopted in the vapour intrusion model. Hence, further soil vapour investigations may be considered to validate these outcomes.

- Although TCE in well GW9 was interpreted as unacceptable for a residential area, this well is located in an area of commercial/industrial land use, adjacent to the Philips Crescent site, and is therefore not considered representative of conditions associated with more sensitive land uses further to the south and west. An assessment of vapour risks associated with commercial/industrial land use was beyond the scope of this investigation.

3.5 Additional environmental site assessment (Parsons Brinckerhoff, 2013)

The results of an additional ESA undertaken in the area surrounding the Philips Crescent site were detailed in the following report:

- Parsons Brinckerhoff (2013) *Additional Environmental Site Assessment*, report number 13-0267-01-2171471B, dated 30 October 2013.

The main aims of this additional ESA were to:

- provide additional groundwater and soil vapour data to allow assessment of potential temporal variations and confirm the results of the previous vapour risk assessment
- provide additional soil vapour data in the vicinity of the First Steps Child Care Centre to confirm that vapour intrusion risks in this area are acceptable
- undertake additional assessment of the lateral extent of groundwater contamination to assist EPA in the determination of an appropriate groundwater abstraction exclusion zone
- undertake additional soil vapour assessment to the north, south and east of the previously assessed area to allow assessment of potential vapour risks to residents in these areas
- assess selected service pits to determine whether service trenches may be providing preferential migration pathways for VOC vapours; and
- obtain additional information regarding the potential for natural attenuation of chlorinated contaminants.

The scope of work undertaken included the following:

- installation of ten groundwater monitoring wells to depths of between 5.5 and 6.0 mBGL
- installation of two double cased groundwater wells to depths of 9.4 to 11.5 mBGL to further characterise the vertical spread of TCE contamination
- gauging and analysis of all groundwater samples (including 14 existing wells) for ultra-trace VOCs, metals (Cd, Co, Cu, Ni and Zn) and natural attenuation parameters (nitrate, ferrous iron, sulphate, sulphide, methane, chloride, TOC, alkalinity)
- drilling of ten soil vapour bores to depths of between 2.0 and 2.2 mBGL, followed by soil vapour sampling (including five existing soil vapour bores) for selected VOCs
- installation of three Radiello passive samplers within service pits around the First Steps Child Care Centre and three passive samplers along the western side of West Lakes Boulevard (i.e. adjacent to the residential area), followed by analysis for VOCs; and
- performance of a (conservative) screening vapour risk assessment (VRA) based on the concentrations of designated VOCs (PCE, TCE, 1-1-DCE, *cis*-DCE, *trans*-DCE, vinyl chloride and ethene) measured during the groundwater and soil vapour monitoring program.

Based on the results of this investigation it was concluded that:

- The shallow groundwater beneath the investigation area is not suitable for a range of beneficial uses, including marine ecosystem protection, potable, recreational and irrigation uses, due to the presence of elevated concentrations of chloride, sulphate, nitrate, metals (cadmium, cobalt, copper, nickel, zinc) and VOCs.

- Groundwater contamination was identified north of the Philips Crescent site, as well as detectable concentrations up-hydraulic gradient and it is likely that there is more than one source of the identified groundwater contaminants from historical industrial activities undertaken on surrounding properties.

- Groundwater VOC contamination has been delineated to the east and south-west of the investigation area.

- Based on the available data, including the use of site-specific geotechnical data and vapour intrusion modelling, the vapour intrusion risks (from identified chlorinated hydrocarbons in groundwater) to the residential receptors, including those using the child care centre and the schools in the nominated area in Hendon are considered to be acceptable.

- Whilst actual soil moisture results were used in the calculation of potential risk, it was noted in the sensitivity analysis that lower soil moistures have the potential to result in vapour concentration exceeding the calculated indoor air threshold concentration. It was therefore recommended that further soil vapour monitoring should be considered in the period (e.g. November to March) with low rainfall to evaluate the vapour risks in the drier season.

4. Scope of work

The scope of the intrusive investigation program was undertaken in accordance with standard Parsons Brinckerhoff field procedures, with reference (where applicable) to the following guideline documents:

- National Environment Protection Council (April 2013), National Environment Protection (Assessment of Site Contamination) Measure 1999.
- SA EPA Guidelines for the Assessment and Remediation of Groundwater Contamination 2009.
- SA EPA Guideline – Regulatory Monitoring and Testing Groundwater Sampling 2007.
- ASTM Guide D5314-92 (2001) Standard Guide for Soil Gas Monitoring in the Vadose Zone.
- Relevant Australian Standards.

A plan of the site, showing all soil vapour and groundwater sampling locations, is presented as Figure 2 with a plan of the First Steps Child Care Centre displaying the sub-slab and crawl space vapour sampling locations presented as Figure 3 (Appendix A).

4.1 Groundwater investigations

Groundwater investigations, undertaken between 13 and 20 March 2014, involved groundwater well installation in areas agreed upon through discussions with the EPA.

The groundwater investigation program involved the following:

- installation of five groundwater monitoring wells (MW23 to MW27) to depths of between 5.5 and 6.0 mBGL
- collection of soil samples from each soil bore at nominal depths of 0.35–0.5 m, 0.85–1.0 m and every metre thereafter as well as any additional depth intervals that exhibited visual or olfactory evidence of contamination
- field screening of soil samples using a handheld PID unit to evaluate the presence of VOCs
- to assist in classification of waste soil for disposal, analysis of two soil samples for the SA EPA waste screen, including volatile halogenated compounds
- to assess soil moisture content and the potential for soil contaminants to impact on recorded soil vapour results, analysis of five soil samples for moisture content
- to assist with possible future attenuation modelling, analysis of one soil sample from the approximate depth of the aquifer per location for total organic carbon (TOC)
- development of groundwater wells upon completion of installation and at least seven days prior to sampling
- professional surveying of all wells to Australian Height Datum (AHD)
- well gauging, purging and collection of field readings from newly installed together with the twenty-six existing wells on 18 to 20 March 2014, immediately prior to sampling
- analysis of all groundwater samples for ultra-trace VOCs, natural attenuation parameters and major ions (calcium, magnesium, sodium, potassium, chloride, bicarbonate, sulphate, nitrate, ferrous iron, sulphide, methane, alkalinity, bromide)
- analysis of two blind field intra-laboratory and two blind split inter-laboratory duplicate samples for the above analyses; and
- analysis of equipment rinsate samples for each day of sampling and trip blank samples from each sample batch for ultra-trace VOCs.

4.2 Soil vapour investigations

Soil vapour investigations, undertaken between 13 and 22 March 2014, involved the following:

- drilling of two soil vapour bores (SV16 and SV17), to depths of 2.1 mBGL
- collection of undisturbed soil cores (retained in 63 mm plastic push tube sleeve) from both locations
- field screening of the completed soil vapour bore using a hand-held PID unit
- professional surveying of all soil vapour bores to AHD soil vapour sampling at each location (conducted by SGS Leeder Consulting), at least 6 days after bore installation, for the analysis of trichloroethene, tetrachloroethene, 1,1-dichloroethene, 1,2-dichloroethene (*cis*- and *trans*-), vinyl chloride and general gases (including ethene), as requested by the EPA; and
- analysis of two intra-laboratory duplicate samples for the above analytes.

4.3 Sub-slab, crawl space and ambient air vapour assessment

In order to assess if vapour migration is occurring beneath the First Steps Child Care Centre, the vapour assessment conducted on 22 March 2014 comprised the following:

- installation of a Vapour Pin^{tm} through the concrete slab in accordance with standard procedures and collection of a vapour sample immediately following installation
- collection of vapour sample within the crawl space using a silonite canister sampling over an eight hour period; and
- analysis of samples, including a blank, for VOCs.

Following receipt of the preliminary crawl space vapour analysis, further vapour assessment was conducted and comprised the following:

- collection of a vapour sample from the original crawl space sampling location using a summa canister sampling over an eight hour period on 12 April 2014
- collection of vapour sample at the original crawl space location, plus three additional crawl space locations, including an intra-laboratory duplicate sample, using summa canisters sampling over a 24 hour period from 12 to 13 April 2014
- collection of five indoor air samples (from within different rooms in the child care centre), including one intra-laboratory and one inter-laboratory duplicate sample, and one outdoor air sample using summa canisters sampling over a 24 hour period from 12 to 13 April 2014
- installation of four Radiello passive samplers, including an intra-laboratory duplicate sample, adjacent the 24 hour crawl space canister sampling point on 12 April 2014
- installation of six Radiello passive samplers (five indoor and one outdoor), including an intra-laboratory duplicate sample, within the same five rooms and near the outdoor air sampling location, placed at least 1 m height above the floor on 12 April 2014
- installation of a Radiello passive sampler within a sewer pit located at the rear of the First Steps Child Care Centre on 12 April 2014
- collection of all Radiello passive samplers on 22 April 2014; and
- analysis of all samples, including a blank, for VOCs.

4.4 Quality control program

4.4.1 Groundwater

The QC sampling undertaken as part of the groundwater investigation program is detailed in Table 4.1.

Table 4.1 Summary of groundwater QC program

Analyte	Number of Groundwater Samples Analysed			% Duplicate Samples Relative to Primary Samples	Number of Blanks Analysed	
	Primary	Field Duplicates (intra-lab)	Laboratory Splits (inter-lab)		Rinsate	Trip
Ultra-trace VOCs	31	2	2	13%	3	4
Major cations/anions	31	2	2	13%	-	-
Natural attenuation	31	2	2	13%	-	-

4.4.2 Soil vapour, sub-slab, crawl space and ambient air

The QC sampling undertaken as part of the soil vapour, sub-slab, crawl space and ambient air investigation program is detailed in Table 4.2.

Table 4.2 Summary of soil vapour, sub-slab, crawl space and ambient air QC program

Analyte	Number of Samples Analysed			% Duplicate Samples Relative to Primary Samples	Number of Trip Blanks Analysed
	Primary	Field Duplicates (intra-lab)	Laboratory Splits (inter-lab)		
Soil vapour					
Trichloroethene	17	2	-	12%	1
Tetrachloroethene	17	2	-	12%	1
1,1-dichloroethene	17	2	-	12%	1
1,2-dichloroethene (*cis*- and *trans*-)	17	2	-	12%	1
Vinyl chloride	17	2	-	12%	1
General gases	17	2	-	12%	-
Sub-slab, crawl space and ambient air vapour					
Canisters					
Trichloroethene	12	2	1	25%	1
Tetrachloroethene	12	2	1	25%	1
1,1-dichloroethene	12	2	1	25%	1
1,2-dichloroethene (*cis*- and *trans*-)	12	2	1	25%	1
Vinyl chloride	12	2	1	25%	1

Analyte	Number of Samples Analysed			% Duplicate Samples Relative to Primary Samples	Number of Trip Blanks Analysed
	Primary	Field Duplicates (intra-lab)	Laboratory Splits (inter-lab)		
Radiello Samplers					
Trichloroethene	11	2	1	27%	1
Tetrachloroethene	11	2	1	27%	1
1,1-dichloroethene	11	2	1	27%	1
1,2-dichloroethene (*cis*- and *trans*-)	11	2	1	27%	1
Vinyl chloride	11	2	1	27%	1

5. Methodology

Prior to the commencement of the field component of the intrusive investigations, a site specific Health, Environment & Safety Plan (HESP) was prepared. All personnel working at the site were required to read, understand, sign and conform to the HESP.

5.1 Soil sampling

Field methodologies adopted during the soil sampling program were consistent with Parsons Brinckerhoff ESA Field Procedures and have been summarised in Table 5.1.

Table 5.1 Soil investigation methodology

Activity	Details
Service Location	All drilled locations were checked for the presence of buried services by a professional services locator before the commencement of the field investigations. In addition, underground service plans for the area were obtained prior to the commencement of the investigations and were used to assist with locating underground services.
Soil Collection Method	Soil bores were hand augered and/or drilled, the latter using pushtube and solid flight auger techniques, by a professional drilling company.
Soil Logging	Soil logging was based on field interpretation and was consistent with AS 1726-1993.
Field Screening	Soil samples were screened in the field using PID units that were calibrated to a known concentration of isobutylene gas prior to use. Instrument calibration data are included in Appendix C. The PID unit was fitted with a 10.6 eV globe, considered suitable for the field screening of the majority of common volatile contaminants of concern.
Soil Sampling Method	Soil cores were discharged from the pushtubes into a clean core tray and samples were obtained from the relevant intervals. Soil samples were handled using gloves and samples were stored in glass jars supplied by the primary laboratory. Gloves were changed prior to the collection of each sample.
Sample Preservation	Soil samples were stored on ice in an insulated chest immediately after sampling. Samples were kept chilled prior to and during delivery to the laboratory.
Decontamination	Clean drilling and sampling equipment was used for each sampling location and was washed down off-site at the end of each day using mains water and a phosphate free detergent (Decon 90).
Waste Soil Disposal	Waste soil was collected for off-site disposal by a licensed contractor.

5.2 Groundwater well installation and sampling

Field methodologies adopted during the groundwater well installation and sampling program were consistent with Parsons Brinckerhoff ESA Field Procedures and have been summarised in Tables 5.2 and 5.3.

Well permits are included in Appendix D and borehole log reports showing well construction details are included in Appendix E.

Table 5.2 Groundwater well installation methodology

Activity	Details
Well Construction Permits	Individual well permits were obtained from the Department of Environment, Water and Natural Resources prior to well installation.
Service Location	Groundwater well locations were checked for the presence of buried services by a professional services locator before the commencement of the field investigations. In addition, underground service plans for the area were obtained prior to the commencement of the investigations and were used to assist with locating underground services.
Drilling Method	Drilling and installation of the groundwater wells was undertaken by a professional drilling company in accordance with National Uniform Drillers Licensing Commission (2012) *Minimum Construction Requirements for Water Bores*. Drilling involved pushtube and solid flight auger techniques.
Well Construction	All wells were constructed with 50 mm, class 18 uPVC screen and casing and completed with gatic covers. A filter pack comprising clean graded sands and/or gravels of suitable size to provide sufficient inflow of groundwater was installed within the annular space between the borehole and the well casing. The filter pack extended from the base of the screened interval to 0.5 m above the termination of the slotted casing. In order to minimise the likelihood of surface water or perched groundwater infiltrating the aquifer, a bentonite plug, comprising pelleted or granulated bentonite, was placed above the filter pack to a minimum thickness of 0.5 m. Grout was used to complete the well from the bentonite plug to the surface.
Well Development	In order to ensure interconnection between the aquifer and the well, and to remove drilling fines from the gravel pack and well, each well was developed by purging a minimum of five well volumes and/or until it purged dry.
Well Surveying	Following construction, the location of each groundwater well was surveyed to Geocentric Datum of Australia (GDA) 1994. The highest point on the top of the internal uPVC casing (TOC) was surveyed relative to Australian Height Datum (mAHD) and marked for future gauging reference.
Waste Disposal	Waste soil was collected for off-site disposal by a licensed contractor. Water removed during well development was collected for off-site disposal by a licensed contractor.

Table 5.3 Groundwater assessment methodology

Activity	Details
Well Gauging	All wells were gauged for standing water level (SWL) and the presence of Light Non-Aqueous Phase Liquid (LNAPL) before sampling using an interface meter.
Sampling Method	With the exception of MW07, MW09, MW10, MW20 and MW25 (sampled via bailer due to minimal groundwater present in the well and slow groundwater recharge), groundwater sampling was undertaken using low flow (micropurge) techniques, in accordance with AS/NZS 5667.11:1998 and SA EPA (2007) *Regulatory Monitoring and Testing Groundwater Sampling*, ensuring that: ▪ the flow rate (0.2-0.3 L/min) was regulated to maintain an acceptable level of drawdown (<100 mm), with minimal fluctuation of the dynamic water level during pumping and sampling ▪ groundwater drawdown was monitored constantly during micropurging and sampling using an interface probe ▪ the stabilisation parameters were recorded after every half to one litre of groundwater purged, using a TPS 90FLMV water quality meter (calibrated prior to use) and a flow cell suspended in a bucket with litre intervals marked. Samples were collected once two to three consecutive stabilisation parameters were recorded. Instrument calibration data are included in Appendix C.

Activity	Details
Sample Preservation	All samples were collected in bottles which were supplied by the laboratory and contained the appropriate preservatives (where required). Samples for metals analysis were filtered in the field. All samples were stored on ice in an insulated chest immediately after sampling. Samples were kept chilled prior to and during delivery to the laboratory.
Equipment decontamination	In order to minimise the potential for cross-contamination, the disposable bladder and sample tubing or bailer were replaced prior to each sampling event and the pump casing was cleaned with a Decon 90 (phosphate-free) solution between individual groundwater wells.
Wastewater Disposal	Water removed during well purging was collected for off-site disposal by a licensed contractor.

5.3 Soil vapour bore installation

Shallow soil bores were drilled using pushtube drilling techniques, as described in Section 5.1. They were converted to vapour wells by backfilling with 0.1 m of clean washed sand, a ¼” diameter stainless steel vapour implant (105 mm in length) installed and embedded within another 0.35 m of clean washed sand. A Swagelock union joined the vapour implant to ¼” OD Teflon tubing guaranteed to be volatile free. The top of the sand interface was plugged with bentonite and the installation completed with grout and a gatic cover.

This methodology decreased the zone of impact to the depth of the backfilled sand (0.45 m) to allow for more targeted investigations of sandy lenses within the sand/clay soil matrix.

5.4 Soil vapour, sub-slab, crawl space and ambient air sampling

SGS Leeder Consulting were subcontracted to undertake the sampling and analysis of the two newly installed wells, fifteen existing wells, sub-slab, crawl space and ambient air sampling.

Field methodologies adopted during the soil vapour, sub-slab, crawl space and ambient air sampling program were consistent with ASTM Guide D5314-92 (2001) *Standard Guide for Soil Gas Monitoring in the Vadose Zone* and have been summarised in Tables 5.4 and 5.5, respectively.

Table 5.4 Soil vapour assessment methodology (active sampling)

Activity	Details
Sampling locations	Vapour samples were collected at seventeen locations (SV01 to SV17) within the investigation area.
Sampling Method	Vapour sampling was undertaken by a professional company (SGS Leeder Consulting). Each sampling location was first purged onto a carbon tube using a calibrated pump and rotameter for 3 minutes at 100 mL/min. A mass flow meter is used to calibrate the rotameter on the day of sampling and a vacuum gauge was used to measure the formation vacuum during purging. Teflon tubing from the vapour probe was connected to the sampling equipment. VOCs were collected from each vapour sampling point using specially cleaned and certified Entech silonite 1.4 L canisters (equivalent Summa). At each sample location a dedicated soil gas sampling train with flow restrictor was connected to the canister to ensure the flow rate did not exceed the pre-determined rate of 200 mL/min. To calculate the volume of sample drawn into the canister, the vacuum pressure is recorded at the start and end of sampling. The vacuum pressure was set to -30”Hg (prior to sampling) and sampling ceased when vacuum reached -5”Hg. Upon receipt at the laboratory, the canister vacuum pressure is measured to determine if any leaks during transit have occurred.

Activity	Details
Leak testing	A liquid leak check compound, i.e. isopropyl alcohol, was employed. This involved applying the liquid leak check compound to a towel which is placed around the surface completion of the probe. Vapour samples were then collected using silonite canisters and analysed for the presence of the leak check compound. In addition, an isopropyl alcohol shroud sample was collected onto a carbon tube as a check of the concentration of the compound at the surface completion of the probe.
Back up sampling	SGS Leeder collected backup samples onto a carbon sorbent tube at the majority of locations (i.e. all locations except SV10, where pump failure occurred after collection of the canister sample). The sampling flow rates were set at the commencement of sampling and checked during the sampling run. To enable calculation of the sample volume collected on each sorbent tube, the sampling time was accurately recorded. These samples were placed on hold at the laboratory and are only utilised if concentrations are too high to quantitate via the TO-15 method.

Table 5.5 Sub-slab, crawl space and ambient air assessment methodology

Activity	Details
Sampling location	Photographs of all sampling locations are presented in Appendix I. A visual inspection of the Child Care Centre was completed to assess any potentially significant vapour sources within the building which could impact on the air monitoring results. The sub-slab sample was collected through a portion of the concrete slab from within an internal room of the First Steps Child Care Centre. Five crawl space samples were collected from within the First Steps Child Care Centre crawl space utilising certified 6 litre Summa canisters. An initial crawl space sample was collected from one location (CS1) on 22 March 2014, followed by the crawl space from four locations (including repeating the initial location) using both Radiello passive samplers and Summa canisters commencing on 12 April 2014. Five indoor air samples were collected from within different rooms in the First Steps Child Care Centre and one outdoor air sample was collected on the eastern side of the building within a sand pit play area. These were collected utilising 6 litre Summa canisters which were generally placed on the floor such that the sampling point was approximately 300 mm above the floor. The sampling location within the office area (IAC5) was placed on the desk and the sampling location within the baby room was placed within a cot (IAC2). Within each room where the canister samples were collected a Radiello passive sampler was placed approximately 1-1.5 m above ground level. In addition, a Radiello sampler was place approximately 1.8 m above ground level outside of the building to sample outdoor air Due to disturbance by children at the site two of the sampling locations (IAR3 and IAR4) were re-located to approximately 1.6 m above floor height after approximately 46 hours from the commencement of sampling. The Radiello sampling period included a weekend (2 days), 4 days of child care centre operation and the Easter break (4 days), to give a total sampling period of approximately 10 days. One Radiello passive sampler was also suspended for the same period within a grease arrestor pit (connected to the sewer) located at the rear of the First Steps Child Care Centre.

Activity	Details
Sampling Method	Sub-slab sampling was undertaken by SGS Leeder Consulting via installation of a Vapour Pin™. A 1½ inch diameter hole was created, drilling 1¾ inches into the concrete slab, removing drilling fines with a brush. A 5/8 inch diameter hole was drilled through the centre of the previous void and into the underlying soil. The hole was cleaned and drilling fines removed with a brush. The assembled vapour pin was placed within the void, ensuring no obstruction of the pin with sub-slab material. Following installation a protective cap was placed on the vapour pin to prevent vapour loss prior to sampling and the flush mount cover then placed over the vapour pin. ¼" OD Teflon tubing was connected to the male quick connect valve on the vapour pin and following five minutes for the sub-slab soil-gas conditions to equilibrate a sample was collected. Crawl space sampling was undertaken by SGS Leeder Consulting, assisted by a Parsons Brinckerhoff field scientist. Canister samples (8hr and 24hr) were collected by drilling a , 16 mm diameter hole through the timber floor boards and inserting ¼" OD Teflon tubing connected from the canister through the hole and extending to approximately the mid point of the crawl space. Samples were collected over both 8 and 24 hour periods into laboratory prepared and certified canisters using calibrated flow controllers. Ambient air samples were also collected into cleaned and certified canisters using flow controllers to collect a sample over a 24 hour period. Due to site logistical constraints the canister sampling was carried out over a weekend (Saturday to Sunday) when the centre was not in operation. The samples were collected by SGS Leeder Consulting and Parsons Brinckerhoff using canisters provided by NMI and Envirolab. The Radiello sampling system is a passive sampler which works on gaseous molecules passing through the diffusive body followed by absorption onto the internal cartridge. Passive sampling in the crawl space was undertaken by SGS Leeder Consulting by drilling a 35 mm diameter hole through the floor boards adjacent to the canister sampling point. The Radiello sampler was suspended from the floor boards with wire and the penetration hole sealed with a timber cover. The ambient air Radiello samplers were hung or attached to walls within different rooms of the child care centre, plus one attached to an outside wall and one suspended within a sewer pit, and collected by SGS Leeder after 10 days.
Leak testing	The liquid leak check compound isopropyl alcohol was employed during the sub-slab sample collection using the method described in Table 5.4 above.

5.5 Laboratory analysis

All primary soil and groundwater samples, as well as blind field (intra-laboratory) duplicate (groundwater) samples were submitted to Australian Laboratory Services (ALS) for analysis. Laboratory split (inter-laboratory) duplicate groundwater samples were submitted to Eurofins MGT. Both of these laboratories were accredited by the National Association of Testing Authorities (NATA) for the analyses performed.

Soil vapour, sub-slab, Radiello and the original crawl-space (eight hour) vapour sample was submitted to the SGS Leeder Consulting Laboratory in Victoria which was NATA accredited for all analyses performed.

The subsequent eight hour crawl space vapour sample and laboratory split (inter-laboratory) duplicate 24 hour ambient air vapour sample was submitted to Envirolab Group which was NATA accredited for all analyses performed.

The 24 hour crawl space, indoor air and outdoor air vapour samples, as well as blind field (intra-laboratory) duplicate samples were submitted to National Measurement Institute (NMI) which was NATA accredited for all analyses performed.

6. Screening criteria

In order to assess the relative concentration and significance of any potential contaminants detected through laboratory analysis it is usual to reference established human health and environmental screening criteria. These contaminant screening criteria represent threshold concentrations of specific contaminants which, if exceeded in a particular sample, may pose a health or environmental risk and may therefore warrant further site specific investigation or risk analysis.

All criteria adopted for the assessment of the soil and groundwater results are presented in the analytical results tables (Appendix F) and results exceeding the adopted criteria have been highlighted.

6.1 Off-site disposal of soil

In order to classify the soil for off-site disposal, the total soil data (from two monitoring well sampling locations) was compared to the SA EPA (2010) *Current Criteria for the Classification of Waste – including Industrial and Commercial waste (Listed) and Waste Soil* waste fill (WF), intermediate waste (IW) and low level contaminated waste (LLCW) disposal criteria.

6.2 Groundwater

6.2.1 Beneficial use assessment

In accordance with NEPM (1999) Schedule B(6) Guideline on Risk Based Assessment of Groundwater Contamination and SA EPA (2009) Guidelines for the Assessment and Remediation of Groundwater Contamination, a Beneficial Use Assessment (BUA) was undertaken for the site in 2012 and presented in the ESA report (2012). It assessed both the current and realistic future uses of groundwater within the uppermost aquifer beneath the site. This is aimed at determining what groundwater uses need to be protected and assessing the risk(s) that groundwater may pose to human health and the environment. The current DEWNR bore search area was expanded and only one additional beneficial use was identified (i.e. industrial). This beneficial use has therefore been added to the 2012 BUA which will be utilised for the purposes of this report.

Within South Australia, the assessment of groundwater quality is governed by the SA EPA (2003) Environment Protection (Water Quality) Policy (Water Quality EPP). This policy lists the default protected environmental values for groundwater. The BUA, as described in the SA EPA (2009) groundwater guideline document is linked to the Water Quality EPP and needs to identify all beneficial uses of groundwater and other applicable scenarios. The protected environmental values, as well as the beneficial uses of groundwater that need to be protected, are detailed in Table 6.1.

As stated in Section 2.2, a review of the DEWNR (2014) bore database for the area has indicated that there are 449 registered groundwater bores within a 2 km radius of the Tapleys Hill Road – West Lakes Boulevard intersection. In terms of their primary purpose, 119 bores were listed as being for investigation purposes, 66 bores were listed as being for domestic purposes, 49 bores for monitoring purposes, 45 bores for observation purposes, 15 bores for irrigation purposes, 14 bores for drainage purposes, three bores for industrial purposes, one bore for town water supply purposes, one bore for environmental and observation purposes, one bore for environmental and recreational purposes, one bore for investigation and observation purposes, and one bore for irrigation and observation purposes. The purpose/s of the remaining 133 bores were not listed. Groundwater salinity recorded for 275 shallow wells (drilled to depths of up to 12 m) ranged between 200 and 26,382 mg/L TDS.

A summary of the beneficial uses assessed for the site, and considered realistic, is presented in Table 6.1 and the reasoning behind this is discussed below.

Table 6.1 Assessment of groundwater beneficial uses for Hendon

Environmental Values / Beneficial Uses		SA EPA (2003) Protected environmental value	SA EPA (2009) Potential Beneficial Uses	Hendon Beneficial Use Assessment	
				Considered	Realistic
Aquatic Ecosystem	Fresh	✓	✓	✓	No
	Marine	-	✓	✓	Yes
Recreation & Aesthetics	Primary contact	✓	✓	✓	Yes
	Aesthetics	✓	✓	✓	Yes
Potable		✓	✓	✓	Yes (but unlikely)
Agriculture	Irrigation	✓	-	✓	Yes
	Livestock	✓	-	✓	No
	Aquaculture	✓	-	✓	No
Industrial		✓	✓	✓	Yes
Human health in non-use scenarios	Vapour flux	-	✓	✓	Yes
Buildings and structures	Contact	-	✓	✓	No

Maintenance of aquatic ecosystems

The nearest marine water body, located approximately 1 km west of the investigation area, is Boating Lake (also known as West Lakes), which flows into Barker Inlet. Based on a general westerly groundwater flow direction, it is considered possible that shallow groundwater beneath the investigation area could discharge into the marine ecosystem.

Since the nearest freshwater body is the River Torrens, located some 4.5 km to the south of the investigation area, groundwater discharge to a freshwater ecosystem is considered unlikely.

Recreation and aesthetics

Due to the presence of a reticulated mains water supply in the area it is considered unlikely that groundwater would be used by residents for activities such as the filling swimming pools. However, given the relatively close proximity to a down-gradient water body (i.e. Boating Lake) that is used for recreational (e.g. swimming, boating and fishing) purposes, primary contact recreation and aesthetic (smell, colour, clarity and general appearance) issues should be considered.

Potable

From the DEWNR database search, it was identified that 66 bores within 2 km were used for domestic purposes, including 15 within the EPA Investigation Area. Therefore, although the presence of a reticulated mains water supply, and the moderate to high salinity of the groundwater within the investigation area (i.e. up to 15,869 mg/L TDS), indicates that extraction of groundwater for potable use is unlikely, the SA EPA (2009) groundwater guidelines state that “the EPA considers beneficial use of groundwater is potable unless proven otherwise”.

Agriculture

As the DEWNR database search identified 15 bores for irrigation purposes plus bores for domestic use (i.e. which could include irrigation), this is considered a likely beneficial use.

Due the metropolitan location of the site, and the high salinity of the groundwater, it is considered unlikely that groundwater would be used for stock watering purposes.

As no specific aquaculture activities are undertaken within Boating Lake, this has not been considered a realistic beneficial use and the adoption of the marine ecosystem criteria is considered appropriate to assess possible effects on marine species living in the lake and caught for recreational purposes (i.e. fishing).

Industrial

The DEWNR database search identified three bores within 2 km of the investigation area that were listed as being used for industrial purposes, this is therefore considered to be a potential beneficial use.

No specific guidance for industrial water quality is provided in either the Water Quality EPP or the ANZECC/ARMCANZ (2000) Australian Water Quality Guidelines for Fresh and Marine Waters, the latter stating that “the current guidelines provide no specific guidance for industrial water use because industrial water requirements are so varied (both within and between industries) and sources of water for industry have other coincidental environmental values that tend to drive management of the resource”.

Human health in non-use scenarios

As volatile contaminants have been identified within groundwater in the investigation area, it is considered that there is a potential for these contaminants to migrate beneath occupied areas and thus give rise to vapour generation into indoor/outdoor areas. Therefore, the migration of volatile contaminants from groundwater has been considered and the risks are addressed in more detail in Section 10.

Buildings and structures

As discussed in Section 7.2.1, field measurements taken during the recent monitoring event indicate that the pH (6.06 to 8.13) of shallow groundwater is relatively neutral and is unlikely to present a significant risk to built structures. The depth to groundwater (approximately 3.3 to 4.6 mBGL – refer to Section 7.2.1) in this area, suggests that only deep underground structures would be likely to come into direct contact with groundwater.

6.2.2 Health and ecological criteria

The health and ecological screening criteria used for the assessment of groundwater have been based on the results of the BUA.

Based on the fact that the Water Quality EPP has detailed water quality criteria for a range of protected environmental values for groundwater within South Australia, an initial comparison of contaminant concentrations has been made to the criteria contained within Schedule 2 (Table 1) of that document. These criteria have also been used as the basis for determining whether site contamination is present, with respect to groundwater, whereby the laboratory limit of reporting (LOR) has been adopted for an analyte in the absence of a specified Water Quality EPP criterion.

Where criteria are unavailable for certain analytes, reference has been made to alternative Australian and international criteria to assess likely risks to identified beneficial uses.

A summary of the references used to source the health and ecological groundwater screening criteria is provided in Table 6.2.

Table 6.2 Sources of adopted groundwater screening criteria

Beneficial Use	Reference
Marine Ecosystems	SA EPA (2003) *Environment Protection (Water Quality) Policy* – protected environmental values for marine aquatic ecosystems
	NEPM (2013) *National Environment Protection (Assessment of Site Contamination) Measure Schedule B1* – GILs for marine waters
	ANZECC/ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* – trigger values for marine waters (95% protection)
Recreation and Aesthetics	NHMRC (2008) *Guidelines for Managing Risks in Recreational Water* – drinking water guidelines (i.e. with an assumed daily consumption rate of 2 L) adjusted by a factor of 10 to account for a more likely (accidental) recreational water consumption of 100 to 200 L/day*
	ANZECC/ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* – recreational guidelines
Potable	SA EPA (2003) *Environment Protection (Water Quality) Policy* – protected environmental values for potable use
	NHMRC/NRMMC (2011) Australian Drinking Water Guidelines
	WHO (2011) *Guidelines for Drinking-Water Quality*
	US EPA (2013) *Region 9 Screening Levels* – tap water

Note:
* this does not take account of substances that can enter the body through skin adsorption.

6.2.2.1 Health screening levels

The health screening criteria adopted to assess the significance of the groundwater concentrations have been sourced from the National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013 (No. 1), Schedule B1 *Investigation Levels For Soil and Groundwater*, Table 1A(4).Based on the gauging data, groundwater was intersected between 3.3 and 4.6 mBGL. Monitoring well and soil vapour logs for the site describe soil layers as containing sand, therefore the relevant screening criteria is listed in the table below.

Table 6.3 Groundwater health screening levels for vapour intrusion (mg/L)

Sand	HSL-A&B		HSL-D	
Chemical	**2 m to < 4 m**	**4 m to < 8 m**	**2 m to < 4 m**	**4 m to < 8 m**
Benzene	0.8	0.8	5	5
Toluene	NL	NL	NL	NL
Ethyl benzene	NL	NL	NL	NL
Xylenes	NL	NL	NL	NL
Naphthalene	NL	NL	NL	NL

Note:
A&B = Low to high density residential, D = Commercial/industrial

6.3 Soil vapour

To assess the relative concentration and significance of the inferred soil vapour concentrations, concentrations have been compared to published screening criteria. These contaminant screening criteria represent threshold concentrations of specific contaminants in groundwater which, if exceeded in a particular sample, may pose a vapour risk and may therefore warrant further site specific investigation or risk analysis.

The health screening criteria adopted to assess the significance of the soil vapour concentrations have been sourced from the NEPM 2013 guidelines, Table 1A(2) and 1A(5). Table 1A(2) presents the Interim Soil Vapour Health Investigation Levels (HILs) for volatile organic chlorinated compounds. The application of the Interim Soil Vapour HILs is based on a measurement of shallow soil vapour to 1 m depth. Given that the soil vapour implants were all installed below 1 m depth (1.0–1.1 m, 1.4–1.5 m, 1.7–1.8 m, 1.9–2.0 m, and 2.1-2.2 m), comparison has been made to the Interim Soil Vapour HILs to provide an initial screening assessment and is considered to be a conservative approach.

Based upon the soil lithology encountered, the predominant soil type was clayey sand and sandy clay and so soil vapour concentrations for TRH and BTEXN have also been compared to the residential health screening levels (HSL-A and HSL-B) for sand at 1 m to <2 m and 2 m to <4 m.

6.4 Ambient air

The health screening criteria adopted to assess the significance of the ambient air concentrations have been sourced from NEPM (2013) Schedule B7, Appendix A6 *The Derivation of Interim HILs for Volatile Organic Chlorinated Compounds*. Based on a review of Australian and international sources an inhalation toxicity reference value (TRV) has been derived for selected VOCs. This value has also been used in the determination of the Interim Soil Vapour HILs whereby an attenuation factor of 0.1 for indoor air-to-soil gas has been applied for HILs A, B and D (and an outdoor attenuation factor of 0.05 for HIL-C).

The adopted TRV for the primary contaminants of concern are presented in Table 6.4.

Table 6.4 Indoor Air TRV for residential land use

Chemical	TRV (mg/m^3)
TCE	0.002
1,1,1 –TCA	6
PCE	0.2
cis-1,2-dichloroethene	0.008
Vinyl Chloride	0.003

In the absence of readily available Australian screening criteria for other analytes, reference has also been made to the US EPA (2013) *Regional Screening Levels for Chemical Contaminants at Superfund Sites - Residential Air*. These screening criteria are presented in the results tables within Appendix F. It is noted that a carcinogenic target risk of 1x 10^{-6} has been used to develop these screening criteria, along with a non-cancer hazard index of 0.1, therefore these criteria are considered to be conservative based on the more commonly adopted carcinogenic target risk of 1x10^{-5} typically adopted in Australia.

7. Results

7.1 Soil

7.1.1 Soil profile

Soil borehole, groundwater well and soil vapour log reports are included in Appendix E and provide details of soil types encountered at each of the sampling locations.

Surficial fill materials, present to depths of between 0.4 and 0.5 mBGL, at all sampling locations, included brown, fine grained **silty sands** and brown or grey, fine grained **sandy silt**.

The underlying natural soil profile comprised alternating layers of:

- fine to coarse grained, low to medium plasticity, **clayey** and **silty sands/sandy clays** of varying colour
- medium to coarse grained, orange-brown **sands**
- brown, yellow-brown, orange-brown, or orange-brown mottled grey-brown, low plasticity **clayey silt**; and
- low to high plasticity **silty clays** of varying colour.

7.1.2 Soil PID readings, odour and staining

No odours or visual impacts (i.e. staining or obvious signs of contamination such as unhealthy vegetation) were noted in the sampled soils.

Headspace PID readings within soils across the site ranged from 0.0 to 0.6 ppm.

7.1.3 Soil analytical results

Tables of soil analytical results are included in Appendix F and copies of laboratory certificates are included in Appendix G.

Soil samples were not selected by the EPA for analysis, however to assist in classification of waste soil for disposal, two samples were analysed for the SA EPA Waste screen. All results were reported below the adopted assessment criteria and/or laboratory LOR.

To assist in potential future contaminant attenuation modelling, total organic carbon (TOC) analysis was completed on soil samples from the aquifer at each new groundwater well location. In addition, selected soil samples from well locations MW24 and MW26, immediately adjacent to soil vapour bores SV16 and SV17 respectively, were analysed for moisture content to provide additional data which may be relevant to vapour migration at these locations.

The measured TOC within the aquifer material ranged from 0.11 to 0.2% in the five new groundwater well locations.

The moisture content within the vadose zone ranged from 12.7 to 13.2 at location MW24 from depths of 1 and 2 mBGL respectively. At location MW26 moisture content varied from 4.3% at 0.5 mBGL depth to 15.4% at 2.2 mBGL.

7.2 Groundwater

On 18 March 2014 the depth to the uppermost aquifer within the 29 shallow monitoring wells sampled ranged from 3.376 to 4.189 m below top of casing (BTOC). On 18 March 2014 the depth to groundwater within double-cased wells MW21 and MW22 was 3.922 and 4.581 mBTOC respectively. No odour or sheen was noted during groundwater purging or sampling and no NAPL was detected during the gauging of the wells.

Groundwater well gauging data and field parameters measured immediately prior to sampling are presented in Table 7.1, along with historic data, and can be summarised as follows:

- measured pH values ranged from 6.06 to 8.13, thereby indicating slightly acidic to slightly alkaline groundwater conditions
- electrical conductivity (EC) readings ranged from 0.83 to 27.3 mS/cm (approximating 414 to 15,869 mg/L TDS), thereby indicating fresh to saline groundwater conditions
- dissolved oxygen (DO) levels ranged from 0.12 to 11.23 mg/L, thereby indicating low to moderate oxygen conditions; and
- field redox potential[1] readings ranged from -69 to 238 mV, thereby indicating both reducing and oxidising conditions.

As indicated in Figure 4 (Appendix A), groundwater within the uppermost aquifer beneath the investigation area east of Tapleys Hill Road was inferred to flow in a general westerly direction, towards Boating Lake and Gulf St Vincent. West of Tapleys Hill Road, groundwater was inferred to flow in an east and north-easterly direction with a depression again present around monitoring well MW07 in the vicinity of Tapleys Hill Road (as was the case during the 2013 monitoring event).

A review of deep underground services in the area identified that a deep sewer system exist along Tapleys Hill Road , with an invert level of below -1.0 mAHD within the vicinity of West Lakes Boulevard intersection. This sewer is understood to comprise a 525 mm diameter vitreous clay pipe, therefore there is a possibility this sewer may leak. The measured groundwater gradients support the fact that this sewer line may be acting as a drain for groundwater within the local area. It is noted that the sewer system along the sewer branch lines near Tapleys Hill Road and also along Farman Avenue and the northern portion of Gordon Street are also below 0 mAHD, therefore the sewer in these areas is also below the expected water table level.

Groundwater field sampling sheets are included in Appendix H.

Table 7.1 Groundwater field parameters – September 2012, June/July 2013 and March 2014

Groundwater Well	Date	SWL (mBTOC)	RSWL (mAHD)	pH	EC (mS/cm)	Redox (mV)	DO (mg/L)	Temp (ºC)
MW01	Sept 2012	3.597	0.403	7.48	13.38	115	0.50	18.9
	June 2013	3.986	0.014	6.80	11.83	96	1.87	-
	March 2014	3.802	0.198	7.57	10.18	14	5.89	22.0
MW02	Sept 2012	3.54	0.900	7.30	9.31	126	0.16	18.6
	June 2013	4.051	0.389	6.95	7.99	-125	0.66	18.9
	March 2014	3.852	0.588	7.40	8.85	50	4.78	21.0

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[1] Relative to a Ag/AgCl electrode

Groundwater Well	Date	SWL (mBTOC)	RSWL (mAHD)	pH	EC (mS/cm)	Redox (mV)	DO (mg/L)	Temp (ºC)
MW03	Sept 2012	3.661	0.729	7.62	6.97	117	3.24	17.9
	June 2013	4.140	0.250	6.62	5.73	138	2.67	23.7
	March 2014	3.934	0.456	6.99	5.17	169	5.99	23.3
MW04	Sept 2012	3.569	0.601	7.01	22.12	117	0.35	19.5
	June 2013	4.015	0.155	6.76	15.16	-101	0.70	20.5
	March 2014	3.842	0.328	6.73	20.01	-69	0.66	19.7
MW05	Sept 2012	3.554	0.686	7.20	15.03	108	1.05	18.1
	June 2013	4.003	0.237	6.85	11.13	93	1.05	19.9
	March 2014	3.821	0.419	7.12	14.98	-2	3.27	21.8
MW06	Sept 2012	3.787	0.313	7.03	16.71	176	3.25	16.3
	June 2013	4.152	-0.052	7.20	10.76	184	1.82	19.7
	March 2014	3.982	0.118	7.78	12.51	39	5.09	21.7
MW07	Sept 2012	3.635	-0.005	7.07	8.47	212	2.96	18.5
	June 2013	3.95	-0.320	-	-	-	-	-
	March 2014	3.775	-0.145	7.38	6.72	-27	2.92	25.3
MW08	Sept 2012	3.631	0.359	7.62	5.50	137	4.18	16.5
	June 2013	4.156	-0.166	7.57	20.95	-17	-	18.8
	March 2014	3.971	0.019	7.45	6.39	46	1.58	25.1
MW09	Sept 2012	3.769	0.301	7.54	1.076	121	1.59	16.8
	June 2013	4.187	-0.117	7.64	1.831	112	2.29	20.1
	March 2014	4.011	0.059	7.61	0.832	103	2.62	22.1
MW10	Sept 2012	3.827	0.423	7.44	30.7	107	3.49	17.3
	June 2013	4.263	-0.013	7.24	60.88	143	8.84	22.2
	March 2014	4.120	0.130	7.75	14.56	104	4.35	24.6
MW11	June 2013	3.736	0.309	6.61	9.38	81	1.26	24.7
	March 2014	3.502	0.543	7.19	8.84	85	4.28	22.2
MW12	June 2013	4.032	0.536	7.04	8.49	201	1.64	20.5
	March 2014	3.812	0.756	7.07	18.20	150	4.07	19.0
MW13	June 2013	3.992	-0.110	6.92	13.22	133	0.66	19.7
	March 2014	3.922	-0.040	6.84	15.53	190	4.87	21.0
MW14	June 2013	4.122	0.112	7.35	5.14	187	1.44	21.6
	March 2014	3.880	0.354	7.47	5.75	81	5.25	21.0
MW15	June 2013	4.003	0.807	7.13	13.84	86	41.04%*	22.0
	March 2014	3.782	1.028	6.68	7.69	114	2.40	23.1

Groundwater Well	Date	SWL (mBTOC)	RSWL (mAHD)	pH	EC (mS/cm)	Redox (mV)	DO (mg/L)	Temp (ºC)
MW16	June 2013	3.924	0.576	7.26	15.47	121	41.15%*	21.6
	March 2014	3.750	0.750	6.54	9.69	199	5.28	23.0
MW17	June 2013	3.990	0.450	7.18	14.86	146	41.60%*	21.1
	March 2014	3.821	0.619	6.17	8.90	238	3.30	21.3
MW18	June 2013	4.091	-0.098	7.73	4.24	159	2.84	20.1
	March 2014	3.917	0.076	8.13	4.89	22	2.44	21.9
MW19	June 2013	4.132	-0.221	7.79	1.71	130	2.80	21.0
	March 2014	3.922	-0.011	8.00	2.55	83	0.92	22.8
MW20	June 2013	4.912	-0.410	7.23	57.26	120	6.49	19.8
	March 2014	3.801	0.701	7.67	27.3	107	2.21	20.1
MW21	July 2013	4.058	0.298	7.48	9.11	121	0.33	19.7
	March 2014	3.922	0.434	7.85	8.14	51	11.23	20.4
MW22	July 2013	4.672	-0.088	7.18	13.27	217	1.28	19.3
	March 2014	4.581	0.003	7.72	11.79	55	0.65	22.9
MW23	March 2014	4.071	0.579	7.61	7.46	97	2.31	22.4
MW24		3.855	0.316	7.84	4.84	91	2.45	23.4
MW25		4.043	-0.164	7.83	13.95	116	5.71	21.7
MW26		4.189	0.911	7.57	6.19	100	1.62	24.3
MW27		3.599	0.782	7.58	6.32	91	0.12	23.5
BH22	Sept 2012	3.37	0.470	7.61	10.71	100	2.53	19.7
	June 2013	4.041	-0.201	7.24	11.35	177	6.27	20.9
	March 2014	3.834	0.006	7.54	12.34	109	1.02	25.7
GW1	July 2013	3.662	0.180	6.24	6.28	265	1.29	19.1
	March 2014	3.546	0.296	6.06	6.92	204	0.75	21.6
GW2	July 2013	3.521	0.289	7.09	10.00	104	0.67	20.4
	March 2014	3.442	0.368	7.76	9.07	58	0.47	23.8
GW9	Sept 2012	3.064	0.836	7.32	12.28	150	2.29	18.9
	June 2013	3.562	0.338	7.03	10.36	122	1.43	21.5
	March 2014	3.376	0.524	7.20	12.52	45	3.72	22.3

Note:
RWSL = reduced standing water level
* These DO readings are believed to be measured as a % rather than mg/L

7.2.1 Groundwater analytical results

The number of groundwater samples analysed, analytes tested for, minimum/maximum constituent concentrations and samples that exceeded the adopted screening criteria are detailed in Table 7.2.

Tables of groundwater analytical results are included in Appendix F and copies of laboratory certificates are included in Appendix G.

Individual sample results can be interpreted as follows:

- Only MW09 and MW19 reported chloride concentrations below the adopted recreational and/or potable water criteria. Of those that exceeded the screening criteria, concentrations ranged from 392 (GW1) to 10,100 mg/L (MW20).
- Twenty out of thirty one monitoring wells contained sulphate (as SO_4) concentrations exceeding the SA EPA (2003) potable water criteria (500 mg/L), ranging from 513 (MW7) to 2,100 mg/L (MW20).
- Concentrations of bromide ranged from 0.05 (MW9) to 26.6 mg/L (MW20), however there is no criteria available for this analyte.
- Of the major cations, only sodium has screening criteria to compare against and only MW09 was below the recreational and/or potable water criteria, 1,800 and 180 mg/L respectively.
- Total alkalinity as $CaCO_3$ ranged from 63 (GW1) to 1,500 mg/L (MW20).
- Ferrous iron was only detected above the laboratory LOR in MW04 with a concentration of 910 µg/L.
- Only GW2 reported a detectable concentration of methane with 86 µg/L.
- MW10, MW14, MW17, MW18, MW20 and MW22 contained concentrations of nitrate (as N) exceeding the adopted potable and recreational screening criteria of 10 mg/L.
- All concentrations of sulphide were reported below the laboratory LOR.
- Detectable concentrations of benzene were reported within GW1, GW2, GW9, MW07, MW08 and MW14, however these were below adopted criteria.
- A xylene concentration of 0.22 µg/L was reported in MW18, while remaining wells were below the laboratory LOR.
- 1,1-dichloroethene within MW14 (96.1 µg/L) exceeded the potable water criteria of 30 µg/L. Twelve other wells reported detectable concentrations.
- Monitoring wells MW02, MW04, MW05, MW12 and MW13 contained concentrations of the cis- and trans- isomers of 1,2-dichloroethene exceeding the adopted potable water criteria (60 µg/L), while GW2 and GW9 exceeded the adopted recreational criteria (600 µg/L).
- Nine wells reported concentrations of TCE exceeding adopted recreational and/or potable water criteria with concentrations in these wells ranging from 27 (BH22) to 1,000 µg/L (GW9). A further 10 monitoring wells reported detectable concentrations of TCE.
- Monitoring wells GW9, MW02 and MW12 contained concentrations of PCE up to 188 µg/L, exceeding the SA EPA (2003) potable water criteria of 40 µg/L. A further 14 monitoring wells reported detectable concentrations of PCE.
- Vinyl chloride within GW1 (23.4 µg/L) and GW2 (110 µg/L) exceeded the potable and recreational criteria (0.3 µg/L and 3.0 µg/L respectively), while all remaining wells reported concentrations below the laboratory LOR (0.3 µg/L).
- Only wells MW09, MW10 MW11, MW15, MW16, MW20, MW22 and MW25 did not record any detectable VOCs.

A groundwater contaminant plan is included as Figure 5 in Appendix A.

Table 7.2 Summary of groundwater results

Number of Primary Samples	Number of Duplicates (intra-lab)	Number of Duplicates (inter-lab)	Analyte (µg/L unless otherwise marked)	Min. Conc.	Max. Conc.	Sample Results Exceeding Screening Criteria
31	2	2	Nitrate as N (mg/L)	<0.01	**29.5**	SA EPA (2003) Potable Water: 10 mg/L and ANZECC/ARMCANZ (2000) Recreational Guidelines: 10 mg/L MW10: 29.5 mg/L MW14: 11.3 mg/L MW17: 11.8 mg/L MW18: 19.2 mg/L / QC03: 17.4 mg/L / QC04: 18.8 mg/L MW20: 13.4 mg/L MW22: 18.4 mg/L
31	2	2	Ferrous iron	<50	910	No criteria available
31	2	2	Sulphate as SO_4 (mg/L)	11	**2,100**	SA EPA (2003) Potable Water: 500 mg/L BH22: 903 mg/L GW1: 1,900 mg/L GW2: 675 mg/L GW9: 1,000 mg/L MW01: 626 mg/L / QC100: 690 mg/L MW02: 567 mg/L MW04: 1,420 mg/L MW05: 1,020 mg/L MW06: 940 mg/L MW10: 2,040 mg/L MW11: 716 mg/L MW12: 650 mg/L MW13: 540 mg/L MW16: 931 mg/L MW17: 513 mg/L MW20: 2,100 mg/L MW21: 631 mg/ L MW22: 983 mg/L MW23: 558 mg/L MW25: 890 mg/L
16	2	-	Sulphide**	<100	<100	None
31	2	2	Methane	<10	86	No criteria available

Number of Primary Samples	Number of Duplicates (intra-lab)	Number of Duplicates (inter-lab)	Analyte (µg/L unless otherwise marked)	Min. Conc.	Max. Conc.	Sample Results Exceeding Screening Criteria
31	2	2	Chloride (mg/L)	16	**10,100**	NHMRC/NRMMC (2011) Australian Drinking Water Guidelines: 250 mg/L GW1: 392 mg/L MW03: 1,180 mg/L MW07: 1,980 mg/L MW08: 856 mg/L MW14: 1,250 mg/L MW15: 2,070 mg/L MW18: 816 mg/L / QC03: 824 mg/L / QC04: 816 mg/L MW23: 1,860 mg/L MW24: 891 mg/L / QC04: 830 mg/L MW26: 1,510 mg/L MW27: 1,510 mg/L NHMRC/NRMMC (2011) Australian Drinking Water Guidelines: 250 mg/L and NHMRC (2008) Recreational: 2,500 mg/L BH22: 3,640 mg/L GW2: 2,870 mg/L GW9: 4,280 mg/L MW01: 3,380 mg/L / QC100: 3,000 mg/L MW02: 2,670 mg/L MW04: 7,140 mg/L MW05: 5,030 mg/L MW06: 3,940 mg/L MW10: 6,300 mg/L MW11: 2,600 mg/L MW12: 3,320 mg/L MW13: 5,900 mg/L MW16: 2,960 mg/L MW17: 2,900 mg/L MW20: 10,100 mg/L MW21: 2,500 mg/L MW22: 3,910 mg/L MW25: 4,920 mg/L
31	2	2	Bromide	50	26,600	No criteria available
31	2	2	Alkalinity (total as $CaCO_3$) (mg/L)	63	1,500	No criteria available
31	2	2	Calcium (mg/L)	4	323	No criteria available

Number of Primary Samples	Number of Duplicates (intra-lab)	Number of Duplicates (inter-lab)	Analyte (µg/L unless otherwise marked)	Min. Conc.	Max. Conc.	Sample Results Exceeding Screening Criteria
31	2	2	Magnesium (mg/L)	9	813	No criteria available
31	2	2	Sodium (mg/L)	25	**5,520**	NHMRC/NRMMC (2011) Australian Drinking Water Guidelines: 180 mg/L GW1: 681 mg/L GW2: 1,760 mg/L MW02: 1,700 mg/L MW03: 918 mg/L MW07: 1,340 mg/L MW08: 704 mg/L MW11: 1,800 mg/L MW14: 1,050 mg/L MW15: 1,260 mg/L MW17: 1,550 mg/L MW18: 803 mg/L / QC03: 808 mg/L / QC04: 817 mg/L MW19: 523 mg/L MW21: 1,650 mg/L MW23: 1,320 mg/L MW24: 949 mg/L / QC04: 920 mg/L MW26: 1,130 mg/L MW27: 1,220 mg/L NHMRC/NRMMC (2011) Australian Drinking Water Guidelines: 180 mg/L and NHMRC (2008) Recreational: 1,800 mg/L BH22: 2,610 mg/L GW9: 2,450 mg/L MW01: 2,000 mg/L / QC100: 2,000 mg/L MW04: 3,600 mg/L MW05: 3,100 mg/L MW06: 2,660 mg/L MW10: 3,830 mg/L MW12: 1,900 mg/L MW13: 2,760 mg/L MW16: 1,950 mg/L MW20: 5,520 mg/L MW22: 2,550 mg/L MW25: 2,680 mg/L
31	2	2	Potassium (mg/L)	12	150	No criteria available

Number of Primary Samples	Number of Duplicates (intra-lab)	Number of Duplicates (inter-lab)	Analyte (µg/L unless otherwise marked)	Min. Conc.	Max. Conc.	Sample Results Exceeding Screening Criteria
31	2	2	Benzene	<0.05	0.7	None
31	2	2	Toluene	<0.5	<0.5	None
31	2	2	Ethylbenzene	<0.05	<0.05	None
31	2	2	Xylenes	<0.10	0.22	None
31	2	2	Naphthalene	<0.05	<0.05	None
31	2	2	Trichloroethene	<0.05	**1,000**	WHO (2011) Drinking Water: 20 µg/L BH22: 27 µg/L WHO (2011) Drinking Water: 20 µg/L and ANZECC/ARMCANZ (2000) Recreational: 30 µg/L GW2: 955 µg/L GW9: 1,000 µg/L MW04: 43.6 µg/L MW07: 330 µg/L MW08: 51.7 µg/L MW13: 34.6 µg/L MW14: 366 µg/L MW23: 87.5 µg/L
31	2	2	Tetrachloroethene	<0.05	**188**	SA EPA (2003) Potable: 40 µg/L GW9: 188 µg/L MW02: 54.3 µg/L MW12: 49.8 µg/L
31	2	2	1,1-dichloroethene	<0.1	**96.1**	SA EPA (2003) Potable Water: 30 µg/L MW14: 96.1 µg/L

Number of Primary Samples	Number of Duplicates (intra-lab)	Number of Duplicates (inter-lab)	Analyte (µg/L unless otherwise marked)	Min. Conc.	Max. Conc.	Sample Results Exceeding Screening Criteria
31	2	2	*cis*-1,2-dichloroethene	<0.1	**796**	SA EPA (2003) Potable Water: 60 µg/L* MW02: *cis* 217 µg/L / *trans* 1.3 µg/L MW04: *cis* 107 µg/L / *trans* 2.4 µg/L MW05: *cis* 189 µg/L / *trans* 1.5 µg/L MW12: *cis* 171 µg/L / *trans* 1.2 µg/L MW13: *cis* 73.3 µg/L / *trans* 4.6 µg/L SA EPA (2003) Potable Water: 60 µg/L and NHMRC (2008) Recreational: 600 µg/L GW2: *cis* 651 µg/L / *trans* 8.9 µg/L GW9: *cis* 796 µg/L / *trans* 2.5 µg/L
31	2	2	*trans*-1,2-dichloroethene	<0.1	**8.9**	
31	2	2	Vinyl chloride	<0.3	**110**	SA EPA (2003) Potable Water: 0.3 µg/L and NHMRC (2008) Recreational: 3 µg/L GW1: 23.4 µg/L GW2: 110 µg/L
31	2	2	VOCs (individual compounds)	<0.05	11.5	None

Note:
*exceedance of the guideline is based on the total concentration of the *cis* and trans isomers (i.e. it has been assumed the guideline is based on a mixture of the two isomers)
**laboratory detection limits exceeded the adopted assessment criteria for some or all analytes
Numbers in bold exceed adopted assessment criteria

7.3 Soil vapour results

Tables of soil vapour analytical results are included in Appendix F and copies of laboratory certificates are included in Appendix G. A soil vapour contaminant distribution plan of volatile organic compounds, is included as Figure 6 in Appendix A.

Soil vapour results can be interpreted as follows:

- Elevated concentrations of TCE ranged from 52 (SV03) to 16,000 µg/m^3 (SV10), with SV01-SV04, SV06, SV07, SV09, SV10, SV12, SV13, SV15 and SV17 exceeding the interim HIL for a residential land use (20 µg/m^3).
- Concentrations of PCE within SV01, SV02, SV06, SV13 and SV17 exceeded the residential interim HIL (2,000 µg/m^3), with concentrations ranging from 2,700 (SV6) to 26,000 µg/m^3 (SV2).
- SV02, SV09, SV10 and SV13 reported cis-1,2-dichloroethene exceeding the residential interim HIL of 80 µg/m^3 with concentrations ranging from 280 (SV09) to 12,000 (SV13) µg/m^3.
- The following VOCs were reported at detectable levels: 1,1-dichloroethane, 1,1-dichloroethene, 2-butanone (methyl ethyl ketone), chloroform, dichlorodifluoromethane, naphthalene, trans-1,2-dichloroethene and trichlorofluoromethane.
- The leak check compound isopropyl alcohol was detected in several soil vapour bores up to 430 µg/m^3 which is approximately 0.006% of the isopropyl alcohol concentration recorded in the shroud sample (11,000,000 µg/m^3). The concentration of the leak detection compound within the soil gas sample is considered to be negligible, and is well below the suggested allowable amount of 10% documented with the CRC Care Technical Report 23: *Petroleum Hydrocarbon Vapour Intrusion Assessment: Australian Guidance*.

7.4 Sub-slab, crawl space and ambient air results – child care centre

Prior to commencement of sampling within the First Steps Child Care Centre a brief inspection of the building was undertaken to assess the presence of potentially significant VOC sources within the building. The results of the building survey identified the following:

- The building appears to have been constructed in stages, with the western portion of the building having a concrete floor slab and the remainder of the building (excluding wet areas) having a suspended timber floor, with crawl space beneath. The timber floor varied from timber floor boards to a manufactured timber floor sheet. The extent of timber and concrete flooring is indicated on the site plan presented as Figure 3, Appendix A.
- The height of the crawlspace at the sampling locations varied between 0.15 m to 0.44 m, with soil present immediately below the crawl space.
- The timber floor was directly covered by a vinyl floor covering throughout, with carpet above the vinyl within one room (i.e. the room containing sampling location IAC2). The floor covering appeared to be quite old throughout, with some holes and gaps. No recent use of adhesives is likely.
- No existing floor penetrations into the crawl space were observed.
- Various cleaning products are stored and utilised in the building, including a product named Chlorophos, which is known to be a germicidal detergent used to clean, sanitise and deodorise. This product contains chlorinated trisodium phosphate and is classified as a hazardous substance according to criteria of National Occupational Health and Safety Commission Australia (NOHSC).
- Small quantities of water based paints and other art supplies are also stored on site. Food is stored in a cupboard in the western portion of the building and cooking facilities are present.

- The furniture and floor coverings within the building do not appear to be new and are likely to have been present for a number of years.
- A grease arrestor pit was observed immediately to the north-east of the building and appears to be connected to the sewer.

Although the use of adhesives and vinyl floor coverings can be a source of VOCs, the age of the floor coverings is likely to mitigate any impact from these sources.

Tables of the sub-slab, crawl space and ambient air results from the child care centre are included in Appendix F and copies of laboratory certificates are included in Appendix G.

The sub-slab sample collected from the child care centre did not report any VOC concentrations exceeding adopted screening criteria.

The crawl space results can be interpreted as follows:

- The eight hour crawl space sample taken on 22 March 2014 reported a TCE concentration of 26 µg/m^3 and the subsequent eight hour sample from the same location (CS1B collected on 12 April 2014) reported a TCE concentration of 6.4 µg/m^3.
- All five 24 hour crawl space canister samples reported detectable concentrations of TCE (up to 11 µg/m^3), 2-butanone (MEK), acetone, dichlorodifluoromethane and trichlorofluoromethane, ethanol, hexane, iso-propanol and toluene. All remaining VOCs were below the laboratory LOR.
- All four crawl space Radiello samplers (approx. 10 day sampling period) reported detectable concentrations of TCE ranging from 3.5 µg/m^3 (CSR3) to 7.4 µg/m^3 (CSR2 and CSR1 dup). A wide range of other VOCs were detected by the Radiello samplers in the crawl space.

The indoor air results from the five 24 hour air canister samples indicated the following:

- The concentration of ethyl benzene in three samples (IAC2, IAC4 and IAC5), ranging from 1 to 2 µg/m^3, marginally exceeded the US EPA Regional Screening Level for Residential Air of 0.97 µg/m^3. It is noted, however, that these concentrations are acceptable on the basis of the toxicity criteria used for deriving the NEPM HSLs.
- Three indoor air locations (IAC1, IAC3B and IAC5) exceeded the US EPA Regional Screening Level for bromomethane (0.52 µg/m^3), with concentrations ranging from 8.3 to 11 µg/m^3.
- Detectable TCE concentrations of between 1.2 and 1.3 µg/m^3 were reported in three samples, however these are below the inhalation toxicity reference value of 2 µg/m^3 adopted in the amended NEPM.
- The following VOCs were also reported at detectable levels within two or more indoor air canisters: toluene, ethylbenzene, 2-butanone (MEK), acetone, dichlorodifluoromethane, dichloromethane, ethyl acetate and trichlorofluoromethane.

The outdoor air results from the 24 hour air canister sample indicated the following:

- TCE was detected at 1.1 µg/m^3 within the outdoor air (24 hour) canister sampling location, similar to the indoor air result.
- The following additional VOCs were reported at detectable levels within the outdoor air (24hr) canister sample: toluene, ethylbenzene, xylenes, 1,2,4-trimethyl benzene, 2-butanone (MEK), acetone, chloromethane, dichlorodifluoromethane, ethyl acetate and trichlorofluoromethane.

The indoor air results from the five Radiello Samplers indicated:

- The concentrations of ethylbenzene in samples IAR3 dup (1 µg/m^3) and IAR4 1.1 µg/m^3 slightly exceeded the USEPA Region 9 Screening Level Criteria of 0.97 µg/m^3. It is noted, however, that these concentrations are acceptable on the basis of the toxicity criteria used for deriving the NEPM HSLs.
- The concentrations of benzene in all samples ranged from 0.87 to 0.97 µg/m^3, therefore exceeded the USEPA Region 9 Screening Level Criteria of 0.31 µg/m^3. It is noted, however, that these concentrations are acceptable on the basis of the toxicity criteria used for deriving the NEPM HSLs.
- The concentration of dichlorethane in sample IAR1 (0.13 µg/m^3) exceeded the USEPA Region 9 Screening Level Criteria of 0.094 µg/m^3.
- The concentration of chloroform in all indoor air samples varied from 0.18 to 0.32 µg/m^3, exceeding the USEPA Region 9 Screening Level Criteria of 0.11 µg/m^3.
- The concentration of carbon tetrachloride in all indoor air samples varied from 0.53 to 0.63 µg/m^3, exceeding the USEPA Region 9 Screening Level Criteria of 0.41 µg/m^3.
- The concentrations of numerous other VOCs exceeded the laboratory LOR, however did not exceed the screening criteria.
- The concentrations of TCE varied between 0.74 to 0.9 µg/m^3 and did not exceed the adopted toxicity reference value of 2 µg/m^3.

The outdoor air results from the Radiello Sampler indicated:

- The concentrations of carbon tetrachloride and benzene in the outdoor air sample was 0.61 µg/m^3 and 1.1 µg/m^3 respectively, exceeding the USEPA Region 9 Screening Level Criteria, and consistent with the indoor air samples.
- The concentrations of numerous other VOCs exceeded the laboratory LOR, however did not exceed the screening criteria.
- A TCE concentration of 0.7 was recorded in outdoor air, similar to the indoor air concentrations.

The Radiello sampler within the grease arrestor pit recorded numerous VOCs exceeding the laboratory LOR, however did not exceed the screening criteria, with the exception of a benzene (0.83 µg/m^3), chloroform (0.28 µg/m^3.) and carbon tetrachloride (0.48 µg/m^3) which exceeded the USEPA Region 9 Screening Level Criteria of 0.31, 0.11 and 0.41 µg/m^3 respectively. The TCE concentration within the pit was 0.59 µg/m^3. The concentrations of all compounds detected within the pit were similar to the indoor air sample results.

7.5 Quality assurance/Quality control (QA/QC)

Data quality is typically discussed in terms of accuracy, precision and representativeness. In order to assess the quality of the data collected during the investigation program, specific QA/QC procedures were implemented during both the field sampling and laboratory analysis programs, in accordance with the requirements of the following documents:

- Australian Standard AS4482.1-2005 Guide to the Sampling and Investigation of Potentially Contaminated Soil Part 1: Non-Volatile and Semi-Volatile Compounds.
- Australian/New Zealand Standard AS/NZS 5667.1:1998 Water Quality Sampling, Part 1: Guidance on the Design of Sampling Programs, Sampling Techniques and the Preservation and Handling of Samples.
- NEPM (2013) *Schedule B(2) Guideline on Site Characterisation*).
- South Australian Environment Protection Authority (2007) *Regulatory Monitoring and Testing Groundwater Sampling*.

7.5.1 Field QA/QC

Field QA procedures generally include the collection of the following QC samples, aimed at assessing possible errors associated with cross contamination as well as inconsistencies in sampling and/or laboratory analytical techniques:

- Intra-laboratory duplicate (blind replicate) samples: submitted to the same (primary laboratory) to assess variation in analyte concentrations between samples collected from the same sampling point and/or the repeatability (precision) of the analytical procedures.
- Inter-laboratory duplicate (split) samples: submitted to a second laboratory to check on the analytical proficiency (accuracy) of the results produced by the primary laboratory.
- Equipment rinsate blank: used to assess whether decontamination procedures have been sufficient and/or whether cross-contamination may have occurred between samples.
- Trip blank: used to assess whether cross-contamination may have occurred between samples during transport.

Whereas analyte concentrations within both the rinsate and trip blanks should be below the laboratory LORs, the duplicate sample results are assessed via the calculation of a relative percentage difference (RPD), as follows:

$$RPD = \frac{(Concentration\,1 - Concentration\,2)\ x\,100}{(Concentration\,1 + Concentration\,2)\ /\ 2}$$

A maximum RPD within the range of 30% to 50% is generally considered acceptable, with higher RPD values often recorded for organic compounds and where low concentrations of an analyte are recorded.

Table 7.3 indicates conformance to field QA/QC procedures.

Table 7.3 Field QA/QC procedures

QA/QC Requirement	Completed	Comments
Field instruments calibrated	Yes	Refer to Tables 5.1 and 5.3 as well as Appendix C.
Appropriate and well documented sample collection, handling, logging, transportation and decontamination procedures	Yes	Refer to Tables 5.1 (soil), 5.2 to 5.3 (groundwater), 5.4 (soil vapour) and 5.5 (sub-slab, crawl space and ambient air) for details
Chain of custody documentation completed	Yes	All samples were transported under strict Parsons Brinckerhoff or SGS Leeder Consulting chain of custody procedures and signed chain of custody documents are included in Appendix G.
Required number (1:10) of blind field duplicates collected	Yes	Refer to Tables 4.1 (groundwater) and 4.2 (soil vapour, sub-slab, crawl space and ambient air) for details.

QA/QC Requirement	Completed	Comments
Acceptable groundwater QC sample RPD results	Mostly	Groundwater RPD results for the intra- and inter-laboratory duplicate sample pairs are included in the analytical results tables in Appendix F. An RPD value above 50% was obtained for bromide (157%) within inter-laboratory duplicate sample pair MW01 and QC100. This is not considered to significantly impact upon the outcomes of this report. While the ionic balance (63%) within intra-laboratory duplicate sample pair MW18 and QC04_190314 was also outside the acceptable range, the major anions and cations used to calculate the ionic balance were all within the acceptable range.
Acceptable soil vapour, crawl space and ambient air QC sample RPD results	Mostly	Soil vapour, crawl space and ambient air RPD results for the intra- and inter-laboratory duplicate sample pairs are included in the analytical results tables in Appendix F. An RPD value above 50% was obtained for toluene (58%) within inter-laboratory duplicate sample pair IAC3 and IAC3C. For the sake of conservatism, the highest concentration in the primary sample has been adopted for interpretive purposes.
Acceptable soil vapour leak detection results	Yes	The concentration of isopropyl alcohol recorded within the samples ranged from <50 µg/m^3 to 620 µg/m^3, with the isopropyl alcohol concentration in the shroud measured as 11,000,000 µg/m^3. This equates to less than 0.006% of the shroud concentration and is considered to represent negligible leakage.
Required numbers of trip and rinsate blank samples collected	Yes	Refer to Tables 4.1 (groundwater) and 4.2 (soil vapour, sub-slab, crawl space and ambient air) for details.
Acceptable trip and rinsate blank results	Yes	Trip and rinsate blank results are included in the analytical results tables in Appendix F. All results were below the laboratory LORs.
Samples delivered to laboratories within sample holding times and with correct preservative(s)	Yes	All samples were delivered to the laboratories within the sample holding times and in laboratory-supplied containers prepared with the appropriate preservative (where required).

7.5.2 Laboratory QA/QC

Laboratory QA procedures generally include the performance of a number of internal checks of data precision and accuracy that are aimed at assessing possible errors associated with sample preparation and analytical techniques. Specific types of QC samples analysed by laboratories, and the relevant acceptance criteria are as follows:

- internal laboratory replicate samples: maximum RPD values of 20% to 50%
- spike (matrix[2] and surrogate[3]) recoveries: recoveries of between 75% and 125%; and
- laboratory control blanks: results below the laboratory LORs.

Table 7.4 indicates conformance to laboratory QA/QC procedures.

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[2] A matrix spike is prepared by splitting a field sample and spiking each portion with a known quantity of a target compound to ascertain the effects of the specific sample matrix on the recovery of the analyte.

[3] A surrogate spike comprises a sample spiked with a pure substance that has similar chemical properties to the target analyte, but is unlikely to be found in the environment, such that the spike compound is expected to behave, during analysis, in the same way as the target compound.

Table 7.4 Laboratory QA/QC procedures

QA/QC Requirement	Completed	Comments
Samples extracted and analysed within relevant holding times	Yes	Refer to laboratory reports in Appendix G.
All analyses NATA accredited	Yes	ALS, Eurofins MGT, NMI and SGS Leeder are NATA accredited for all the analyses performed.
Appropriate analytical methodologies used, in accordance with Schedule B(3) of the NEPM	Yes	Refer to Interpretive Quality Control reports for methods used and relevance to Schedule B(3) of the NEPM in Appendix G.
Acceptable laboratory LORs adopted	Mostly	Refer to laboratory reports in Appendix G. Soil: Yes. Groundwater: The LOR for sulphide was above the adopted assessment criteria. Soil vapour: The LOR was raised above adopted assessment criteria in SV01 for cis-1,2-dichloroethene and in SV01, SV02 and SV13 for vinyl chloride. Ambient air: The LORs of several analytes within ambient air samples was above the US EPA Regional Screening Level. However, the LORs for the primary contaminants of interest were all below the adopted criteria.
Acceptable laboratory QC results	Mostly	The results of internal laboratory quality control procedures are provided within the laboratory analysis reports (Appendix G). Laboratory replicate RPD values were within the acceptable range. Laboratory recoveries were within the acceptable recovery limits with the exception of some matrix spike recoveries not determined for sulphate, chloride, bromide and methane. The matrix spike recovery was greater than the upper data quality objective for C_6-C_{10} fraction in QC Lot 3349807 (ALS report EM1402478). Laboratory control spike recoveries were outside the limit for 2-hexanone and o-xylene in NMI QA certificate VOC14_094. Laboratory control blank results were all below the LORs.

In summary, it was considered that the QA/QC procedures and results were generally adequate and that the analytical results obtained were of acceptable quality for the purposes of this report.

8. Geochemistry discussion

8.1 Local hydrogeology

Additional data, including major ions, bromide and natural attenuation parameters, was collected during the latest groundwater monitoring event, conducted in March 2014. This additional data allows the further assessment of groundwater conditions below the investigation area. The results are discussed in the following sections.

8.1.1 Anthropogenic influences

It is understood that a sewer main runs north south beneath Tapleys Hill Road. The sewer is located at approximately 5 mBGL (approximately -1 mAHD). The measured groundwater SWLs indicate that the sewer itself or the sewer alignment (e.g. bedding sands in the sewer trench) are acting to drain groundwater from the system. The presence of the sewer may dictate local groundwater flows in the area. Deep sewers are also present beneath Farman Avenue and portion of Circuit Drive. The recent groundwater SWLs indicate that depressed groundwater levels exist from MW07, located at the child care centre, to the north along Tapleys Hill Road and the western end of Farman Avenue.

8.1.2 Lateral migration

The inferred groundwater contours for September 2012, June 2013 and March 2014 have been re-assessed with reference to the sewer alignment (refer Section 8.1.1). Over the three years of monitoring, it can be shown that groundwater has consistently flowed to the west, and that a hydraulic low has been centred in the vicinity of the child care centre. In 2012 and 2014, it can be inferred that groundwater, from the western side of the child care centre, flows to the east towards the sewer alignment.

Based on the 2014 groundwater gauging results, the hydraulic gradient ranges from 0.001 (to the east) to 0.002 (near the sewer). The geology is described as silty and sandy clays. On this basis, the porosity is estimated to range between 0.2 and 0.3. From aquifer testing undertaken in 2012, the hydraulic conductivity was estimated to range from 2.9 to 3.4 m/day. Based on these values, the groundwater seepage velocity is estimated to range from 3.5 to 12 m/year.

8.1.3 Vertical migration

The majority of groundwater wells in the investigation area have been installed to between 4 and 6 mBGL. In two locations, nested wells have been installed to assess the potential for multiple water bearing units and to understand potential vertical hydraulic gradients. With the March 2014 GME, two rounds of nested well sampling have been completed. It is noted that two rounds of data is insufficient to infer definitive trends, however it will allow preliminary conceptualisation of the potential vertical movement of groundwater in the area.

MW03 (screened from 2.5 to 5.5 mBGS) and MW21 (screen from 8.5 to 11.5 mBGS) are located to the south of the main industrial area. The SWLs have been relatively similar (within 0.05 m) for both rounds. An upward gradient in June 2013 reversed to a downward gradient in March 2014.

MW20 (5.5 m) and MW22 (9.4 m) are located to the west of the child care centre. The difference in SWLs has been 0.3 and 0.7 m in the June 2013 and March 2014 respectively. In June 2013, an upward gradient was present, however, in March 2014, this had reversed.

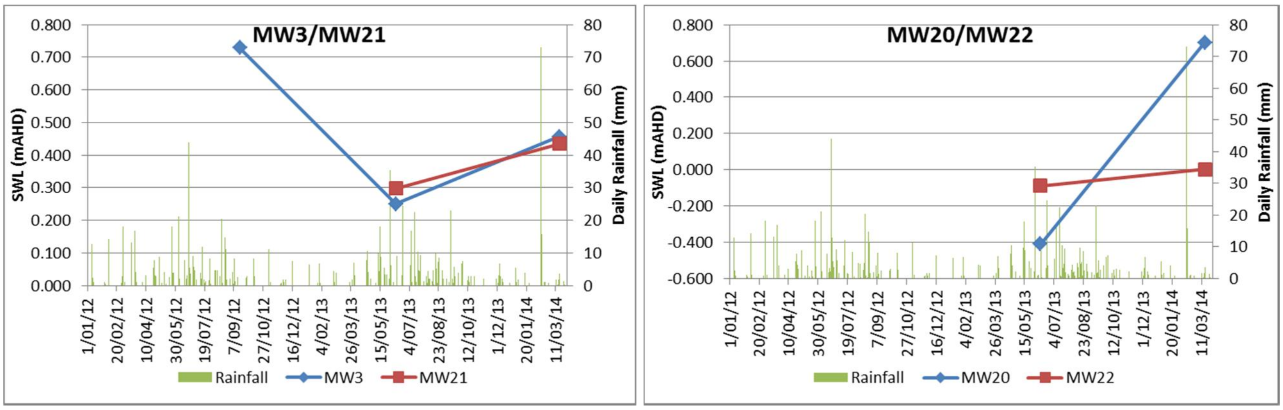

Figure 8.1 **SWLs for nested wells (MW03/MW21 and MW20/MW22) with rainfall over time**

8.2 Groundwater geochemistry

8.2.1 Piper plots

In order to classify the groundwater type, the major ion chemistry was assessed using a Piper diagram. A Piper diagram comprises two main triangles and a central diamond. The left hand triangle depicts the relative proportions of cations and the right hand triangle depicts the relative proportions of anions. The central diamond is populated by projecting the cation and anion proportions until they intersect within the diamond. The Piper plot was prepared using GW Chart[4], a free program developed by the US Geological Survey (USGS). Laboratory reported carbonate and bicarbonate alkalinity “as CaCO3”, was converted to carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) prior to use.

The groundwater cation geochemistry was dominated by sodium, however the groundwater from one well (MW9) was dominated by magnesium. The groundwater anion geochemistry was dominated by chloride, however, groundwater from two wells (MW9 and MW19) was dominated by bicarbonate and one well (GW1) was dominated by sulphate.

The groundwater geochemistry was assessed based on the depth of well. No significant trend was discernable, suggesting that the groundwater from all wells (except the above identified outliers) is derived from the same water bearing unit.

The groundwater anion geochemistry from MW9 is indicative of freshwater. The groundwater cation geochemistry indicates a high calcium and magnesium proportion. It is noted that the TDS measured in groundwater from this well is typically low (less than 1,000 mg/L). The groundwater from this well is likely to be influenced by a leaky stormwater or water supply service.

The groundwater geochemistry from MW19 has a disproportionate concentration of sodium to that of chloride, which suggests an external source of sodium is present in this area. The bicarbonate concentration is also elevated which may be due to fresh water input. The calcium and magnesium concentrations were the lowest of all wells sampled, by an order of magnitude.

The groundwater geochemistry from GW1 has a high proportion of sulphate and an elevated proportion of calcium and magnesium. The reasons for this are not clear.

The groundwater geochemistry from MW8, MW18 and MW24 show a mixing trend between groundwater and freshwater and may be indicative of areas with higher recharge from rainfall. The TDS in groundwater from these wells is also lower than the average for groundwater in the investigation area.

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[4] http://water.usgs.gov/nrp/gwsoftware/GW_Chart/GW_Chart.html

Figure 8.2 below presents a Piper diagram showing major ion composition of groundwater across the site.

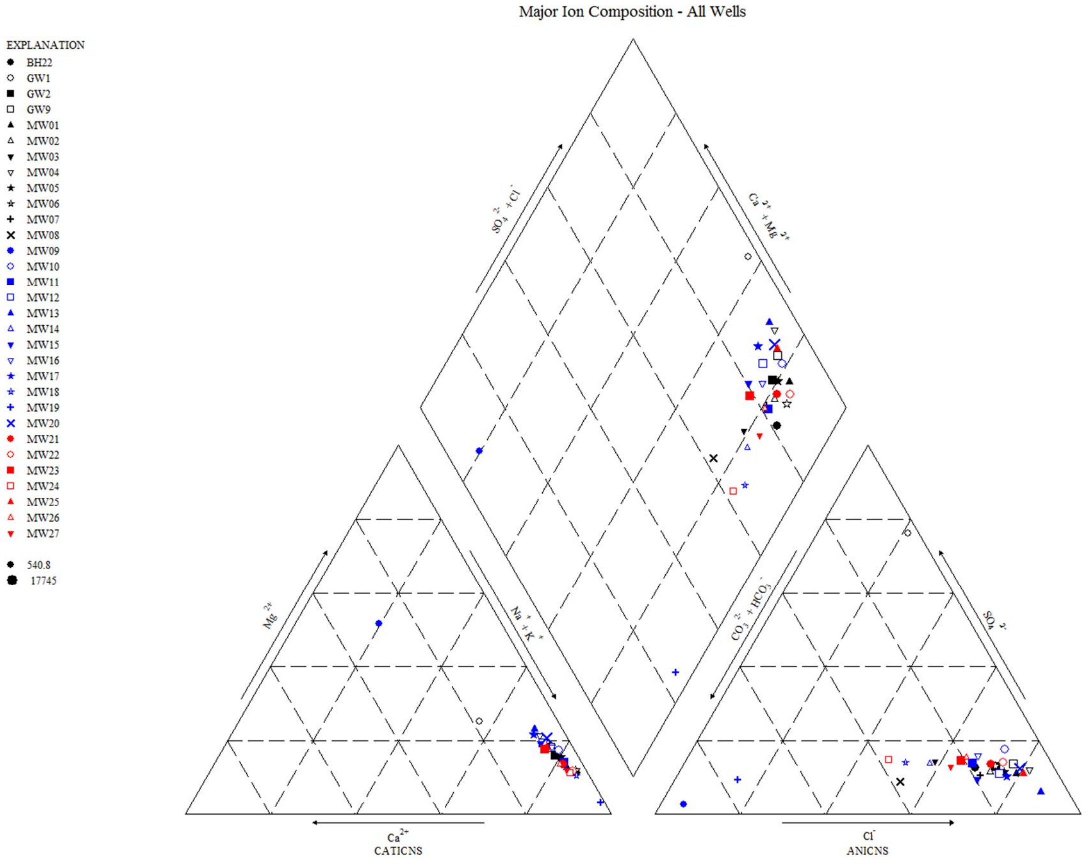

Figure 8.2 **Piper plot showing major ion composition of groundwater sampled across the investigation area**

8.2.2 Stiff diagrams

A Stiff diagram is a graphical representation of chemical analysis used, in this instance, to display the major ion composition of groundwater sampled from the groundwater wells across the investigation area. A polygonal shape is created from four horizontal axes extended on either side of a zero vertical axis. Cations are plotted to the left of the vertical axis and anions are plotted to the right. The resultant polygon allows for easy visual comparison of groundwater from different sources. The Stiff diagrams were prepared using Microsoft Excel. The Stiff diagrams for each groundwater sample are presented in Appendix J.

8.2.3 Chloride/bromide ratios

An assessment of chloride bromide ratios was undertaken. Both chloride and bromide are conservative ions in groundwater – their concentrations do not change significantly during migration through a system. On this basis, the chloride/bromide ratio can provide an indication as to where additional chloride is being added to a system due to dechlorination of chlorinated hydrocarbons.

Using results for groundwater from wells that had not been impacted with chlorinated hydrocarbons (MW11, MW16 and MW25), an average “background” chloride/bromide ratio of 349 was obtained. Groundwater from the majority of wells across the site had chloride/bromide rations within 5% of this “background” ratio. However, MW24 (448), BH22 (401) and MW20 (380) had greater ratio (more chloride present) and MW15 (309), MW26 (317), GW1 (288), MW18 (296), MW07 (272), MW09 (320), MW10 (275), MW08 (312), and MW19 (252) had a lower ratio (less chloride present).

Broadly, the ratio is lower in groundwater from wells with chlorinated hydrocarbon impact and is lowest in groundwater from the vicinity of the child care centre. It is likely that the change in chloride/bromide ratio are indicative of mixing processes (e.g. surface water / groundwater) rather than being indicative of degradation processes. This is also reflected in the Piper plots and stiff plots.

The highest TCE concentration (1,710 µg/L) was detected in groundwater from GW9 in 2013. If this concentration of TCE was to degrade completely, it would lead to a change in chloride concentration of 1.4 mg/L. The average chloride concentration in groundwater was approximately 3,000 mg/L, and as such, the change in chloride concentration is 0.05%. This is well within the margin of natural variation and as such chloride concentration changes, due to degradation of chlorinated hydrocarbons, is not able to be deduced.

8.3 Behaviour of chlorinated solvent plumes in the environment

When discussing changes in the concentration of chlorinated hydrocarbons, it is often practical to use molar concentrations due to the significant atomic weight of chloride atoms. For example, 1 mol/L of PCE will degrade to give 1 mol/L of TCE, however 1 µg/L PCE will produce only 0.79 µg/L TCE upon degradation. The use of molar fractions (proportions of chlorinated hydrocarbons) can aid in the assessment of processes occurring in groundwater. Ratios between parent and daughter compounds (e.g. TCE/PCE) also aids in the understanding of processes occurring.

The following classification system has been developed to help determine how chlorinated solvents may behave in different geochemical environments (from Wiedemeier et al, 1999):

- Type 1 environment:
  - Anthropogenic carbon supply (BTEX, land fill leachate etc.)
  - Strongly reducing conditions
  - Low concentrations of dissolved oxygen, nitrate and sulphate
  - Elevated concentrations of Fe(II), methane, hydrogen, alkalinity
  - Rapid dechlorination of PCE, TCE, CT and TCA
  - Slow degradation of DCE and VC (if reaction is purely biological).
- Type 2 environment:
  - Natural organic carbon supply (swamp deposits, wetlands, peat, etc.)
  - All other factors the same as Type 1 Environment.
- Type 3 environment:
  - Low natural and anthropogenic carbon
  - Oxidising or only slightly reducing conditions
  - Elevated background concentrations of dissolved oxygen, nitrate and sulphate:
    - e.g. dissolved oxygen (and nitrate) greater than 1 mg/L
  - Low background concentrations of Fe(II), methane, hydrogen, alkalinity
  - Reductive dechlorination will not occur:
    - highly halogenated compounds, such as PCE, TCE, TCA and CT will not degrade
  - Oxidation of DCE, VC, etc. can occur.

Based on the information collected from the site to date, it is considered that a Type 3 environment prevails over the majority of the site. However, there are localised areas where a Type 1 environment may occur.

The above classification scheme is relevant mainly to biotic degradation processes. Chlorinated hydrocarbons can degrade through abiotic processes. This typically requires the presence of iron, but does not rely on the presence of organic carbon or reducing redox conditions (however, the presence of iron sulphides requires a somewhat reducing environment). Abiotic degradation of chlorinated hydrocarbons can occur without the production of daughter compounds (Brown, et al[5]).

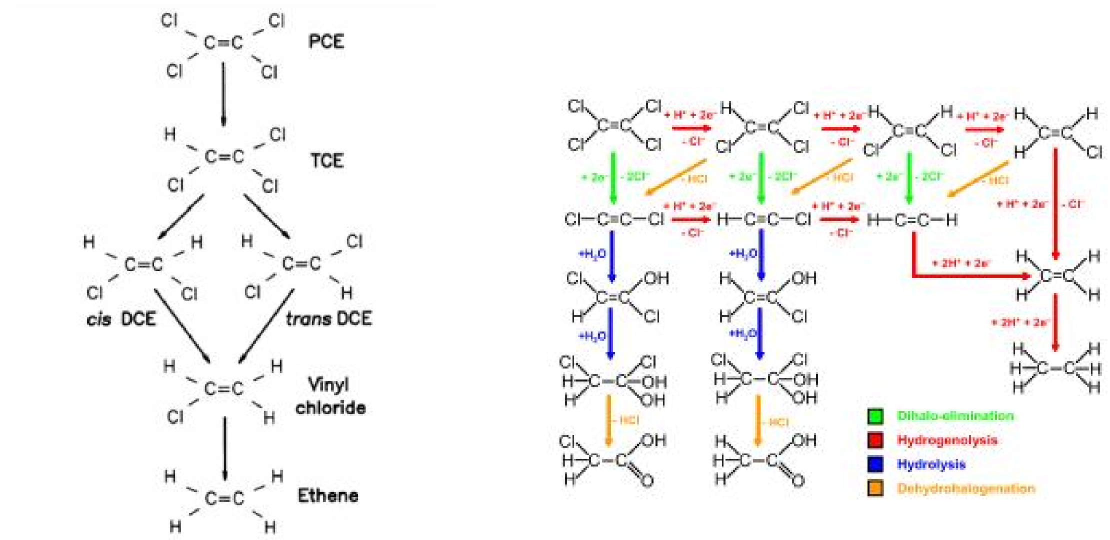

Figure 8.3 Biodegradation sequence (left) and abiotic reaction processes (right) (from Brown, et al)

Tetrachloroethene (PCE) is used as a solvent and is likely to be a source contaminant. PCE has been detected in groundwater from across the assessment area. PCE degrades to TCE through reductive dechlorination or to dichloroacetylene through abiotic reaction.

Trichloroethene (TCE) is used as a solvent, but can also be generated due to the degradation of PCE. Given the observed dissolved concentrations in groundwater across the site, it is considered that TCE is both a source contaminant and a degradation product. The extent of TCE is similar to PCE.

Dichloroethene (DCE) is used as a solvent (typically in trans-DCE form), but can also be generated due to the degradation of TCE. At this site, it is considered that the presence of DCE is prominently from degradation processes.

Chloroform is from the trihalomethane (THM) group of chlorinated hydrocarbons. The presence of chloroform is noted in groundwater from wells both with and without PCE, TCE or DCE. Chloroform can be used in industrial processes as a solvent and it is not a degradation product of PCE, TCE or DCE. However, chloroform can be generated through a reaction between chlorine based bleach and / or cleaning products with organic matter contained within sewer systems. Given that chloroform is present in groundwater from wells located within residential areas and cross-hydraulic gradient of the industrial source area of PCE, TCE and DCE (as well as within the source area), it is considered that the presence of chloroform may suggest that leaky sewers are present in the area.

8.4 Chlorinated hydrocarbon concentration vs distance

The concentration of chlorinated hydrocarbons has been assessed along three main transects, which run in the approximate direction of groundwater flow.

- Transect 1: MW26, MW12, MW02, MW05, MW04, MW06 and MW07
- Transect 2: MW16, GW9, GW2, GW1 and MW18; and
- Transect 3: MW23, MW24 and MW13.

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[5] http://www.environmental-expert.com/Files%5C8969%5Carticles%5C13245%5Cart11.pdf

8.4.1 Transect 1

Transect 1 runs from MW26, located to the east, to MW07, located close to the child care centre. It is noted that the groundwater flow pattern is radial towards MW07 and as such, there may be multiple sources effecting this location.

PCE was detected in MW26, and chlorinated hydrocarbons are present in all other wells along this transect. The concentrations are highest in groundwater from wells MW12, MW02, MW05, MW04.

The molar fraction indicates that DCE comprises the majority of chlorinated hydrocarbons in groundwater from all wells except MW26 (in which only PCE was detected) and MW07. TCE is the dominant chlorinated hydrocarbon in groundwater from MW07.

The TCE/PCE ratio for groundwater from MW12, MW02 and MW05 is less than 1 suggesting that TCE may be present due to the degradation of PCE. This ratio changes to greater than 10 in MW04, suggesting that a TCE source is present between MW05 and MW04. The ratio further increases to greater than 1000 in MW7, which may suggest an additional source between MW18 and MW07 (noting that MW07 may be impacted by more than one groundwater flow path as noted above).

The DCE/TCE ratio is greater than 10 in groundwater from MW12, MW02 and MW05, greater than 1 in groundwater from wells MW04, MW06 and MW18, and below 1 in groundwater from MW07. This suggests that DCE is not likely to be solely sourced from TCE degradation in all wells except MW07.

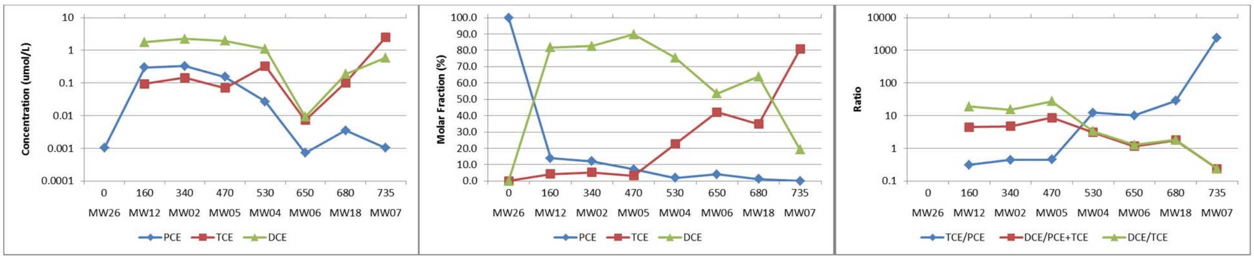

Figure 8.4 Transect 1 – concentration (left), molar fraction (centre), and VCH ratios (right)

8.4.2 Transect 2

Transect 2 runs from MW16, located to the east, to MW18, located close to the intersection of Tapleys Road and West Lakes Boulevard. Chlorinated hydrocarbons have not been detected in MW16 to date. It is considered that a source of chlorinated hydrocarbons is present in the vicinity of GW9. This is confirmed by the concentration trend along the transect, which peaks at GW9. The concentration of PCE decreases between GW9, GW2 and GW1, and then increases at MW18. The concentration of TCE is stable between GW2 and GW1, decreases at GW1 and increases at MW18. The concentration of DCE is stable between GW9 and GW2 and then decreases to MW18. Vinyl chloride was detected in wells GW1 and GW2, but not in wells up and down gradient.

The molar fraction indicates that TCE and DCE make up the majority of chlorinated hydrocarbons in GW9 and GW2, and DCE makes up the majority in GW1 and MW18. The TCE/PCE ratio in groundwater from wells GW9, GW2, GW1 and MW18 is greater than 1 (greater than 10 in most cases) indicating that the TCE is unlikely to be solely due to PCE degradation. The DCE/TCE ratio in groundwater from GW9 and GW2 is close to 1 which suggests that the DCE could be from TCE degradation. This ratio becomes greater than1 in GW1, which may suggest a second source of DCE between GW9 and GW1.

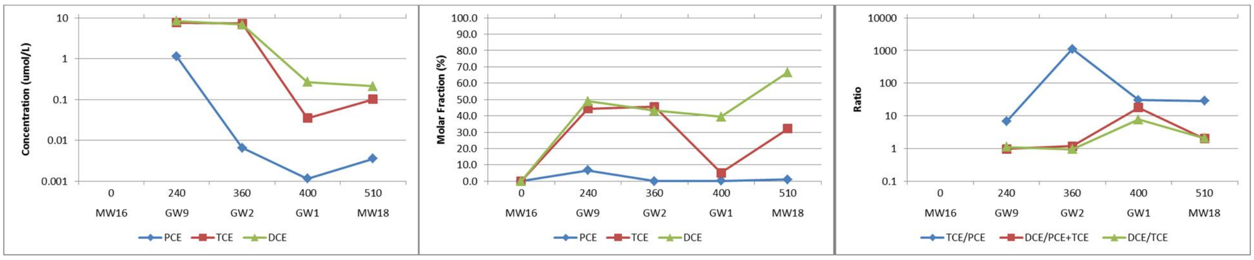

Figure 8.5 Transect 2 – concentration (left), molar fraction (centre), and VCH ratios (right)

8.4.3 Transect 3

Transect 3 runs from MW17, located to the east of the main industrial area, to MW13 located to the north of the industrial area. It is noted that due to the well locations this transect is not aligned perfectly with groundwater flow and MW17 and the wells are staggered either side of the transect line. Chlorinated hydrocarbons have been detected in all wells (only TCE in MW17) along this transect, with peak concentrations in groundwater from MW14. The concentrations decrease towards MW13.

The molar fraction indicates that TCE comprises the majority of chlorinated hydrocarbons in groundwater from MW17, MW23 and MW14. DCE becomes dominant in groundwater from MW13. The TCE/PCE ratio is around 10 in groundwater from MW23 and MW14, and drops to 2 in groundwater from MW13. This suggests that TCE is a source compound. The DCE/TCE and DCE/(TCE+PCE) ratios are less than 1 in groundwater from both MW23 and MW14 suggesting that DCE may be a degradation product. In groundwater from MW13, the ratios are above 1, which may suggest that PCE and TCE have degraded abiotically without generating DCE or that a source of DCE is present which is affecting MW13. It is noted that redox conditions become less oxidising in groundwater from MW23 and MW14 than other wells on the transect, which supports the possibility of degradation occurring (it is noted that dissolved oxygen and sulphate remain relatively even for all wells).

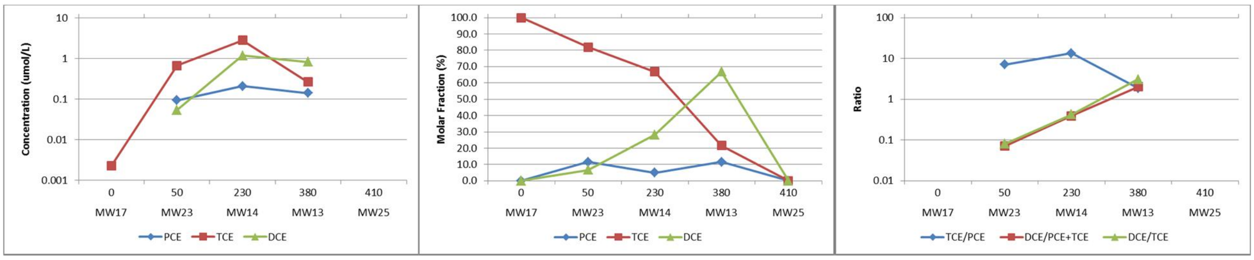

Figure 8.6 Transect 3 – concentration (left), molar fraction (centre), and VCH ratios (right)

8.5 Chlorinated hydrocarbon concentration vs time

The site assessment is in relatively early stages in terms of temporal data collection. There are a maximum of three rounds of groundwater analytical data for key wells close to the area originally considered as the source. Furthermore, the data collected is from September 2012, June 2013 and March 2014. These periods are representative of different seasons and as such, are not necessarily representative of the same groundwater conditions.

From Transect 1, wells MW02, MW04, MW05, MW06 and MW07 have been sampled more than twice. The PCE concentration in groundwater from wells MW04, MW05 and MW06 increased between 2012 and 2013 and then decreased in 2014. The PCE concentration in groundwater from MW02 decreased then increased. The TCE concentrations in MW04 and MW07 have increased between 2012 and 2014. TCE in groundwater from well MW02 and MW06 have decreased between 2012 and 2013. TCE in groundwater from MW05 increased between 2012 and 2013 and then decreased in 2014.

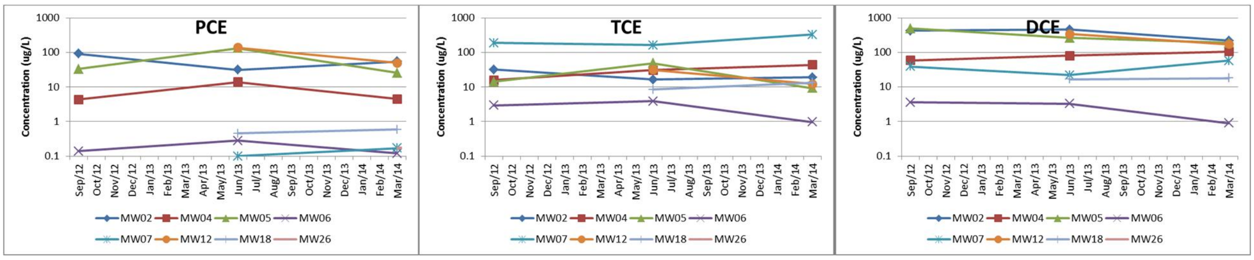

Figure 8.7 Transect 1 – PCE (left), TCE (centre), and DCE (right)

From Transect 2, GW9 is the only well with more than two rounds of data collection. The PCE and TCE concentrations have shown a slight increase between 2012 and 2013, and a slight decrease between 2013 and 2014. The DCE concentration has shown a steady, slight decrease between 2012 and 2014.

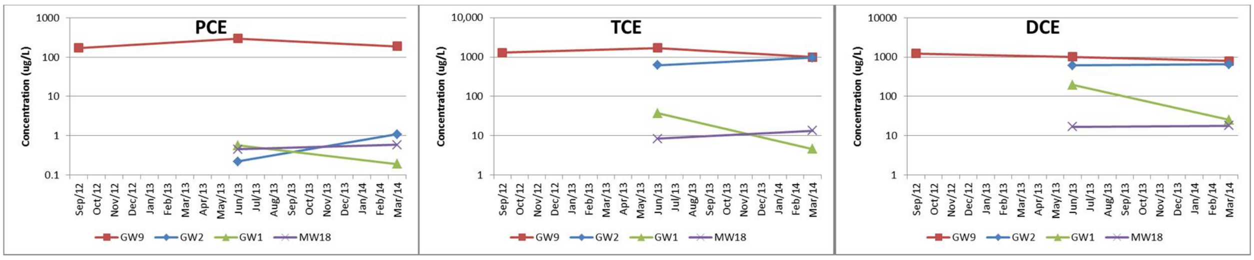

Figure 8.8 Transect 2 – PCE (left), TCE (centre), and DCE (right)

None of the wells along Transect 3 have been sampled more than twice. And as such, concentration trends over time are not able to be discussed.

8.6 Potential chlorinated hydrocarbon source areas

To assist is conceptualising potential source areas of the identified chlorinated hydrocarbons within groundwater, contaminant concentration contour plots have been prepared for TCE, PCE and 1,2-DCE and are presented in Appendix K. These plots have been created using Surfer contouring software, with contours weighted 5:1 along the direction of inferred groundwater gradients. By plotting the contours in this way it can assist with establishment of possible source areas and differentiating between possible sources. This data can then be used as an additional tool, together with the transect analysis discussed in Section 8.5, to build upon the identification of possible source areas.

Given the lack of groundwater wells within the industrial precinct, the identification of potential source areas is very difficult, as most of the available data is from the edge of the industrial area and within surrounding residential areas. However, based on the contour plots the following potential source areas are inferred:

- PCE source(s) in the vicinity of and/or south-east of GW9 within the existing industrial area
- Possible additional PCE source south-east of MW14 within the existing industrial area
- Possible 1,2-DCE source to the east of MW12/MW02
- Possible TCE source(s) within the vicinity of GW2 &GW9, south-east of MW14 and within the vicinity of MW07.

It is considered that at least three or four source areas are likely, however cannot be confirmed based on existing data. The most likely source areas based on existing data are as follows:

- the property at 3-5 Phillips Crescent (PCE/TCE/1,2-DCE)
- a property to the south-east of 3-5 Phillips Crescent, north of West Lakes Boulevard (PCE/1,2-DCE)
- a property within the north-eastern portion of the industrial area, between MW14 and MW23 (PCE/TCE)
- possibly a property between well MW18 and Tapleys Hill Road (TCE).

It is also considered possible that the deep sewer beneath Tapleys Hill Road, the western portion of Circuit Drive, Farman Avenue and possibly other portions of the investigation area could act as a preferential pathway for migration of chlorinated hydrocarbon impacts.

9. Conceptual site model

In order to enable an assessment to be made of the potential sources of impact, chemicals of concern, transport mechanisms and receptors, a Conceptual Site Model (CSM) has been developed from the information obtained to date.

A diagrammatic representation of the CSM, illustrating known contaminant sources, transport mechanisms/pathways and environmental receptors associated with the contamination of groundwater in the investigation area, is included as Figure 7 (Appendix A).

9.1 Local and regional setting

The investigation area is located within the local council area of Charles Sturt and incorporates the suburbs of Hendon, Seaton, Albert Park and Royal Park. Land use within the investigation area is illustrated in Figure 8, Appendix A. The investigation area incorporates both industrial/commercial and residential land, as well as a school and a child care centre. Land uses in the vicinity of the 3-5 Philips Crescent site include the following:

- commercial/industrial to the east of Tapleys Hill Road and north of West Lakes Boulevard
- residential to the south of West Lakes Boulevard; and
- Hendon Primary School, First Steps Child Care Centre and residential and commercial properties to the west of Tapleys Hill Road.

The region is underlain by the Quaternary (Pleistocene) Pooraka Formation which comprises pale red-brown sandy clay containing carbonate of the Loveday soil. The shallow unconfined water table is located within interbedded sands and clays and, based on the field investigations and proximity to Boating Lake (West Lakes), groundwater within the uppermost aquifer is inferred to generally flow towards the west, however monitoring data in the vicinity of Tapleys Hill Road suggests that the deep sewer in this area may be acting as a groundwater drain, resulting in an easterly groundwater gradient in the area west of Tapleys Hill Road. Groundwater seepage velocity ranges between 3.5 and 12 m/year.

Based on the DEWNR (2014) data it is apparent that groundwater bores in the area are mainly utilised for investigation, observation, domestic, monitoring, irrigation and drainage purposes. Shallow wells (drilled to depths of up to 12 m) recorded standing water levels of 1.0 to 7.0 mBGL and salinity levels between 200 and 26,382 mg/L TDS.

9.2 Current and proposed site use and general condition

The current land uses within the investigation area include residential, commercial and industrial. No proposed changes to existing land use are known.

The soil profile encountered during the additional environmental assessment indicated that fill materials were present at all sampling locations to depths of between 0.4 and 0.5 mBGL. The underlying natural soil profile consisted of fine to coarse grained, low to medium plasticity, clayey and silty sands/sandy clays of varying colour; medium to coarse grained, orange-brown sands; brown, yellow-brown, orange-brown, or orange-brown mottled grey-brown, low plasticity clayey silt; and low to high plasticity silty clays of varying colour.

The depth to the uppermost aquifer ranged from 3.376 to 4.189 mBTOC.

9.3 Sources of impact and chemicals of concern

9.3.1 Dissolved compounds

As a result of previous industrial activities having been undertaken within parts of the investigation area, elevated concentrations of chemical substances are present within shallow groundwater.

Previous investigations at the Philips Crescent site have identified chemicals used in the manufacture of copper-based printed circuit boards, several underground and above ground tanks (some containing chemicals/chemical waste), drums, a pit and sumps as possible contaminant sources. Identified chemicals of concern within both soil and groundwater at the Philips Crescent site include metals (copper, tin, lead, nickel), boron, fluoride and VOCs. The results of the Parsons Brinckerhoff 2012 investigation in the surrounding area did not identify VOC contaminants in soil.

Groundwater beneath the (surrounding) investigation area is present at shallow depth (typically 3.5 to 5 mBGL) within an unconfined aquifer of interbedded sands and clays. Based on investigations carried out in the area to date, nitrate, sulphate, chloride, metals (cadmium, cobalt, copper, nickel and zinc), naphthalene and VOCs (PCE, TCE, 1,1-DCE, chloroform, 1,2-dichloroethane and vinyl chloride) are present in groundwater at concentrations that exceed beneficial use criteria. Detectable concentrations of various additional VOCs are also present, including the TCE breakdown products *cis*- and *trans*-DCE. These contaminants are considered likely to be present in groundwater as a result of historical industrial activities at the 3-5 Philips Crescent site (located up-hydraulic gradient) and potentially at least 3 other properties within the industrial precinct bounded by West lakes Boulevard, Tapleys Hill Road, Farman Avenue and Gordon Street, as discussed in Section 8.6.

Residents within the EPA Investigation Area (as illustrated on Figure 1, Appendix A) have been advised by the EPA not to use groundwater until further notice.

9.3.1 DNAPL

Pure chlorinated hydrocarbons (CHs) are dense non-aqueous phase liquids (DNAPLs), which are denser than water. As such, when spilled or leaked into the subsurface, they typically migrate vertically downward through the aquifer. They are also able to migrate through leaky confining layers into underlying aquifers. When encountering low permeability units, the DNAPLs spread laterally following topographical gradients, and as such DNAPL migration is typically independent of groundwater flow direction. Once within the sub-surface environment, DNAPLs transform into vapour and aqueous phases through volatilisation and dissolution respectively. The presence of DNAPLs is difficult to detect and as such, it is considered that a dissolved CH concentration, which is greater than 1% of the solubility limit for that compound, is indicative of DNAPL presence. At this site, the maximum PCE and TCE concentration detected in groundwater to date have been 296 µg/L and 1,710 µg/L respectively. The maximum PCE and TCE solubility is 200 mg/L (200,000 µg/L) and 1,000 mg/L (1,000,000 µg/L) respectively. On this basis, the detected concentration of PCE is less than 0.15% of the maximum PCE solubility and TCE is less than 0.2% of the maximum TCE solubility. While this information does not indicate the presence of DNAPL at the site, it should not be considered that there is no potential for DNAPL to be present.

9.4 Fate and transport

9.4.1 Possible transport mechanisms

The anticipated primary transport mechanisms for the migration of the identified contaminants of concern in groundwater are as follows:

- lateral migration within the shallow aquifer, potentially impacting off-site down-hydraulic gradient receptors (e.g. groundwater bores and local water bodies)
- vertical migration (i.e. of the VOCs, many of which are denser than water) from the shallow aquifer to deeper aquifer(s); and
- diffusion of vapours generated from the VOCs through the soil profile into surface indoor and/or outdoor air as well as into service pits/trenches
- lateral migration of impacted groundwater and/or vapour through preferential migration within the deep sewer system , particularly in the vicinity of Tapleys Hill Road, Circuit Drive and Farman Avenue. This migration could occur through the bedding sands or through the sewer pipe itself given that the sewer invert level is below the water table throughout much of this area. The fact that the sewer is predominantly made of vitreous clay suggests that some leakage of the sewer system is likely.

9.4.2 Exposure pathways and potential receptors

Anticipated human exposure pathways for the chemicals of concern identified within groundwater in the investigation area include the following:

- Direct contact with contaminated water – this could occur through the use of groundwater to fill swimming pools, during subsurface excavation/maintenance work that intersects the water table and/or during the extraction of groundwater for use as drinking water or for irrigation purposes.
- Ingestion of contaminated groundwater – this could occur through the deliberate or accidental consumption of bore water if it is used for potable, irrigation or recreational purposes.
- Inhalation of vapours generated from the VOCs contaminants – this could occur via the breathing in of impacted surface indoor or outdoor air, via contact with accumulated vapours in utility pits/trenches or during excavation works.
- Inhalation of vapours generated from the VOCs which may migrate within sewer trenches and/or pipes.

Should impacted groundwater discharge to a down-gradient surface water body (e.g. Boating Lake) or groundwater bore, primary and secondary contact recreation could also result in human exposure via direct contact and/or accidental ingestion.

Identified possible receptors within the vicinity of the site include the following:

- residential, recreational or commercial land users
- construction/maintenance workers undertaking subsurface excavation works and/or accessing utility pits/trenches
- down-gradient groundwater users
- the marine ecosystem of Boating Lake, located approximately 1 km to the west, which drains into Barker Inlet; and
- recreational users of Boating Lake.

10. Vapour risk assessment

A supplementary vapour risk assessment (VRA) was undertaken by Dr Sim Ooi of Salcor Consulting for the Hendon investigation area, based on the concentrations of designated VOCs (PCE, TCE, 1,1-DCE, *cis*- and *trans*-DCE and vinyl chloride) measured during the recent groundwater and soil vapour monitoring events, as described in Section 7. The recent monitoring included vapour investigations of the sub-surface soil, sub-slab, crawl space, indoor and outdoor air at selected areas. The VRA was conducted as a supplement to the previous vapour risk assessment (previous VRA) (Parsons Brinckerhoff, 2013). The previous VRA, as well as the previous environmental site assessments (ESAs) should be read in conjunction with this supplementary VRA for the historical information.

10.1 Objectives

The primary objective of the supplementary VRA was to update the assessment of vapour intrusion risks from the designated VOCs identified in the residential areas and the child care centre, based on the findings of the latest assessment.

10.2 Risk assessment approach

The supplementary VRA has drawn on the methodology used in the previous VRA (Parsons Brinckerhoff, 2013), which was conducted in accordance with the National Environment Protection (Assessment of Site Contamination) Measure 1999 as amended in 2013 (Amended ASC NEPM). The Guideline on Health Risk Assessment Methodology, Schedule B (4) outlined in the amended ASC NEPM was referred to in specific.

For the purpose of this assessment:

- Conservative assessment criteria for the designated VOCs including inhalation specific toxicity criteria (based on plausible maximum 24/7 exposure) and derived risk-based levels for indoor air (based on generic residential exposure assumptions) were adopted.
- The supplementary VRA focussed on designated VOCs such as PCE, TCE, 1,1-DCE, cis- and trans-1,2-DCE and VC. Ethylene has not been detected at the site and therefore excluded from further evaluation. The toxicity criteria adopted for the purposes of the VRA are based on the chemical properties and the relevant exposure route (i.e. vapour inhalation). The toxicity criteria considered for the VRA are consistent with the amended ASC NEPM and presented in Appendix L4. The basis of the toxicity criteria is provided in Schedule B7 of the amended ASC NEPM and not presented in this report.
- Consistent with the previous VRA, screening assessments (for both groundwater and vapour) and site-specific assessment are provided in the supplementary VRA. Hence, the previous VRA shall be referred to and read in conjunction with the supplementary VRA for details and clarification of the methodology and approaches
- A site-specific assessment is conducted when exceedances are identified in the screening assessments. The site-specific assessment involves the use of more site related measurements in the VRA, which include geotechnical analysis and direct measurement of VOC in the indoor and outdoor environments.

10.3 Groundwater screening assessment

To simplify the VRA, a stepwise screening assessment of the groundwater impacts was adopted. This allowed the risk assessment to identify and focus on the chemicals of concern that drive the risks. The stepwise approach consisted of the following steps:

- Step 1 screening assessment – Compare the measured groundwater concentrations of the designated VOCs to the Australian Drinking Water Guidelines (NHMRC/NRMMC, 2011) or to the applicable environmental guidelines for South Australia.
  - Step 1 screening assessment is presented in Appendix L5. For chemicals with concentrations above the adopted guidelines or with no guideline values, proceed to Step 2.
- Step 2 screening assessment – Compare the estimated source vapour concentrations to the assessment criteria derived for vapour under the slab. In addition to adopting inhalation toxicity criteria as the toxicity based assessment criteria, risk-based assessment criteria for indoor air were also derived for the VRA. The toxicity based assessment criteria are air acceptance criteria which assumed lifetime 24/7 exposure. The risk-based assessment criteria are landuse and exposure based air acceptance criteria which were derived based on the exposure assumptions for residential settings in accordance to the amended ASC NEPM.
  - Vapour concentrations of VOCs at the source were estimated using the groundwater concentration and the unitless Henry's Law constants. The estimated vapour concentration at the source is considered to be the highest concentration emitted from the groundwater.
  - To derive the assessment criteria for vapour under the slab, a sub-slab to indoor air attenuation factor of 0.005 and the toxicity based or risk-based assessment criteria for indoor air (see Appendix L5) were used. Adoption of the sub-slab to indoor air attenuation factor of 0.005 [as discussed in Friebel and Nadebaum (2011) for the development of health screening level (HSL) for petroleum hydrocarbons] removed the influence of the soil properties on volatilisation of chemical vapour through the soil column. This is a conservative approach as it assumed the presence of source vapour concentration right beneath the slab, when the source vapour concentrations were originated and measured in the sub-surface at depths or groundwater levels.
  - Step 2 screening assessment is presented in Appendix L5. For chemicals with estimated source vapour concentrations above the assessment criteria for vapour under the slab, proceed to Step 3.
- Step 3 screening assessment – Compare the estimated source vapour concentrations to the assessment criteria derived for soil vapour or groundwater at the source at depths.
  - Similar to Step 2, the assessment criteria for sub-surface soil vapour were derived using vapour attenuation factors and the toxicity based or risk-based assessment criteria for indoor air (see Section 10.2 and Appendix L4).
  - Step 3 involved the use of sub-surface to indoor air vapour attenuation factors, which were estimated based on the following:
    - USEPA's Johnson and Ettinger (JE) vapour intrusion model assuming a slab-on-ground construction. For this assessment, the JE vapour intrusion model for the groundwater source was used, similar to the previous VRA. The vapour intrusion model outputs are presented in Appendix L5.
    - Site-specific soil profile based on the information in the borelogs collected from previous investigations (2012 and 2013). The borelogs indicated that soils in the vadose zone across the residential area consisted primarily of both sandy and silty materials. In general, it was estimated that the average thicknesses of the sandy and silty materials at the vadose zone above the groundwater across the area at Hendon are 2.37 m and 1.23 m, respectively (PB, October 2013). These soil profiles and thicknesses were adopted for the vapour intrusion modelling.

  - For screening purposes, the generic soil parameters [(for sand/sandy clay and silt/silty clay) used in the development of HSL (Friebel and Nadebaum, 2011) (HSL parameters)] were adopted for the site-specific soil profile and used in the vapour intrusion modelling (see Appendix L5).
  - The average standing water levels were 3.6 mBGL in 2012, 4.0 mBGL in 2013 and 3.9 mBGL in 2014. Given the depth to water adopted in the previous VRA was 3.6 mBGL, no adjustments to the vapour intrusion model, except for groundwater concentrations of the designated VOCs, was considered required.
- Step 3 screening assessment is also presented in Appendix L5. For chemicals with estimated source vapour concentrations above the assessment criteria for subsurface vapour at the source, proceed to soil vapour investigations and site-specific assessments (see Section 10.4).

10.3.1 Results of the groundwater screening assessment

Based on the latest dissolved phase concentrations of the designated VOCs, the groundwater screening assessment identified TCE as the chemical of concern in the groundwater for vapour intrusion. The results are presented in Appendix L5 and confirm the findings of the previous VRA.

The groundwater results also indicated that, except for the MW07 (which is located in the vicinity of the First Steps Child Care Centre), TCE concentrations in the groundwater at residential area were lower during the latest monitoring event (March 2014) compared to the 2013 monitoring rounds. The TCE concentration in MW7 has increased from 189 µg/L to 330 µg/L over the same period.

10.4 Soil vapour risk assessment

10.4.1 Soil vapour investigations

Soil vapour investigations were carried out using fifteen existing soil vapour bores (SV01 to SV15) and two new soil vapour bores (SV16 and SV17) installed within or near the residential properties or the child care centre (see Figure 2, Appendix A for locations of soil vapour wells). All soil vapour bores, except SV15, were located within or adjacent to residential areas. SV15 was located within the First Steps Child Care Centre site.

The results of the soil vapour analysis specific to this VRA are presented in Appendix L1.

10.4.2 Soil vapour screening assessment

A stepwise screening approach, similar to that described in Section 10.3, was also adopted for the assessment of soil vapour. The measured soil vapour concentrations were assessed against the adopted assessment criteria for indoor air (Step 1) and the screening level for vapour under the slab (Step 2) (see Appendix L6). The interim health investigation levels (HILs) for chlorinated hydrocarbons in soil vapour, as well as the toxicity based and the risk-based assessment criteria for chemicals in air (see Appendix L4) were adopted in the Step 1 and Step 2 screening, respectively.

Exceedances were found in seven locations: SV01 (TCE), SV02 (cis 1,2-DCE and TCE), SV04 (TCE), SV06 (TCE), SV10 (TCE), SV13 (cis 1,2-DCE and TCE). SV01, SV02, SV04, SV06, SV10 and SV13 are located within or adjacent to residential areas. SV04 is also located in a public area close to the child care centre. The results indicated that TCE and cis-1,2-DCE were the chemicals of concern in soil vapour (see Appendix L6) at the residential premises within the investigation area. This is consistent with the findings of the previous VRA.

In this assessment, only the residential zone within the area of investigation were subject to the soil vapour screening assessment. A more extensive investigation and assessment of vapour intrusion risks was conducted separately for the child care centre (see Section 10.4.4).

10.4.3 Site-specific vapour risk assessment-residential

As in the previous VRA, a site-specific assessment was triggered following the soil vapour screening assessments. The assumptions adopted in the previous VRA were also adopted in this assessment, which include:

- TCE and 1,2-DCE are the chemicals of concern for the residential area.
- Estimation of indoor exposure concentrations using vapour attenuation factor generated by the USEPA JE vapour intrusion model for the soil vapour source (see Appendix L7) beneath a slab-on-grade construction. The estimated indoor air concentrations were compared to the toxicity based assessment criteria or the risk-based assessment criteria derived for the purpose of this assessment.
- Information from the previous VRA (based on borelogs) indicated that the soil profile above the vapour sampling depths consisted of both sandy and silty materials across the residential area, except for the child care centre. Based on the borelogs there is at least 0.5 m of silty materials in the soils within the residential area.
- Soil parameters (i.e. total porosity, air porosity and water porosity) derived from the geotechnical analysis and sampling depths, the same as those used in the previous VRA, were adopted in the vapour intrusion model (see Appendix L7). This geotechnical data was obtained from samples collected in September 2012. Soil within the residential area consisted generally of at least 0.5 m of silty materials. It was assumed that, for vapour intrusion modelling, soils in residential area consisted of 0.5 m of silty materials with sandy materials making up the rest of the soil column within the sampling depth for soil vapour.
- Based on the limited number of soil samples submitted for environmental analysis between 2012 and 2014, the average soil moisture content was similar from 2012 to 2014, with the average concentration varying from 11% to 14% in soil between 0.5 and 2 mBGL. Only soil samples collected in September 2012 (from SV1 and SV2 within the residential area) were subjected to geotechnical analysis, and showed a moisture content varying from 11.9% (sandy soil) to 25.6% (silty soil). For the purposes of vapour intrusive modelling, moisture contents from the geotechnical analysis (where un-disturbed soil handling was required during sampling) were considered to be more appropriate and adopted. The data is consistent with the range (at the higher end) reported by Friebel and Nadebaum (2011) for sandy soils (2–12%) and silty soil (13–23%). Note that moisture of 8% (sandy soil) and 22% (silty soil) were adopted by Friebel and Nadebaum (2011) for the development of the NEPM HSL. A site specific moisture content of 12% (sandy soil) and 24% (silty soil) were adopted for the site-specific assessment in the previous VRA.
- In addition to the similarity in the average moisture contents from 2012 and 2013 in the environmental samples, it is observed that the latest investigation was conducted in March 2014, which is generally the month with lower rainfall, if not the lowest, in the past years. This indicated that soil moisture content remained relatively stable during the past three years, and the rainfall at Hendon did not appear to have a large impact on the variability of the average soil moisture content, in particular the deeper soil. However, the available geotechnical data is considered insufficiently robust to provide a verification of the soil moisture content of the soil profile across the area of investigation.
- On the basis of the above information, this VRA assumed that the soil profile and soil parameters remain the same since 2012. Hence, with the exception of the VOC concentrations, the same vapour intrusion models used in the previous VRA were adopted for the supplementary VRA.
- The assessment of vapour inhalation exposure was based on the Risk Assessment Guidance for Superfund (RAGS) Part F from the USEPA (2009) where the exposure air concentrations, instead of intake dose, are used to assess the risks associated with vapour inhalation. This approach is adopted

by Friebel and Nadebaum (2011) for the development of HSLs which are adopted in the amended ASC NEPM.

The assessment of the potential vapour intrusion risks in the residential area was based on comparing the model predicted air concentrations to the adopted or derived assessment criteria for indoor residential air. The results are presented in Appendix L7 and summarised in Table 10.1.

Table 10.1 Summary of site-specific vapour risk assessment – residential area

Vapour sampling depth (mBGL)	Bore location	Max soil vapour conc (ug/m^3)		Predicted indoor air conc (ug/m^3)	
		TCE	cis 1,2-DCE	TCE	cis 1,2-DCE
1.0 m	SV04	5200	44	0.05	0.001
1.5 m	SV01,07,08,09, 10,11, 12,13,14	16000	12000	0.14	0.15
2.0 m	SV02,03,05,06	1100	1800	0.01	0.02

Residential air assessment criteria	TCE	cis 1,2-DCE
Tox-Based (NEPM)	1.8	7.0
Risk-Based	2.2	8.4

The results indicated that the TCE and/or cis-1,2-DCE concentrations in indoor air predicted using the site-specific information are below the adopted assessment criteria.

It is noted that a significant increase in the soil vapour concentration of TCE (from 2300 ug/m^3 in 2013 to 16000 ug/m^3 in March 2014) was observed at location SV10. This is in contrast to the decrease in the groundwater concentrations for TCE within the vicinity of SV10 (at MW 14), from 551 ug/L in 2013 to 366 ug/L in March 2014. In other area of investigation, increased soil vapour concentrations were observed with increased groundwater concentrations.

10.4.4 Site-specific vapour assessment – child care centre

A more extensive vapour monitoring program has been conducted at the First Steps Child Care Centre. It involved the collection of vapour samples from sub-slab, crawl space, indoor air and outdoor air, using canisters for the 24-hour sampling and Radiello passive sampler for the 10-day sampling. Outdoor air was collected from one area only, whilst another Radiello was placed within the sewer pit (see Figure 3, Appendix A for sampling locations).

Given the availability of measured concentrations for the designated VOCs, in particular the indoor air concentrations; these measured concentrations will be used primarily in the site-specific assessment of the potential vapour risks to the users of the First Steps Child Care Centre.

The assessment criteria for the residential receptors were also adopted for the evaluation of the receptors at the child care centre. This is based on the assumption that residents in the area may attend the child care centre and be continuously exposed to the designated VOC vapours in their residence and at the child care centre.

The results are presented in Appendix L2 and Appendix L3, and indicated the following:

- An initial crawl space sample collected in March 2014 identified the presence of TCE (at 26 µg/m^3) in one crawl space location (CS1) beneath the child care centre building. This triggered a more extensive vapour investigation program at the child care centre. It is understood that crawl spaces existed only within the main child care centre building (i.e. beneath the timber floored area shown on Figure 3, Appendix A). Full details of the construction of the crawl space beneath the site building were not available at the time of this assessment.

- TCE was the only designated VOCs that detected above the PQLs in all samples. Hence, TCE is currently considered as the only chemical of concern in air at the child care centre.
- TCE was not detected in the sub-slab sample. Only one sub-slab sample was collected from a location separate to the main child care centre building (see Figure 3, Appendix A). No indoor air samples were collected at this specific location.
- Crawl space sampling conducted in April 2014, subsequent to the initial sampling in March 2014, showed the concentrations of TCE varied between 4 ug/m^3 and 8.3 ug/m^3 in the primary samples collected using the 24-hour canisters. The 10-day Radiello sampling at the same locations showed a similar result with TCE concentrations ranging from 3.5 µg/m^3 to 7.2 µg/m^3 in the primary samples. Both sampling methodologies (i.e. canister and Radiello) provide the same indications of impacts qualitatively. Quantitatively, the Radiello provided 10-day time-weighted-average concentrations which were reported as being slightly lower concentrations. Based on these results, it appeared that there was no large variability observed between the 24-hour and the 10-day exposure (see Appendix L8).
- The outdoor air concentration of TCE was 1.1 ug/m^3 using the 24-hr canister, and 0.7 ug/m^3 using the 10-day Radiello (see Appendix L8).
- Indoor air sampling was conducted at the same time as the crawl space sampling. One outdoor air sample was also collected for analysis. Sampling of indoor and outdoor air was conducted to investigate if TCE in crawl space is a source of indoor air concentrations. More importantly, it is a direct measure of the concentrations exposed to the users of the child care centre.
- The indoor air concentrations were between <1 ug/m^3 to 1.3 ug/m^3 using the 24-canister. A slightly lower time-weight-average concentrations of between 0.74 ug/m3 to 0.9 ug/m^3 were reported for the 10-day Radiello. Similar to the crawl space investigation, no large variability was observed between the 24-hour canister and 10-day Radiello sampling methods. No large variability was also observed in the TCE concentrations among the indoor sampling locations. It appeared that the both the indoor and outdoor air have very similar TCE concentrations (Appendix L8).
- In contrast to the outdoor air, despite sampling from multiple locations, no obvious correlation may be drawn between the crawl space and the indoor concentrations of TCE (see Appendix L8).
- TCE vapour was also detected in the sewer pit at a concentration only slightly lower than those observed for the outdoor air.

In summary, both the 24-hour canister and 10-day Radiello studies indicated that the measured indoor and outdoor TCE concentrations (up to 1.3 µg/m^3) at the First Steps Child Care Centre did not exceed the adopted assessment criteria (i.e. residential air assessment criteria of 1.8–2.2 µg/m^3, see Table 10.2).

Table 10.2 Summary of site-specific vapour risk assessment – child care centre

Type	Bore location	Max TCE conc in air (2014) (ug/m^3)	
		24-Canister	10-Day Radiello
Indoor	IA1 to IA5	1.3	0.9
Outdoor	OA1	1.1	0.7

Residential air assessment criteria	TCE
Tox-Based (NEPM)	1.8
Risk-Based	2.2

10.5 Sensitivity analysis

A sensitivity analysis was conducted in the supplementary VRA (see Appendices L9 and L10) consistent with the approach used in the previous VRA, using the latest soil vapour data and the generic soil parameters adopted in the development of the HSLs presented in the amended ASC NEPM.

An additional sensitivity analysis (see Appendices L11 and L12) was also conducted using geotechnical analysis used in the site specific assessment with adjustment to the water porosity and air porosity using more conservative moisture content of 8% (sandy soil) and 22% (silty soil) adopted by Friebel and Nadebaum (2011) in the development of HSL.

The results of the sensitivity analysis are presented in Appendices L9 and L11 (for residential area) and Appendices L10 and L12 (for child care centre), and indicated that:

First Steps Child Care Centre:

- For the sensitivity analysis, the indoor air concentrations of TCE in the child care centre were predicted using the latest soil vapour data collected at SV4, SV14 and SV15 which are located in the vicinity of the main building. The predicted indoor air concentration of TCE exceeded the assessment criteria based on the default HSL soil parameters with low moisture content, but not when the HSL parameters was adjusted with the higher moisture content in soil (as measured at the site) (see Appendix L9).
- The highest measured indoor air concentration of TCE at the child care centre was 1.3 $\mu g/m^3$, at the same time when the latest soil vapour and groundwater data were collected. Hence, the results indicated that use of HSL parameters (without adjustment) is conservative and likely to overestimate the indoor air concentrations of TCE at this property.
- The conservatism of the HSL parameters for this site is also support by the observation that sub-slab concentration of TCE was found below the PQL during the latest phase of investigation (see Appendix L2). It is also noted that (see Section 10.4.4) no obvious correlation may be drawn from the results of the latest investigation between the concentrations of the indoor air TCE and the crawl space at the child care centre (see Appendix L8).
- The additional sensitivity analysis using geotechnical data for SV14 and SV15 located at the child care centre, but adjusted for reduced moisture content [from measured average of 14% to 8% (default for HSL's sandy soil)], produced similar soil parameters as the HSL and thus the same model outcomes (see Appendices L9 and L11). The results indicated that the measured soil parameters for sandy soil at the child care centre are similar to the HSL parameters for sandy soil after adjusting for moisture contents.
- It must be noted that the sensitivity analysis was based on a slab-on-grade construction. The health risks due to vapour intrusion at the child care centre were assessed based on measured air concentrations of TCE, which were below the assessment criteria and deemed acceptable.

Residential area:

- For the sensitivity analysis, the indoor air concentrations of TCE in the residential dwellings were predicted using the latest soil vapour data collected at SV1 to SV17 (all soil vapour locations including the two new locations at SV16 and SV17), located within or adjacent to the residential area. The predicted indoor air concentration of TCE was elevated primarily at one location (SV10) using the HSL parameters (see Appendix L10). Based on the sensitivity analysis for the child care centre, it is reasonable to assume that use of HSL parameters were conservative and likely to over predict the indoor air concentrations.
- While the soil vapour results indicated that health risks at the residential areas are acceptable, further evaluation should be considered for SV10. The discrepancy observed in the soil vapour concentrations at SV10 was inconsistent with the trend observed in all other locations between the source (or potential

source) concentrations and the soil vapour concentrations. These include the decrease in the groundwater concentrations of the designated VOCs in the vicinity of SV10 (i.e. MW14). In other locations, elevated soil vapour concentrations were observed with elevated groundwater concentrations. It is also understood that resistance was encountered during the latest soil vapour sampling at SV10. This may be due to sampling in soil with high moisture content and may result in ‘stripping’ of vapour or moisture that potential caused the detection of elevated COPC concentrations which are not necessarily representative of the steady state soil vapour concentration.

- In the additional sensitivity analysis where for reduced moisture content of 8% (sandy soil) and 22% (silty soil) were used with the site-specific geotechnical parameters, more vapour attenuation was predicted, in comparison to the use of default HSL soil parameters (see Appendices L10 and L12). This was due to the lower total porosity of the soil analysed and resulted in predicted indoor VOC concentrations that were below the adopted assessment criteria. While the results suggested that vapour intrusion risks may be mitigated by the site-specific properties of the soil, the sample size of the geotechnical analysis is not considered sufficiently robust for this to be implied across the area of investigation at Hendon.

10.6 Conclusion

A supplementary vapour risk assessment was conducted to determine if the designated chlorinated hydrocarbons pose vapour risks to the residential receptors, including those using the Child Care Centre and the schools in the nominated area in Hendon, based on the information from the latest environmental assessment results presented in Section 7.

It is concluded that:

- based on the measured indoor air concentrations of the designated VOCs, the health risks associated with inhalation of the designated VOCs at the First Steps Child Care Centre are considered to be acceptable
- the health risks associated with indoor vapour intrusion of the designated VOCs within the residential area (based on consideration of slab on ground construction) are currently considered acceptable, and mitigated on the basis of the moisture content and geotechnical properties of the soil
- the designated VOCs may pose vapour intrusion risks in the future, drawing on the findings of the sensitivity analysis, if increased vapour volatilisation due to changes in concentrations and soil conditions (particularly the reduction in soil moisture content) occurs.

Additional targeted assessment to confirm geotechnical soil properties (including moisture content), variations in vapour and groundwater conditions, and housing construction details within the residential area should be considered to further verify the conclusions of the VRA for the wider area of investigation. Further assessment of temporal variation of VOCs within the Child Care Centre should also be considered.

11. Conclusions

The results obtained during the additional environmental assessment undertaken across the Hendon investigation area have been interpreted to indicate the following:

- The shallow (typically 3.3 to 4.2 mBGL) unconfined aquifer that underlies this area is located within interbedded sands and clays, and inferred to generally flow in a westerly direction towards Boating Lake (West Lakes) in the part of the investigation area east of Tapleys Hill Road. The inferred groundwater flow direction west of Tapleys Hill Road is to the east and north east, suggesting that the deep sewer system beneath Tapleys Hill Road is acting as a groundwater drain in this area. Groundwater seepage velocities range from 3.5 to 12 m/year.
- The SWL across the investigation area has increased by approximately 0.1–1.1 m since previous monitoring in June 2013 with MW20, located on the Hendon Primary School oval recording the largest increase in water level. Groundwater gradients have remainder relatively similar to previous monitoring events
- Elevated concentrations of VOCs (PCE, TCE, 1,1 DCE, cis-1,2 DCE, trans-1,2 DCE and vinyl chloride) are present in groundwater at concentrations that exceed one or more of the adopted beneficial use (i.e. potable and/or recreational) criteria and detectable concentrations of various additional VOCs are also present, including chloroform and 1,2-dichloroethane. As with the previous groundwater investigation, GW9, located within the industrial portion of the investigation area and immediately south of the 3-5 Philips Crescent site, recorded the highest groundwater TCE concentration (1,000 µg/L) and the highest PCE concentration (188 µg/L). Only wells MW01, MW9, MW10, MW11, MW15, MW16, MW20 and MW22, MW24, MW25 and MW27 did not record any detectable concentrations of VOCs.
- Based on a review of the hydrochemistry of the groundwater and plotting of contaminant concentrations across the area it appears that a number of potential VOC source areas may exist within the Investigation Area. Possible source areas include:
  - the property at 3-5 Phillips Crescent (PCE/TCE/1,2-DCE)
  - a property to the south-east of 3-5 Phillips Crescent, north of West Lakes Boulevard (PCE/1,2-DCE)
  - a property within the north-eastern portion of the industrial area, between MW14 and MW23 (PCE/TCE/ 1,1-DCE)
  - possibly a property between well MW18 and Tapleys Hill Road (TCE).
- It is also considered possible that the deep sewer beneath Tapleys Hill Road, the western portion of Circuit Drive, Farman Avenue and possibly other portions of the investigation area could act as a preferential pathway for migration of chlorinated hydrocarbon impacts.
- A comparison of the groundwater results with previous investigations has shown that in general analyte concentrations have remained relatively similar, although the following variations are noted:
  - MW10 reported a decrease in naphthalene concentration to below the laboratory LOR, whereas it exceeded adopted criteria in 2013 (1.55 µg/L).
  - MW13 previously reported detectable concentrations of toluene, ethyl benzene and xylene (up to 4.24 µg/L), however concentrations were all below the laboratory LOR in 2014.
  - GW9 reported a decrease in 1,1-dichloroethene and vinyl chloride to below the adopted screening criteria, while remaining VOCs of concern remained at concentrations exceeding adopted criteria.
  - GW1 reported a decrease in *cis-* and trans-1,2-dichloroethene and TCE to below adopted screening criteria compared to the 2013 results, while vinyl chloride remained comparable to the previous concentration.
  - PCE within MW02 increased to exceed criteria (consistent with 2012 results) and within MW05 decreased to below the TCE and PCE criteria (as was the case in 2012).

- TCE concentrations in MW12 decreased to below the TCE criteria, soil vapour results were below the adopted preliminary screening criteria with the exception of:
    - TCE concentrations (up to 16,000 µg/m3 at location SV10) in all bores except SV05, SV08, SV11, SV14 and SV16
    - PCE (up to 26,000 µg/m^3 in SV02) in vapour wells SV01, SV02, SV06, SV13 and SV17
    - Cis 1,2-DCE (up to 1800 µg/m^3 in SV02) in vapour wells SV02, SV09, SV10 and SV13.
- The soil vapour concentrations recorded were generally consistent with previous monitoring results with the following exceptions:
    - PCE in SV01 and SV02 increased since the previous monitoring event in 2013, however remained similar to the results recorded in 2012.
    - The concentrations of TCE, PCE and cis-1,2 DCE increased by an order of magnitude in SV09 and SV10. Further evaluation of the contamination and sub-surface conditions in this area would be prudent.
- Further detailed vapour assessment of the First Steps Child Care Centre, including assessment of VOC concentrations in sub slab soil, crawl space, indoor air and outdoor air concluded the following:
    - The concentrations of VOCs in sub-slab soil were below the adopted assessment criteria.
    - Concentrations of TCE between 3.5 and 26 µg/m^3 have been detected within the crawl space beneath the timber floor of the child care centre.
    - Concentrations of TCE recorded within indoor air varied from 0.74 to 1.3 µg/m^3, consistent with the outdoor air concentrations, and did not exceed the adopted toxicity reference value of 2 µg/m^3.
    - Some elevated Bromomethane, benzene, ethylbenzene, 1,2-dichloroethane, carbon tetrachloride and chloroform concentrations were recorded in indoor air samples in excess of USEPA Region 9 Indoor air screening levels. No further assessment of the risks associated with these compounds has been undertaken as these are not the designated compounds of interest in this assessment. It is noted that Bromomethane, and ethylbenzene concentrations were lower within the underlying crawl space samples than indoor air, therefore unlikely to be associated with vapour intrusion from soil or groundwater. It also noted that the Region 9 screening levels for benzene, ethylbenzene, 1,2-dichloroethane, carbon tetrachloride and chloroform are all based on carcinogenic target risks of 1 x 10$^{-6,}$ therefore are conservative. Given that a target risk of 1 X10^{-5} is more widely adopted in Australia, and the concentrations of these compounds detected generally only marginally exceeded the Region 9 screening levels, the concentrations of these compounds may not present an unacceptable inhalation risk, however this has not been confirmed.
    - Concentrations of other compounds of interest within indoor air did not exceed screening criteria.
    - Concentrations of chlorinated compounds identified within the grease arrestor pit were generally consistent with that identified within indoor air.

Based on the available data, including data from the previous phases of assessment, and the results of a site-specific VRA, it is concluded that:

- Due to the presence of elevated concentrations of chloride, sulphate, nitrate, metals (cadmium, cobalt, copper, nickel, zinc) and VOCs within shallow groundwater beneath the investigation area, it is not suitable for a range of beneficial uses, including marine ecosystem protection, potable, recreational and irrigation uses.
- The lateral extent of groundwater VOC contamination has been reasonably delineated. The estimated extent of VOC impacted groundwater within the shallow aquifer is presented in Figure 9, Appendix A.
- Based on the observed concentrations of VOCs and an assessment of the geochemical data it is inferred that a number of contaminant sources are likely within the Hendon industrial area (i.e. the area bounded by Tapleys Hill Road to the west, West Lakes Boulevard to the south, Gordon Street to the east and Farman Avenue to the north. Potential source areas (and source products) include:

  - the property at 3-5 Phillips Crescent (PCE/TCE/1,2-DCE)
  - a property to the south-east of 3-5 Phillips Crescent, north of West Lakes Boulevard (PCE/1,2-DCE)
  - a property within the north-eastern portion of the industrial area, between MW14 and MW23 (PCE/TCE)
  - possibly a property between well MW18 and Tapleys Hill Road (TCE).

- A supplementary vapour risk assessment was conducted to determine if the designated chlorinated compounds pose vapour risks to residential receptors, including those using the Child Care Centre and schools in the Investigation Area, based on the latest assessment results. The supplementary vapour risk assessment concluded that:
  - Based on the measured indoor air concentrations of the designated VOCs, the health risks associated with inhalation of the designated VOCs at the First Steps Child Care Centre are considered to be acceptable.
  - The health risks associated with indoor vapour intrusion of the designated VOCs within the residential areas (based on consideration of slab on ground construction) are currently considered acceptable, and mitigated on the basis of the moisture content and geotechnical properties of the soil.
  - The designated VOCs may pose vapour intrusion risks in the future, drawing on the findings of the sensitivity analysis, if increased vapour volatilisation due to changes in concentrations and soil conditions (particularly the reduction in soil moisture content) occurs.
- Additional targeted assessment to confirm geotechnical soil properties (including moisture content), variations in vapour and groundwater conditions, and housing construction details within the residential area should be considered to further verify the conclusions of the VRA for the wider area of investigation. Further assessment of temporal variation of VOCs within the Child Care Centre should also be considered.
- The source of the detectable concentrations of TCE within the Child Care Centre crawl space has not been confirmed. It is possible that the identified TCE could be associated with migration from underlying soil /.groundwater, unidentified preferential migration pathways or sources(s). Further assessment of soil gas concentrations from immediately below the Child Care Centre would be required to determine if the elevated crawl space vapour is associated with a sub-surface source.

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13. Statement of limitations

Scope of services

This environmental site assessment report ("the report") has been prepared in accordance with the scope of services set out in the contract, or as otherwise agreed, between the Client and Parsons Brinckerhoff ("scope of services"). In some circumstances the scope of services may have been limited by a range of factors such as time, budget, access and/or site disturbance constraints.

Reliance on data

In preparing the report, Parsons Brinckerhoff has relied upon data, surveys, analyses, designs, plans and other information provided by the Client and other individuals and organisations, most of which are referred to in the report ("the data"). Except as otherwise stated in the report, Parsons Brinckerhoff has not verified the accuracy or completeness of the data. To the extent that the statements, opinions, facts, information, conclusions and/or recommendations in the report ("conclusions") are based in whole or part on the data, those conclusions are contingent upon the accuracy and completeness of the data. Parsons Brinckerhoff will not be liable in relation to incorrect conclusions should any data, information or condition be incorrect or have been concealed, withheld, misrepresented or otherwise not fully disclosed to Parsons Brinckerhoff.

Environmental conclusions

In accordance with the scope of services, Parsons Brinckerhoff has relied upon the data and has conducted environmental field monitoring and/or testing in the preparation of the report. The nature and extent of monitoring and/or testing conducted is described in the report.

On all sites, varying degrees of non-uniformity of the vertical and horizontal soil or groundwater conditions are encountered. Hence no monitoring, common testing or sampling technique can eliminate the possibility that monitoring or testing results/samples are not totally representative of soil and/or groundwater conditions encountered. The conclusions are based upon the data and the environmental field monitoring and/or testing and are therefore merely indicative of the environmental condition of the site at the time of preparing the report, including the presence or otherwise of contaminants or emissions.

Also, it should be recognised that site conditions, including the extent and concentration of contaminants, can change with time.

Within the limitations imposed by the scope of services, the monitoring, testing, sampling and preparation of this report have been undertaken and performed in a professional manner, in accordance with generally accepted practices and using a degree of skill and care ordinarily exercised by reputable environmental consultants under similar circumstances. No other warranty, expressed or implied, is made.

The VRA required a number of assumptions regarding site conditions, human exposure and chemical toxicity. Even though site-specific parameters may be considered (e.g. soil profile and analytical data), it is not possible to fully describe site conditions and human activities at the site for the entire period of time considered in the risk assessment. The assumptions considered for this VRA were generally conservative in nature, to account for uncertainty in the parameter estimates and to protect public health by providing a deliberate margin of safety.

Report for benefit of client

The report has been prepared for the benefit of the Client and no other party. Parsons Brinckerhoff assumes no responsibility and will not be liable to any other person or organisation for or in relation to any matter dealt with or conclusions expressed in the report, or for any loss or damage suffered by any other person or organisation arising from matters dealt with or conclusions expressed in the report (including without limitation matters arising from any negligent act or omission of Parsons Brinckerhoff or for any loss or damage suffered by any other party relying upon the matters dealt with or conclusions expressed in the report). Other parties should not rely upon the report or the accuracy or completeness of any conclusions and should make their own enquiries and obtain independent advice in relation to such matters.

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